Summary of Activities

Our Phase II collaboration goal was to create a science-based design framework to develop and test restoration strategies that combine gray (cement-based) and green (nature-based) defenses to reduce the vulnerability of coastal communities to the impacts of ocean waves and wave-driven flooding. Specifically, we chose to evaluate the benefits to people and property that could be provided by combining submerged breakwaters, designed to dissipate wave energy, with active coral restoration. To accomplish this, our team worked to integrate physical modeling, coastal engineering, architectural and infrastructural risk evaluation, social and economic analyses, ecological assessments, coral resilience experiments, in partnership with local government, materials scientists, and leading coastal modelers. In collaboration with our local (City of Miami Beach) and NGO (The Nature Conservancy) partners, we selected two candidate areas along the valuable and vulnerable shoreline of Miami Beach to focus our efforts with the long-term goal of designing an artificial reef that combines grey and green infrastructure to maximize the benefits of these barriers for coastal protection.

In our second year of funding, we will complete the vulnerability and physical modeling and will move into an implementation and deployment phase. We will use the knowledge gained to design plans for an Artificial Reef (AR) future deployment in Miami Beach and to implement a communications strategy to inform stakeholders on the benefits of nature-based coastal protection strategies for enhanced coastal resilience. Although the permitting process may prevent us from a full AR deployment in Year 2, we will have made significant progress on design, development of local partnerships needed for a successful deployment, and the implementation of a communication strategy to foster stakeholder participation and buy-in. This work will get us shovel-ready to apply for the large-scale funding needed to deploy an AR to enhance coastal resilience at meaningful scales.

Major Accomplishments

SUSTAIN tank experiments

We evaluated the wave dissipation effects of coral reefs through the physical testing of a coral reef model using the UM SUSTAIN facility. To separate the effects of wave breaking and friction (the two major vectors of wave-energy dissipation), physical testing was conducted on two distinct reef model configurations, one which included only a breakwater, and a second which included a breakwater populated with coral skeletons, mimicking a reef restoration scenario (Figure 1). Testing the breakwater structure without corals captured the effect of wave shoaling and/or breaking under negligible friction. The breakwater structure was then populated with coral skeletons to capture the combined effect of wave-breaking and bottom friction caused by corals. The resulting coral array was composed of skeletons of the Caribbean staghorn coral, *Acropora cervicornis*, a species commonly employed in coral restoration in South Florida and presently grown in the UM coral nurseries.

Wave height measurements before and after the breakwater models revealed that there was significant reduction in wave height of **up to 40.5%** as waves moved towards the shore. Comparisons of a breakwater-only to a breakwater-with-reef showed that the **corals reduce up an additional 7% of that wave height, for a total of 47.5% reduction** (Figure 2). The difference in dissipation between the breakwater model and the coral reef model is attributed to friction from the coral skeletons. These benefits are even higher when looking at wave energy dissipation.

Ecological Site Assessment

The health of the reef tract offshore of Miami Beach was assessed for coral restoration viability. We examined coral cover and coral species diversity to identify the areas that could ecologically benefit most from reef restoration. Data from the Florida Reef Resilience Program (FRRP) was analyzed and used to identify areas with low and high cover and coral species richness. Using these data, we identified two areas (offshore of the 11th St. and 63rd St. areas) as sites that would benefit the most from restoration (Figure 3).

Meanwhile, we initiated a field assessment of coral growth and survivorship gradients along the reef of Miami Beach to evaluate the current potential of reef environments to support coral growth. At 7 reef sites (Figure 4), nursery “tree” structures were deployed, with each housing 60 coral fragments. The initial size of corals was measured at deployment and each fragment will be measured again after 3-4 months to assess growth. In addition, we attached temperature and light data loggers to each nursery structure to further characterize the environmental conditions. At each site, surveys were conducted measuring the relief, benthic composition, and coral cover/abundance. Hydrodynamic profiling (wave energy measurements) and water quality testing of each site will also be performed in late summer (Aug-Sept). These combined datasets (on coral growth/survivorship, ecological and environmental characteristics, water quality and hydrodynamic profiles) will allow us to determine which sites to consider as priority areas from an ecological and coastal protection standpoint, and which sites are suitable for coral growth and therefore restoration. Preliminary data show low structural complexity (<20 cm relief), and low coral abundance (<2 species per site, <1% coral cover) for all sites, both of which suggest a potential benefit from future restoration.

Because the 63rd St. region of Miami Beach was selected as an area of particular risk to coastal flooding by our partners, we established a test restoration site on the reef habitat in this area. We planted 900 nursery-grown staghorn corals at this site. The site will be monitored for 1 year to assess site viability for reef restoration.

Building the Thermal Resilience of Restored Corals

Our approach to building coastal resilience incorporates attempts to increase the climate resilience of outplanted corals. We are incorporating the development and testing of state-of-the-science approaches (recently highlighted in a 2019 National Academy of Sciences report) to build thermal tolerance into our restoration efforts. First, we tested several methods of 'stress-hardening' corals through controlled pre-exposure to stress. Using laboratory and field-based approaches, we tested whether: (1) acute exposure to high light; (2) acute exposure to photochemical inhibitors; and (3) chronic exposure to thermally variable [18– 34.5°C] nursery environments, resulted in corals that were better able to survive subsequent thermal stress. We were successfully able to apply these treatments with no short-term negative consequences (i.e., similar survivorship to 'control' colonies of the same genotype that were maintained in our regular nurseries). After >10 months we collected samples of these outplanted colonies and they are currently in a month-long 'stress test' in our controlled lab systems. We expect to know which of these treatments results in an increase in thermal tolerance by the end of August. Secondly, we have begun testing whether local managed relocation of corals (assisted gene flow) of corals sourced from warmer habitats in southern Biscayne Bay can be used to increase the climate resilience of restoration efforts in cooler environments off Miami Beach.

Communications Strategy

To conduct formative research for developing a communication strategy, a questionnaire (IRB approved) that measures, among other variables, understanding of vulnerability from waves, risk knowledge, beliefs about coastal resilience solutions, and trusted information sources is currently being distributed to residents of Miami Beach and other similar coastal barrier municipalities using paid Qualtrics services and the help of City of Miami Beach (CMB).

We are currently working with CMB to hold focus group discussions with residents (once results from the questionnaire are available) to build on our findings and obtain an in-depth/nuanced understanding from a smaller group of residents. Once the formative research is completed, we will finalize our communication strategy (overall approach) and tactics (actual materials). In the meantime, we have begun developing outreach materials and have produced a short, informative video about our project and about coastal resilience with a local focus. We are working with CMB to put the video link on their website, newsletters, and other sources.

We have also enlisted a graduate student from the School of Communications to create content posters about the different components of our project, scheduled to be completed by September. In collaboration with GRID-Arendal, we also built a small-scale, portable wave tank to engage the public at outreach events, which we premiered at the Tortuga Music Festival in April 2019.

Vulnerability Assessment

We aggregated primary data for transect analysis in the Flamingo Park swath of Miami Beach (11th St.), including GIS and other data sets. Data were collected in the field (with the assistance of research assistants from local agencies, and the collaboration of the Office of Resilience of Miami-Dade County), and through a GIS platform. Data sets were merged into GIS to develop a predictive risk model for existing conditions. When the final data sets from the U-LINK team's scientists and engineers are shared in Year 2, a last set of models will be run to compare with the initial model, thereby understanding the role coral reefs play in protecting urban areas. Vulnerability will be assessed by parcel within the Synoptic Survey's transect. The Synoptic Survey layers have been translated into a series of user-friendly graphics, including a vulnerability assessment map of Flamingo Park (Figure 5), to be shared publically and with the CMB and the Miami Dade County (MDC) Offices of Resilience.

Finally, census data and Miami Dade County public income data were combined with a digital elevation model to create a predictive landscape model of risk to flooding for our focus areas of Miami Beach (Figure 6). This analysis revealed an area of high risk between 47th St. and 63rd St (also an area identified as a restoration focus based on reef ecology and status).

Site Selection

A major achievement for our team was the identification of two sites for potential deployment of a test submerged artificial hybrid reef structure. These sites were chosen for different reasons. The site off of 63rd St. was selected because the area experiences frequent flooding and is considered high-risk based on vulnerability models assessing income and population density, and was identified as a priority area for beach erosion control by MDC (Miami Dade County, 2010). Our second site, off Flamingo Park (11th St,) contains a historic preservation district, areas of critical infrastructure and was selected based on the output of our urban vulnerability model. Both of these sites were also identified as target sites that would benefit ecologically from reef restoration, as the habitats adjacent to both sections of shoreline have very low coral cover, species diversity, and rugosity (metrics that are enhanced through active coral reef restoration).

Stakeholder Participation

City of Miami Beach:

In Year 1, we engaged CMB officials as a group on five occasions through in-person meetings and conference calls. The initial meetings were used to describe our project and identify specific areas where collaboration was needed: 1) permitting for the future deployment of an AR, and 2) development and dissemination of a communications strategy describing the value of nature-based defenses for coastal resilience. CMB officials from the Environment and Sustainability Department (S. Torriente, F. Tonioli) agreed to make contacts with the appropriate staff members to help us in this process. After this meeting we were asked to present our program to the CMB Commission. Drs. Baker and Lirman presented the goals of our project on 11/28/18 to the full CMB Commission (video link: https://miamibeachfl.new.swagit.com/videos/11282018-1165). After these initial meetings, we had in-person meetings with the permitting staff of the Department of Regulatory and Economic Resources at Miami-Dade County's Environmental Protection Agency (S. Thanner) and the director of the Miami-Dade County's Park and Recreation Division (M. Nardi). After our meeting with the MDC permit staff, we jointly drafted a set of steps to help guide the permitting process which will be initiated in Year 2 of our program. Our most recent interaction with CMB included a visit by city officials to RSMAS and our SUSTAIN wave tank facilities, where the staff saw first-hand how we run our wave mitigation experiments using hybrid (cement + corals) structures.

In addition to these team meetings, individual co-PIs have had separate meetings with the relevant CMB staff to collaborate in different project components and tasks. Dr. Chao has had semi-monthly meetings with the CMB and MDC Office of Resilience officers, with the aim of updating them on our efforts and solicit insights on the implementation of our Urban Vulnerability Assessment. CMB and MDC officials have requested the results of the synoptic survey once completed, and we plan to continue this mutually beneficial partnership into Year 2. Dr. Ramaprasad met with K. Pulido, outreach expert in the CMB Communications department, who agreed to help distribute our communications strategy questionnaire and to assist with the set-up for focus groups with a diverse pool of respondents from CMB. These focus groups are scheduled for Fall 2019.

The Nature Conservancy (TNC):

In Year 1, we conducted 4 video conference and phone meetings with our partners from TNC (Dr. Mike Beck, Dr. Borja Reguero) to discuss the program, SUSTAIN experiments, and the model outputs that TNC will provide for our site selection analyses. We have not been able to meet in person due to the busy schedules of our California-based TNC colleagues. TNC and the USGS published the national assessment of the value of natural coastal defenses in June 2019. The publication of this report lifted a moratorium imposed by USGS and opened the door for TNC to now run their models focused on our two candidate sites, the results of which we expect to have in September. These runs will provide us with key input into site selection for the permitting and potential deployment of our pilot AR structures (i.e., depth, distance to shore, size).

ECOncrete:

In summer 2019, we met in-person and by phone with representatives of the coastal engineering firm ECOncrete (https://econcretetech.com). This firm works on shoreline enhancement and artificial reef projects around the world. We have now developed a partnership to assist with the design of our AR modules as well as providing concrete samples to determine their viability to hold and grow corals for our hybrid structures. Establishing partnerships with engineering firms such as ECOncrete will help provide the expertise and resources we will need for full implementation in the future. In Year 2, we will continue to foster these partnerships as well as look for local firms that can assist with funding and deployment expertise.

Description of any challenges you encountered. How were those challenges managed?

Coordinating our team's progress and deliverables was our team's most significant challenge. Early in Phase II we felt we were not meeting our self-imposed deadlines and important discussions and decision-making were being stymied by the use of email for communication, impeding our progress as a team. We solved this by increasing our meeting frequency to semi-weekly on a fixed schedule, even if all team members could not attend every meeting. Members who were not in attendance were still updated via meeting summaries. We still continued our small-group conversations and exchanges as project tasks proceeded, but having a set schedule for all-PI meetings has helped us meet our deliverables on time.

Another challenge was coordinating a site visit to RSMAS with our key partners at CMB. We overcame this challenge through persistence and calendar juggling and were ultimately able to host a meeting with 8 members of the Sustainability and Resiliency Committee to discuss public engagement, permitting, and future shared project endeavors in June 2019.

During the initial steps of the communications strategy development, collecting data from CMB residents, even using Qualtrics, has been challenging due to low response rates. We are working to resolve this by expanding into other relevant coastal municipalities like Key Biscayne and North Beach.

Finally, we faced difficulties associated with arranging the payment of the subcontract with The Nature Conservancy. As the U-LINK funds are not from grants or contracts, the business office did not allow us to negotiate a sub-award. Instead, we were required to draft a consulting agreement which was not accepted as form of payment by the University of California, Santa Cruz (where the TNC scientists are based). We finally negotiated a direct consulting agreement with the lead PI, but this was not an easy process from the perspective of the business office. Future U-LINK projects that include sub-awards should be aware of this issue. At RSMAS, the office of sponsored programs and the business office do not follow the same procedures and establishing formal policies and procedures with the Business Office for U-LINK fund disbursements would be beneficial.

Proposed outcomes for Year 1, and how and whether each was met successfully

1. Milestone: *Obtain an initial list of candidate sites based on output of physical models from our partners at The Nature Conservancy* (TNC).
   Outcome: **COMPLETED**: Two focal sites were selected; one adjacent to 63rd St., and one adjacent to Flamingo Park.
2. Milestone: *Evaluate candidate sites within ULINK team and with the CMB: (a) Meet with local resilience, environmental preservation and planning officers to identify and rank potential sites within CMB, (b) Select final site based on available physical, economic, social data.*
   Outcome: (a, b) **COMPLETED**: (see prior milestone)
3. Milestone: *Perform ecological assessments of top 3-5 candidate reef sites*
   Outcome: **COMPLETED**: Ecological assessments were expanded to perform a "gradient" analysis of 7 reef sites along the length of Miami Beach.
4. Milestone: *Conduct hydrodynamic field testing of top sites using Spoondrift Spotter buoys*.
   Outcome: **IN PROGRESS**: We opted to use Seahorse Tilt Current Meters, which can be deployed sub-surface, and for longer periods of time. These instruments are being purchased and tests will be conducted in Sept-Oct 2019.
5. Milestone: *Synoptic survey for urban areas: (a) Aggregate primary data for transect analysis, including GIS based data and supplementary data sets, (b) Incorporate secondary data from Community Engagement Survey (see Communications Strategy) into transect analysis data set, (c) Incorporate tertiary data from Citizen Reporters (see Communications Strategy) into transect analysis data set, (d,e,f) Perform Synoptic Survey of sites, complete dissect and quadrat analysis within transect site, complete Urban Impact Analysis.*
   Outcome: a) **COMPLETED**: Data aggregation was completed as planned, (b) **IN PROGRESS**: The community

engagement survey is underway and will be completed by the end of Year 1, (c) **DELAYED**: The Communication PI and the CMB are determining how to better engage citizens and increase their participation. Plans are underway for community focus groups and workshops. Survey data will be incorporated into the Synoptic Survey and into the predictive model, (d,e,f) **IN PROGRESS**: To be completed in Year 2, as projected.

6. Milestone: *Review artificial reef designs and materials*
   Outcome: (a) **IN PROGRESS**: Concrete testing is ongoing by testing different compositions of concrete and measuring coral attachment, growth, and survivorship, (b) **COMPLETED:** We conducted a literature review of >90 publications on artificial reefs and our team is working to write and submit a review of studies that focus on hydrodynamics and flow fields of artificial reefs.
7. Milestone: *Perform Expected Damages Approach for economic analysis of urban areas*
8. Outcome: a) **COMPLETED**: Our partners at TNC produced a report that models risk and avoided damages in insurance costs and building protections from wave-driven flooding, (b) **COMPLETED**: A GIS analyses based on census and income data was integrated with a Digital Elevation Model (DEM) to get a "bird's-eye view" of income-based and population density-based risk to flooding, which will be refined in Year 2 by the urban planning team's more focused research model. The outcomes of the GIS analysis are linked here: https://umiami.maps.arcgis.com/apps/MapSeries/index.html?appid=667a57c19b2148aca2ebc27a2ded724e, (c) **IN PROGRESS:** We are working to incorporate social vulnerability parameters within the Synoptic Survey and the Urban Impact Assessment. This will be completed in Year 2.
9. Milestone: *Implement coral restoration test plots at MBC sites*
   Outcome: **COMPLETED**: 900 staghorn corals were planted at a reef site in the 63rd St. focal area showing high coral survivorship and high restoration potential. Furthermore, coral growth and survivorship was measured at 7 sites with using restoration structures (Fig 4)
10. Milestone: *Outplanting and monitoring of thermotolerant corals*
    Outcome: **COMPLETED**: Ten staghorn coral genotypes (5 from northern sites and 5 from southern sites) were experimentally stressed using a variety of different approaches, including a chronic stress treatment. Fragments have been outplanted at two sites. Differences in thermal tolerance after >10 months are now being assessed.
11. Milestone: SUSTAIN Testing: (a) Build hybrid gray/green infrastructure models, (b) Assess parameters 1-9 (Parameters Table from proposal), (c) Submit research report to scientific journals.
    Outcome: (a) **COMPLETED**: A reef model with two different slopes was constructed and employed for testing in SUSTAIN, (b) **IN PROGRESS:** 54 tests were conducted at SUSTAIN in the presence of the reef model to investigate the influence on wave characteristics. The analysis of the corresponding data is in progress, (c) **IN PROGRESS:** A paper on our study was accepted at the American Society of Civil Engineering's Coastal Structures 2019 Conference. A manuscript is in preparation for Limnology and Oceanography: Methods.
12. Milestone: (a) Draft a community engagement survey, (b) Development of Facebook site for two-way communication, (c) Conduct community engagement survey within selected urban transect site, (d,e) Conduct stakeholder focus groups of representative community members, develop communications strategy and tactics, (f) project video development, (g) Build portable miniature model wave tank development and use at outreach event.
    Outcome: (a) **COMPLETED**: Team members sent questions that were then integrated into a survey questionnaire (attached), (b) **DELAYED:** We are exploring the use of the CMB website instead of an independent Facebook page for dissemination of our communication content to stakeholder, (c) **IN PROGRESS:** A questionnaire is currently being distributed to residents of Miami Beach with the help of Qualtrics and the City of Miami Beach outreach coordinator, **DELAYED:** (d,e) Scheduled for Year 2 as proposed, (f) **IN PROGRESS:** Footage for a short, informative film for our stakeholders is in the editing phase, (g) **COMPLETED**: We built a miniature model wave tank, which has been used at outreach events such as the Tortuga Music Festival in April 2019.
13. Milestone: Foster team building, Co-PI Integration, and strategic planning with partners
14. Outcome: **COMPLETED**: Our team made it a priority to spend the necessary time integrating new members and defining our respective roles, monthly meetings were increased to twice monthly. Though initially a challenge, we were able to hold several meetings with CMB staff as well as host them at RSMAS in June 2019. The TNC agreement was signed in July 2019 and model runs are in progress. We developed a strategic partnership with ECOcrete as described.

List of publications, grant applications submitted and planned, white papers, etc.

Public Meetings and Outreach Events:
Florida Master Naturalist Program, October 2018, March 2019
Women in Science Day, November, 2018
South Miami-Dade Cultural Arts Center, 'Science Squad' panel presentation, November 2018
CMB Sustainability and Resiliency Committee Commissioners meeting, November 2018
Tortuga Music Festival, Conservation Village table, April 2019
Urbanism Summit panel presentation, May 2019
Frost Science IMPACT student internship, June-July 2019
City of Coral Gables Chamber of Commerce meeting, keynote speech, July 2019

Conferences:
Cabral G, Karp R, Palacio-Castro AM, Strueben M, Lirman D, Baker A (2018) Testing *in situ* stress-hardening techniques to increase the climate resilience of a coral restoration program in South Florida. *Reef Futures* conference, Key Largo, FL

Carrick JV, Lirman D, Haus BK, Rhode-Barbarigos L, Baker A, Ruiz Merchan J, Amendolara J, Mehta S, Smith A. (2018). Using wave-tank experiments to evaluate the influence of coral reefs on wave dynamics. *Reef Futures* conference, Key Largo, FL

Chao, S. R., and Ghansah, B. (2019). A modified method for assessing the vulnerabilities of coastal buildings: Case study of Miami-Florida. ACSA 108TH Annual Meeting, San Diego, CA

Haus BK, Rhode-Barbarigos L, Lirman D, Baker A, Carrick J, Mehta S, Ruiz Merchan J, Amendolara J. (2018). Laboratory Investigation of Wave energy dissipation over submerged coral reef structures. *3rd Latin American Symposium on Water Waves*, Medellin, Colombia

Ruiz-Merchan J, Haus BK, Rhode-Barbarigos L, Lirman D, Baker A, Camilo Restrepo J, Otero Diaz L, Carrick J, Amendolara J. (2018). Laboratory investigation of impact of the infragravity wave on coral reef structures. *3rd Latin American Symposium on Water Waves*, Medellin, Colombia

Papers:
Carrick JV, Ghiasian M, Rhode-Barbarigos L, Haus BK, Baker A, Lirman D. (in prep). Documenting the ability of restored coral reefs to dissipate wave energy and protect shorelines within a wave simulator tank system. *Limnology and Oceanography Methods*

Rhode-Barbarigos et al. (in press) American Society of Civil Engineering's (ASCE) Coasts, Oceans, Ports, and Rivers Institute (COPRI) Coastal Structures 2019 Conference - Paper accepted

Grant applications:
National Fish and Wildlife Foundation, National Coastal Resilience Fund - pre-proposal accepted. Full proposal submitted July 2019.

Florida Sea Grant - proposal submitted Feb 2019 (not funded).

A prospectus detailing the team capabilities was solicited by the InterAmerican Development Bank (IADB). Representatives from the IADB have met on several occasions with PI Haus who is leading this effort to secure additional funding for coastal resilience work in the Caribbean region. Co-PIs are A Baker, D Letson, D Lirman, A Nanni and L Rhode-Barbarigos.

Media Coverage
June 6, 2019 - NBC-6 hurricane feature –Hurricane Simulator Simulates Coastal Concerns
https://www.nbcmiami.com/on-air/as-seen-on/UM-Hurricane-Simulator-Researches-Coastal-Concerns_Miami-510886112.html

Tortuga Music Festival outreach event:
https://www.facebook.com/umiamiulink/posts/449148352488966

Urban risk story map:
https://umiami.maps.arcgis.com/apps/MapSeries/index.html?appid=667a57c19b2148aca2ebc27a2ded724e

Figures

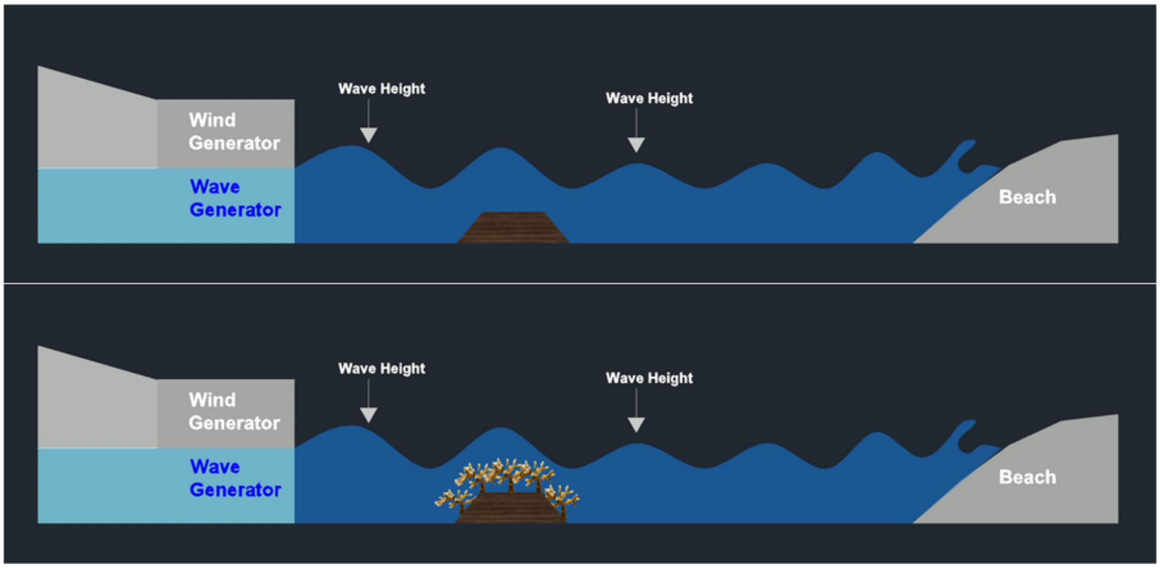

Figure 1. Illustration of the experimental set-up for evaluating the effect of breakwaters and corals on wave properties.

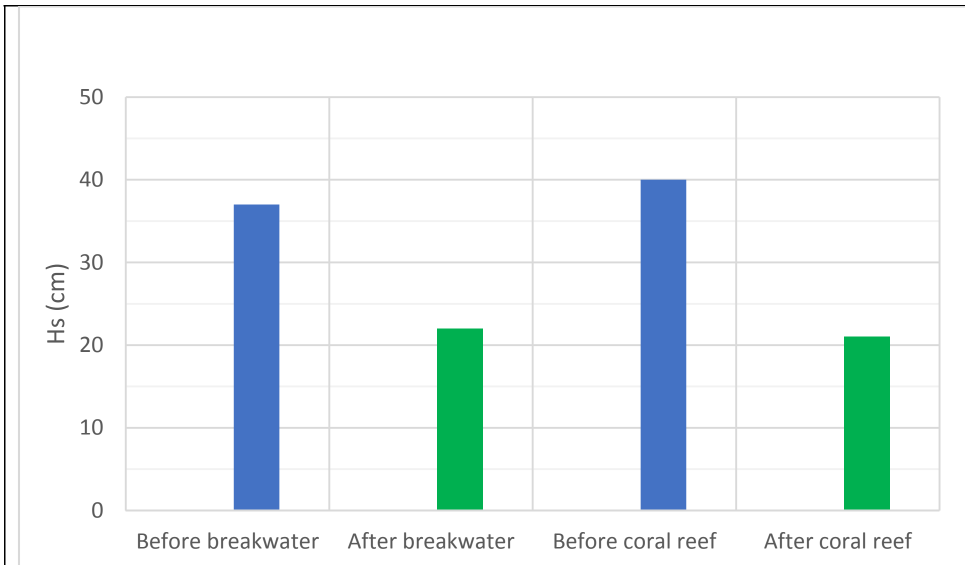

Figure 2. Wave height (H_s) before and after the model breakwater/coral reef calculated from measurements taken with a still water depth of 55cm and a periodic wave with 0.2Hz frequency and 15cm amplitude. The breakwater-only configuration showed a 40.5% decrease in significant wave height (H_s) and the breakwater+coral configuration showed a 47.5% decrease.

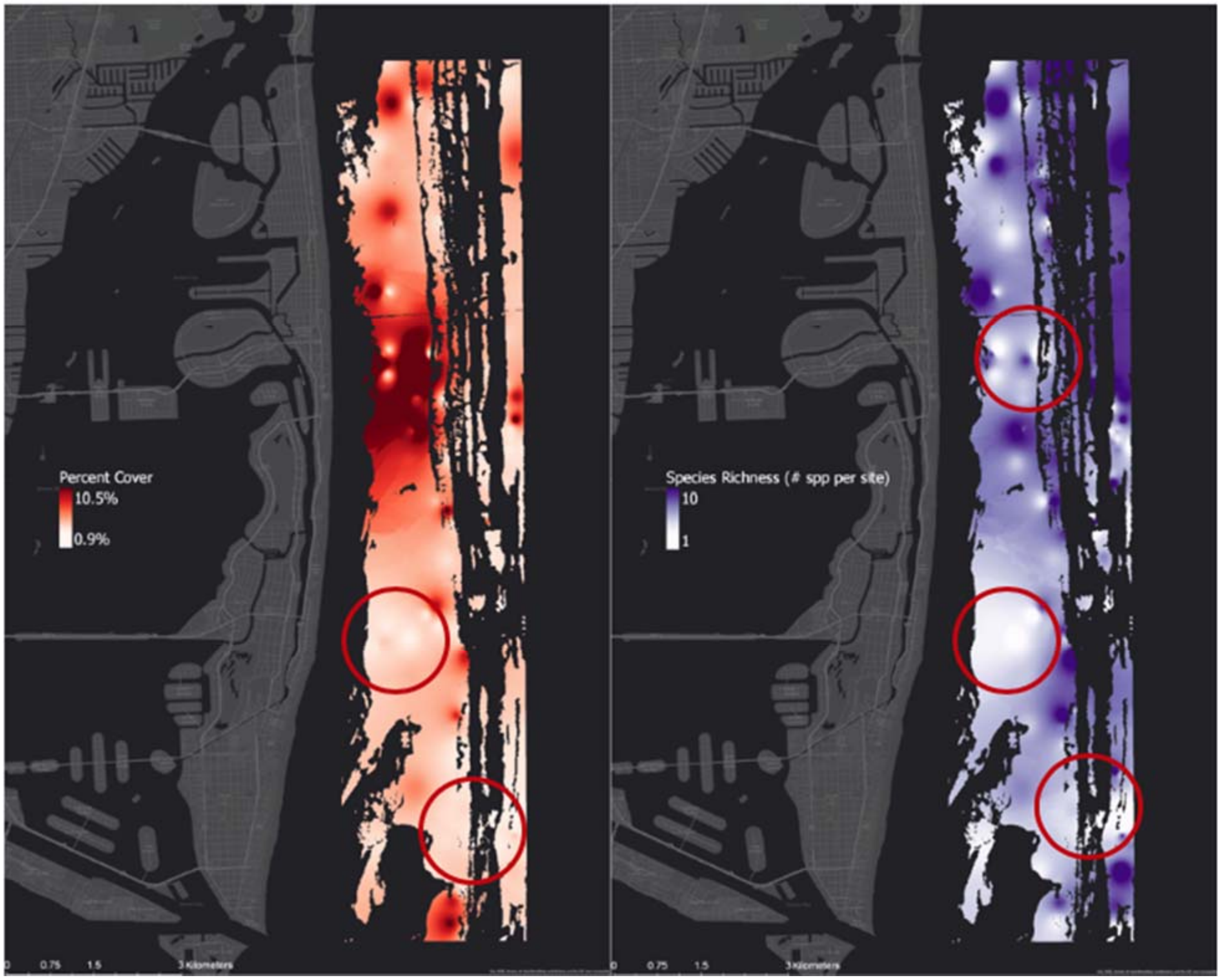

Figure 3. Percent cover (left) and species richness (right) of corals on reefs off of Miami Beach, FL. Colored areas mask the hardbottom and reef substrate off the coast of Miami Beach (Florida Unified Reef Map, FWC). “Cold spot” interpolated regions are indicated with red circles. Data taken from 2005 - 2017 by the Florida Reef Resilience Program.

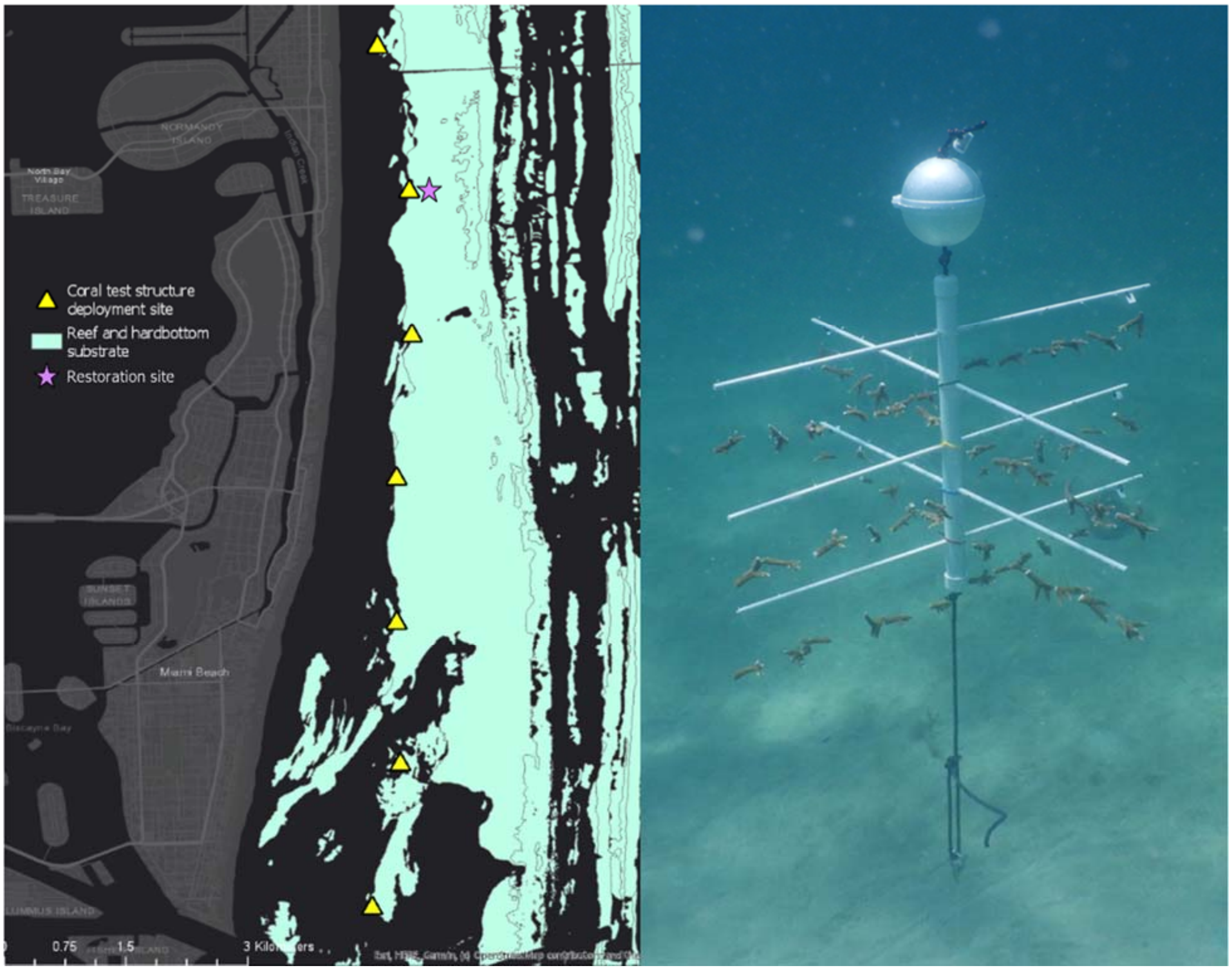

Figure 4. Map (left panel) of the locations where coral nursery tree structures (right panel) were deployed at 7 sites offshore from the City of Miami Beach.

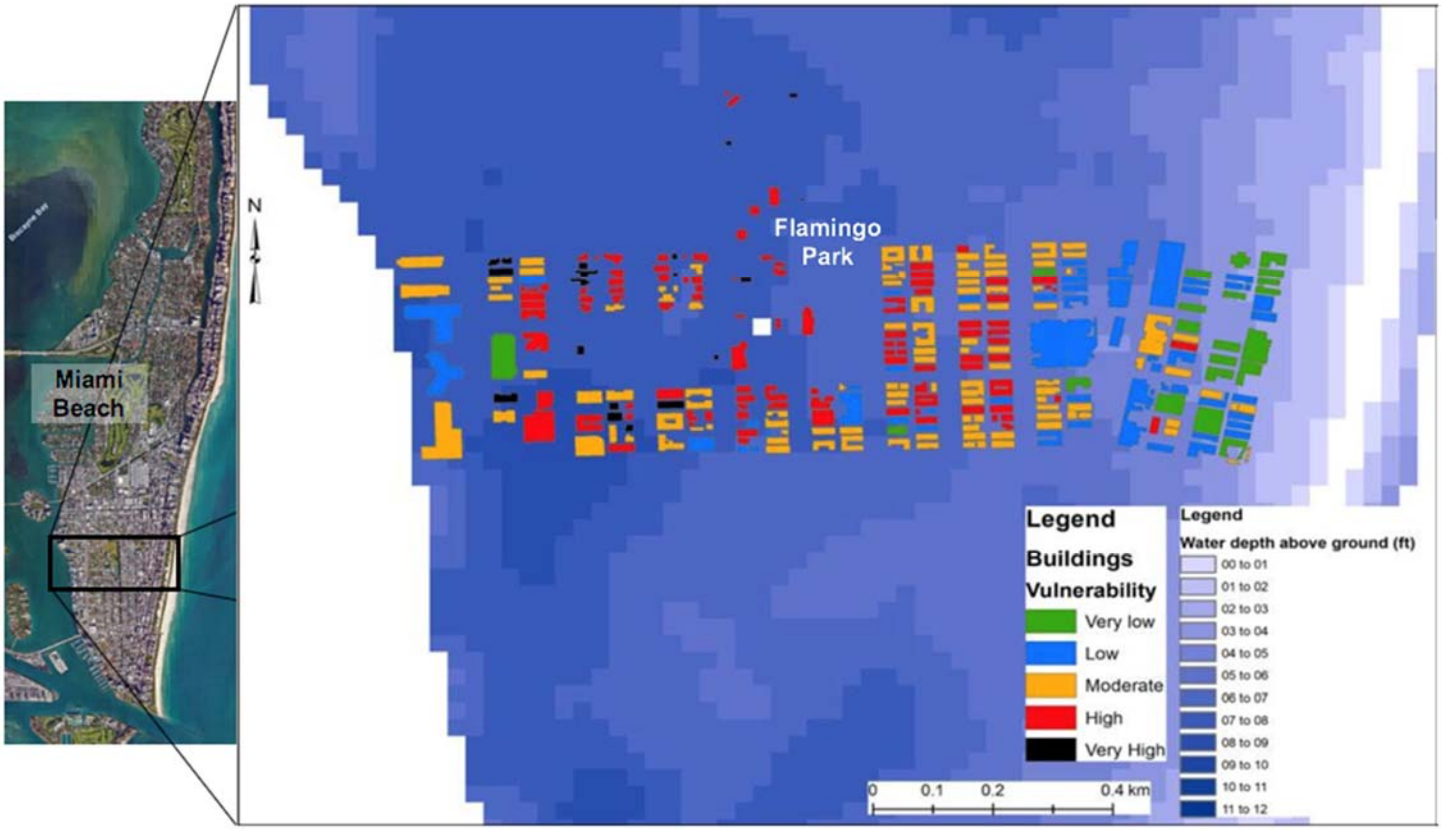

Figure 5. Vulnerability Model for Flamingo Park transect through South Miami Beach. Total weighted vulnerability scores, incorporating seven physical parameters (flooding depth, distance to waterbody, number of stories score, building material, finished floor elevation, effective year built, and distance to an evacuation facility) are shown from on color scale. 40% of buildings analyzed within the study site were either high (red) or very high (black). Flood inundation depth of a Category 5 (Saffir-Simpson scale) storm surge is layered.

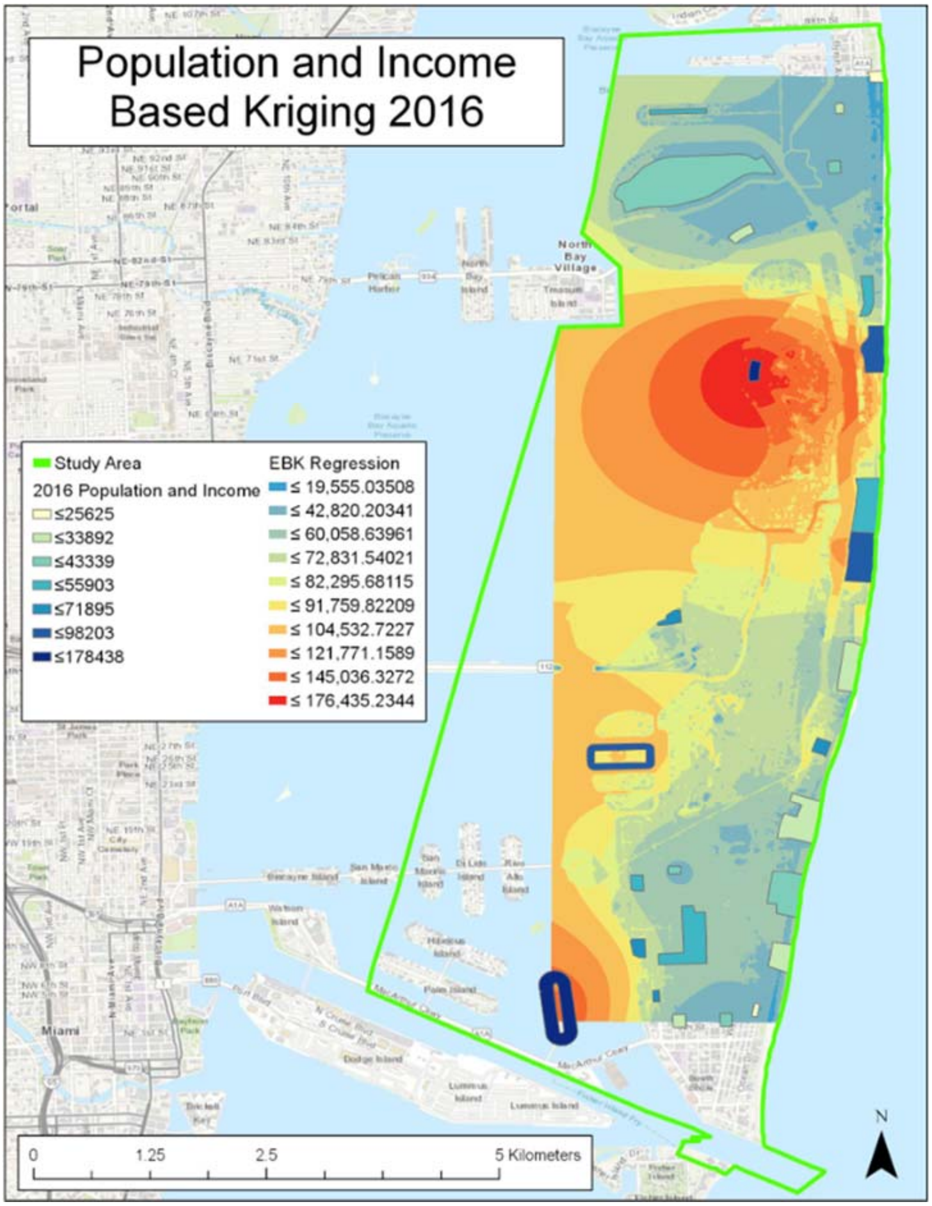

Figure 6. Miami Beach study area in which income data and population density data was interpolated to reveal potential areas of high risk. Data was interpolated using an Empirical Bayesian Kriging (EBK) method. Higher risk areas are shown in darker red. The model reveals a region of high risk encompassing a large section of Miami Beach between 47th St. and 63rd St (red and orange).