IntelliReef Marine Biodiversity and Environmental Impacts

By

Reef Life Foundation

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Table of Contents

1. Summary

Over the past four decades, coral reef degradation due to multiple natural and anthropogenic stressors has accelerated [1,2]. Rising ocean temperatures, ocean acidification, overfishing, invasive species, and disease contribute to a global loss in coral cover, structural complexity, and biodiversity [3,4]. As a result, there has been a rise in active coral restoration projects in an attempt to mitigate further deterioration [5,6]. Artificial reefs are a targeted restoration method that aims to restore select ecosystem metrics such as increasing fish aggregation, coral cover, and marine biomass, while enhancing structural complexity.

Reef Life Foundation's artificial reef system, named IntelliReefs (Image 1), acts as an enhanced substrate, specifically engineered to promote marine species biodiversity through site-specific material substrates called Oceanite. Oceanite is an advanced porous material designed to increase the surface area per square meter while maintaining structural integrity and durability. The high-level strength of Oceanite allows our design team to develop innovative architectural designs that accomplish project and function-specific deployment objectives while withstanding harsh oceanic conditions and storms.

In November 2018, we deployed 60 IntelliReef block units underwater that were assembled into 3 artificial reefs near Philipsburg, Sint Maarten as part of a pilot study. Sint Maarten's marine ecosystems have been degraded by overfishing, hurricanes, runoff, and a suite of other compounding natural and anthropogenic stressors over the past five decades [2]. Like many ecosystems in the Caribbean, coral reef communities in Sint Maarten have been severely affected by hurricane activity. Hurricane Irma (September 2017) caused widespread damage to the island and is one of the strongest hurricanes to have hit in the Atlantic Ocean to date, with winds exceeding 185 MPH [7]. Large surge caused severe damage on reefs and intense rainfall increased freshwater and nutrient input [8]. Sint Maarten coral communities also suffer from continued deterioration due to eutrophication and physical damage from boating traffic [8]. The Reef Life Team identified Sint Maarten as an ideal location for an IntelliReef prototype structure, due to the need to restore and protect rapidly deteriorating marine biodiversity and structural complexity of island reef systems. Our aim for the pilot study was to observe how our Oceanite Growth Matrix (OGM), the specific matrix of minerals used within the oceanite to accomplish site specific objectives, performed physically and biologically at three different sites. Specifically, we wanted to monitor and compare the fish, invertebrate, and algal communities at each site over time, as well as determine the suitability for coral recruits.

Image 1. Reef Life Foundation Deployment team installing one of three IntelliReef structures in Sint Maarten.

During our most recent data collection trip between January 27-31, 2020, funded through the Waitt Foundation's Rapid Ocean Conservation (ROC) Grant, our scientists found that the IntelliReef structures had nearly 100% coverage of biological organisms after just 14 months (Image 2). From these initial surveys and the ongoing analysis being performed, we have documented the settlement of species that facilitate the growth of a healthy, diverse, and resilient benthic coral reef community, including crustose coralline algae (CCA), macroalgae, scleractinian (reef-forming) corals, and sea sponges (Image 3). Our data also shows the important role IntelliReefs play in fostering the marine biodiversity needed in the blue carbon uptake cycle. The Reef Life Foundation's team of scientists has documented these important findings in a scientific publication that can be found on our website or made available upon request.

Image 2. Picture highlighting the biodiversity found on one of the IntelliReef structures after 14 months from initial deployment.

The purpose of this report is to highlight the results of the IntelliReefs for habitat enhancement, IntelliReef conservation impact, and the next phase research and project objectives for IntelliReef structures.

2. Results and Significance

Evaluating the efficacy of artificial reefs (ARs) in enhancing or sustaining biodiversity on coral reefs is vital for understanding their performance in reef restoration. The initial results from our observational Oceanite AR pilot study off the coast of Philipsburg, Sint Maarten indicates an incredible potential for using our structures to increase local biodiversity and provide optimal conditions for rapid species growth due to the physical and chemical designs of our structures. We compared composition of the benthic (i.e. seafloor) community and associated fish assemblages on ARs deployed at a coral reef marine protected area (MPA) and two unprotected seagrass beds. After 14-mo underwater, the ARs were covered in a vibrant community of benthic plants and animals.

We found differences in the total percent cover of benthic organisms and community composition between substrate orientations (horizontal vs. vertical) and among AR sites [26]. Horizontal substrates were dominated by algae and sponge species, and vertical substrates supported a diverse assemblage of suspension- or filter-feeding invertebrates (e.g. sponges, bryozoans, ascidians, etc.). Total percent cover of benthic invertebrates and calcifying organisms was higher on vertically-oriented substrates than horizontally-oriented substrates for all ARs [26].

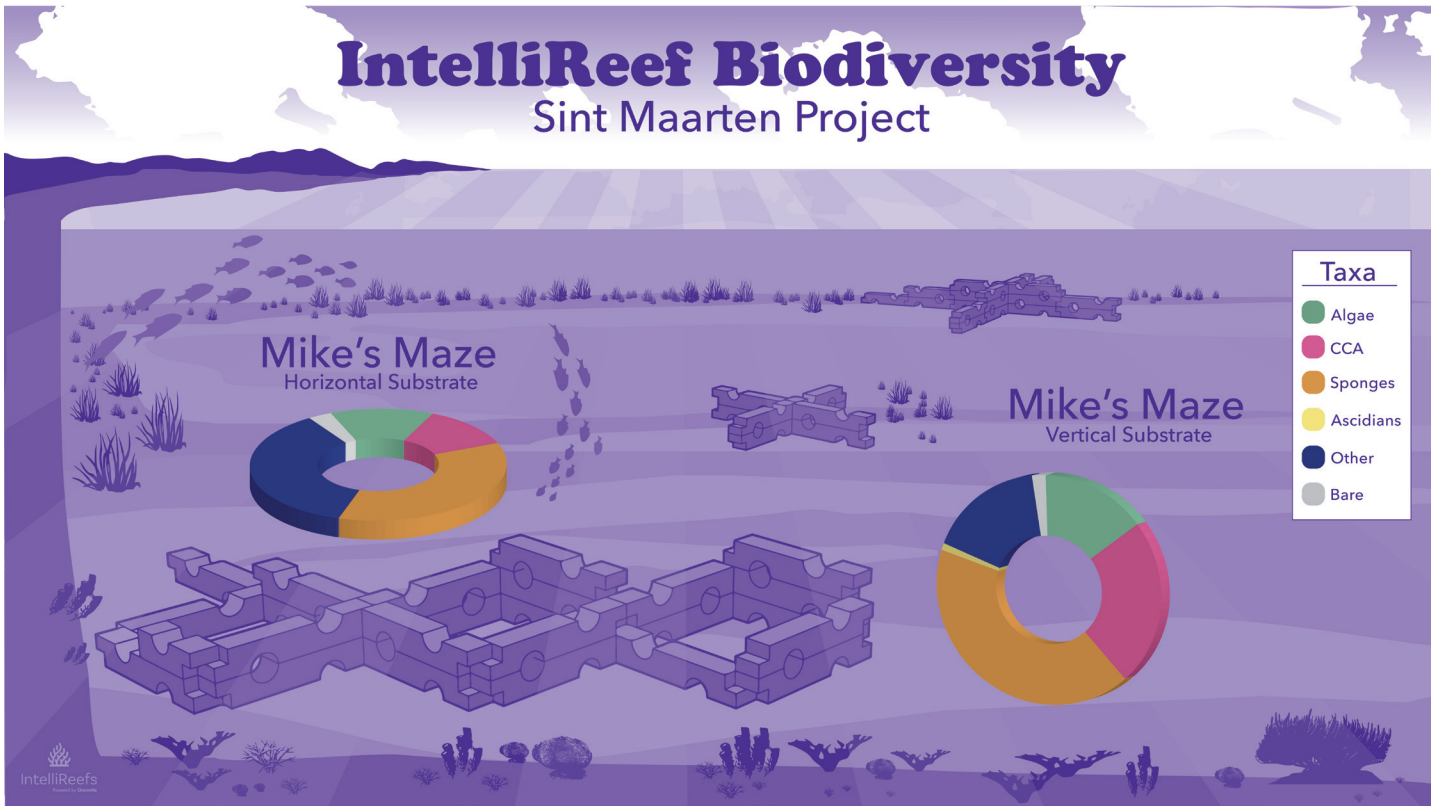


Figure 1. Infographic showing the diverse coverage of marine life found on the IntelliReef.

The AR that was deployed on a coral reef in the MPA had the highest total cover of algae and invertebrates on both substrate orientations, at nearly 100% (See Figure 1). The community composition also differed between the AR in the MPA and the adjacent MPA reef, which is dominated by soft corals. We found that crustose coralline algae (CCA) cover was highest on the AR in the MPA, and both surface orientations had more CCA than the adjacent natural coral reef. CCA is a functional group of calcifying algal species that facilitate coral settlement through the formation of calcium carbonate and microbial communities, supporting healthy coral reef development [9,10]. Oceanite mixtures are specifically designed to attract and incorporate calcifying organisms (e.g. corals, CCA, bivalves, polychaetes, etc.). Finding high levels of CCA on the structures suggests that the chemical/mineral mixtures are performing as expected (or better), and have the potential to be scaled up in future projects to facilitate settlement of reef-building species on regional to global scale.

Image 3. Natural coral recruit found on the IntelliReef structure.

Our AR deployed in the MPA was the only site that divers observed macroscopic coral recruits (Porites Astreoides). This supports our hypothesis that our structures can facilitate wild coral settlement in a relatively short amount of time (See Image 3). Based on the number of polyps on recruits, the corals settled during their last reproductive season (May - September 2019), <1 year after AR deployment.

Corals reproduce by brooding and releasing larvae or broadcasting their gametes into the water column [11]. Larvae choose suitable hard substrate, based on light, chemical, physical, temperature, density, and auditory cues [12-16] . After the coral larvae choose a suitable substrate to land, the larvae still face a high degree of early mortality due to grazing by predators and overgrowth through competition for available space [17-19]. Another challenge around the world is the limited colonizable substrate due to increased rates of reef deterioration (i.e. erosion, hurricanes, ocean acidification) [20]. We suggest that the complex microtopography and porosity of OGM helps address these issues of decreased substrate by providing shelter through cryptic spaces. Our next phase of research includes measuring coral recruitment and survival on our Oceanite mixtures using standardized, replicated settlement tiles across sites.

Our reef site at Great Bay is exposed to the most boat traffic of all three sites and experiences a high amount of sedimentation and abrasion due to its shallow depth, turbulent waters, and sediment composition [26]. As a result, Great Bay had the lowest total cover of benthic invertebrates on both horizontal and vertical substrates of all three sites [26]. Though there was a decrease in benthic invertebrate coverage, the substrates at Great Bay had the highest algal cover of all sites, suggesting that algae species in this area are more tolerant of the environmental conditions than benthic invertebrates.

Surrounding benthic communities and site background data also affect invertebrate colonization patterns, underscoring the importance of compiling environmental data and concurrently monitoring adjacent communities in AR studies. These results are key for considering site-specific design considerations for turbulence in compromised ecosystems (e.g. higher vertical relief, and walls buffering sheltered, internal communities, etc.) in future IntelliReef deployments.

We also examined fish abundance and feeding behaviour on the ARs. Grazing rates are highly dependent on the abundance and composition of fish communities [23]. At Mike's Maze, located in the marine protected area, fish abundance and grazing rates were lower than The Bridge (See Attachment 1: Scientific Report). Herbivorous and omnivorous fish fed directly off our AR structures at both Mike's Maze and the bridge, indicating that the ARs are food sources for resident fish (See Attachment 1: Scientific Report). Grazing rates have not been documented on the coral reef in the MPA, so no comparison can be drawn between the natural reef and our AR at this time, but are in the process of obtaining the required data in partnership with Sint Maarten's Nature Foundation, which is the local MPA management organization. We found that the fish community in the MPA was more diverse than The Bridge, but as the surrounding benthic communities are different at these sites (i.e. coral reef vs seagrass bed), we cannot disentangle differences in fish community composition between the two sites. While water quality was too poor to examine fish abundance and behaviour on the AR at Great Bay, divers observed two gobies sheltering in the structure.

We found that the AR in the unprotected through-way (The Bridge) had an order of magnitude more fish than in the MPA. Increased fish abundance at The Bridge may be due to the shipwrecks (> 3 vessels) located adjacent to the AR. The additional structural complexity provided by these structures have the potential to attract and recruit fish from the water column and surrounding seagrass bed (See Image 4). Both pelagic and demersal fish species have been found to seek shelter in high-relief ARs relatively soon after deployment, indicating that ARs can be highly effective at mitigating the effects of overfishing and rehabilitating depleted fish stocks [24]. However, this is contingent on the simultaneous reduction of fishing pressure in the area [25]. For this reason, large ARs with significant vertical relief deployed in MPAs that prohibit or severely limit fishing have the potential to mitigate the effects of overfishing.

Image 4: MPA Benthic Coverage at near 100%.

Our findings at The Bridge also suggest that ARs in areas IntelliReef AR structures offer dynamic substrate orientations, structural complexity, and high-quality colonizable habitat that calcifying organisms settle on quickly (14-mo) and attract fish from nearby habitats. Our ARs can be tailored structurally and chemically to meet habitat-specific requirements for targeted biological communities. Initial results from our pilot studies suggest that when Oceanite ARs are deployed in MPAs and low-traffic areas, they have the potential to accumulate nearly 100% cover on all surfaces. The results from our preliminary investigations of benthic communities on ARs suggest that structural design of future IntelliReefs should integrate substrates angled to reduce sedimentation and create a variety of light exposure levels to increase diversity on the structure. We contend that Oceanite ARs have the potential to enhance cover reef-associated invertebrates, particularly those occupying vertical and shaded substrates.

We observed that the interior matrix of our Oceanite blocks were completely colonized by cryptic benthic invertebrates (e.g. sponges, polychaetes, bivalves, ascidians, etc.), suggesting that the porous nature and complex microtopography of Oceanite Growth Matrix (OGM) facilitates their diversity and settlement (See Image 5). We also propose that deploying networks of large ARs with high vertical relief over broad spatial scales (i.e. sites > 30 m diameter) may be key to addressing goals to increase the abundance of ecologically and commercially important reef fish. There are many environmental factors that may have contributed to fish community differences among sites, and we would like to examine the effect on organism colonization in our next phase of research. This will involve replicated structures and standardized settlement tiles that can be periodically removed for analysis at each site. Understanding the relationship between colonization patterns on AR structures, given the adjacent background community, will inform future design and monitoring protocol on IntelliReefs.

Image 5. Interior of IntelliReef structure sliced to illustrate engineered material matrices and open crevasses that provide key living conditions for cryptic marine creatures.

3. Conservation Impact

The IntelliReefs system fulfills a global demand for large scale marine habitat revitalization, restoration and protection. We found that the substrate enhanced benthic biodiversity and enabled many stakeholders to actively collaborate on a reef restoration project. Because IntelliReefs can be scaled up to any size and shape, eco-tourist business consortiums recognize its potential to cultivate economic and biological growth.

Recent hurricanes have caused significant reef habitat and coral nursery loss. IntelliReefs can receive corals grown in nurseries as well as provide substrate to facilitate the natural succession of diverse marine species. This pilot program granted us a granular insight into the biology of reef restoration using ARs and how to work together with local partners to better serve Marine Protected Areas and the Blue Economy.

By actively listening to the Nature Foundation and local businesses, we gained a holistic understanding of how to build an ongoing revenue stream for MPA management. To date, this initiative has cultivated a powerful multi-stakeholder collaboration. Local businesses, yacht and scuba volunteers worked with engineers and material scientists who worked with coral research scientists. All these groups came together with valuable input on how to enhance benthic biodiversity and create a multi-agency win for a resilient reef regeneration program.

Impact Observations:

1. **Because of the long time investment, local coral nursery teams want to plant their coral frags, and grow coral trees in the healthy and protected waterways of an MPA.**
2. **The next generation of IntelliReefs needs to be larger and interesting to scuba divers. Beautiful and strong enough to withstand hurricane storm surge.**
3. **Local businesses are willing to use their marketing budgets to support a bold coral regeneration project that enhances biodiversity and attracts dive and eco tourists with unique experiences.**
4. **Spawning coral will land and grow on the IntelliReefs along with a diverse benthic community.**

We developed relationships with three businesses (Pelican Peak, Random Wind and Sint Maarten Scuba Shop) to support IntelliReefs initial prototype deployment and expansion phases (See Image 6). These relationships can expand into a business and government consortium for increasing biodiversity, growing coral and creating unique tourism experiences.

Core to Reef Life Foundation's mission is to create ongoing revenue for coral nurseries and MPA management. In addition, the pilot program expanded awareness around the spreading coral tissue disease amongst local politicians and business owners.

The IntelliReef project was presented as a solution initiative in the schools of Sint Maarten and has gained recognition by PADI dive operators as a way of further engaging divers in coral regeneration via their Coral Restoration program.

Our 14 month pilot program engaged a public private partnership to further catalyze an expanding consortium. All parties are excited to enhance marine biodiversity and continue to build out the educational reef experiences for local and international education.

Our future goals include working closely with worldwide organizations to further develop a repeatable model that creates biological and economic wins for coastal communities and MPA's around the world.

Image 6. Reef Life Foundation Team with Pelican Peak, Random Winds Charters, and the Scuba Shop. Collaborative partnerships for developing biodiversity, growing coral and creating unique tourism experiences in Sint Maarten.

4. Next Phase of IntelliReefs

The next phase of IntelliReefs will incorporate both material and habitat research and development objectives outlined in the IntelliReef scientific report[26]. These objectives will be accomplished in conjunction with Reef Life Foundation's goal of supporting MPAs through a large-scale project in the Sint Maarten MPA. The initial deployment will involve a structure designed to accomplish both research and long term eco-tourism objectives that will support a diverse array of studies within the MPA (> 30 meters in diameter). This large scale project will leverage our current materials, manufacturing and deployment partnerships in the greater Carribean area to create one of the most ambitious research based AR's in the world as well as providing environmental and economic benefits to the area.

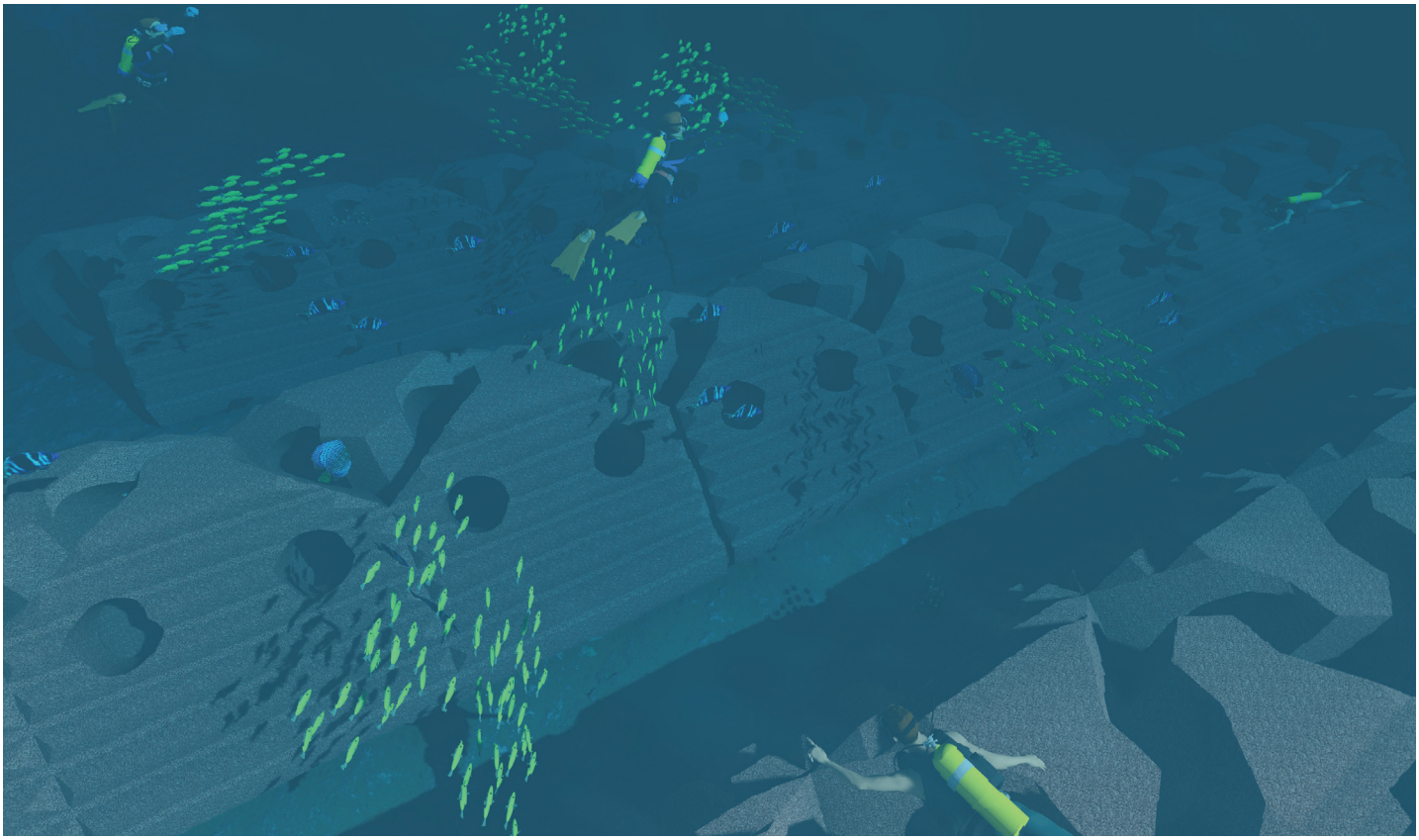


Image 7. The great wall of reef concept developed by Reef Life Restoration. The Wall incorporates angled shelving space for coral outplanting and voluminous interior space.

One important desired outcome of this project is to create an eco-tourism business model that supports MPAs and invites local tourism operators, resorts, and NGOs to invest and participate in building a world class dive and snorkel attraction. This model can be applied world-wide to amplify MPA, business, and local environmental and conservation efforts. By establishing partnerships with MPA organizations and NGOs, the Reef Life Restoration's IntelliReef dive structures will foster relationships with the tourism industry that generates critical revenue for island and coastal communities, while protecting and enhancing the local marine habitat.

When complete, the IntelliReef dive reefs will enable tourists to participate in planting coral fragments grown in nurseries. By integrating coral nurseries into the IntelliReef sites, the dive attraction becomes a compelling tourism experience that bolsters the economics of the MPA and creates a scalable model for larger habitat restoration projects world wide. The images below highlight the exciting process in which tourists and MPA visitors will participate: A visitor will start by visiting an on-site coral growing lab, Choosing your coral, and finally physically participating in the coral planting process or by proxy. With the funds received by this eco-tourism experience going towards growing more corals, manufacturing more substrate, and supporting local communities with jobs that help the local environment.

Images 8 & 9. Tourists at MPA sites selecting and purchasing coral fragmentation pieces for outplanting the corals on specifically designed IntelliReef structures.

Images 10 & 11. Park visitor utilizing the IntelliReef structure for coral outplanting outside the MPA.

Images 12 & 13. Local resort and tourism operator customers engaging with the dive site.

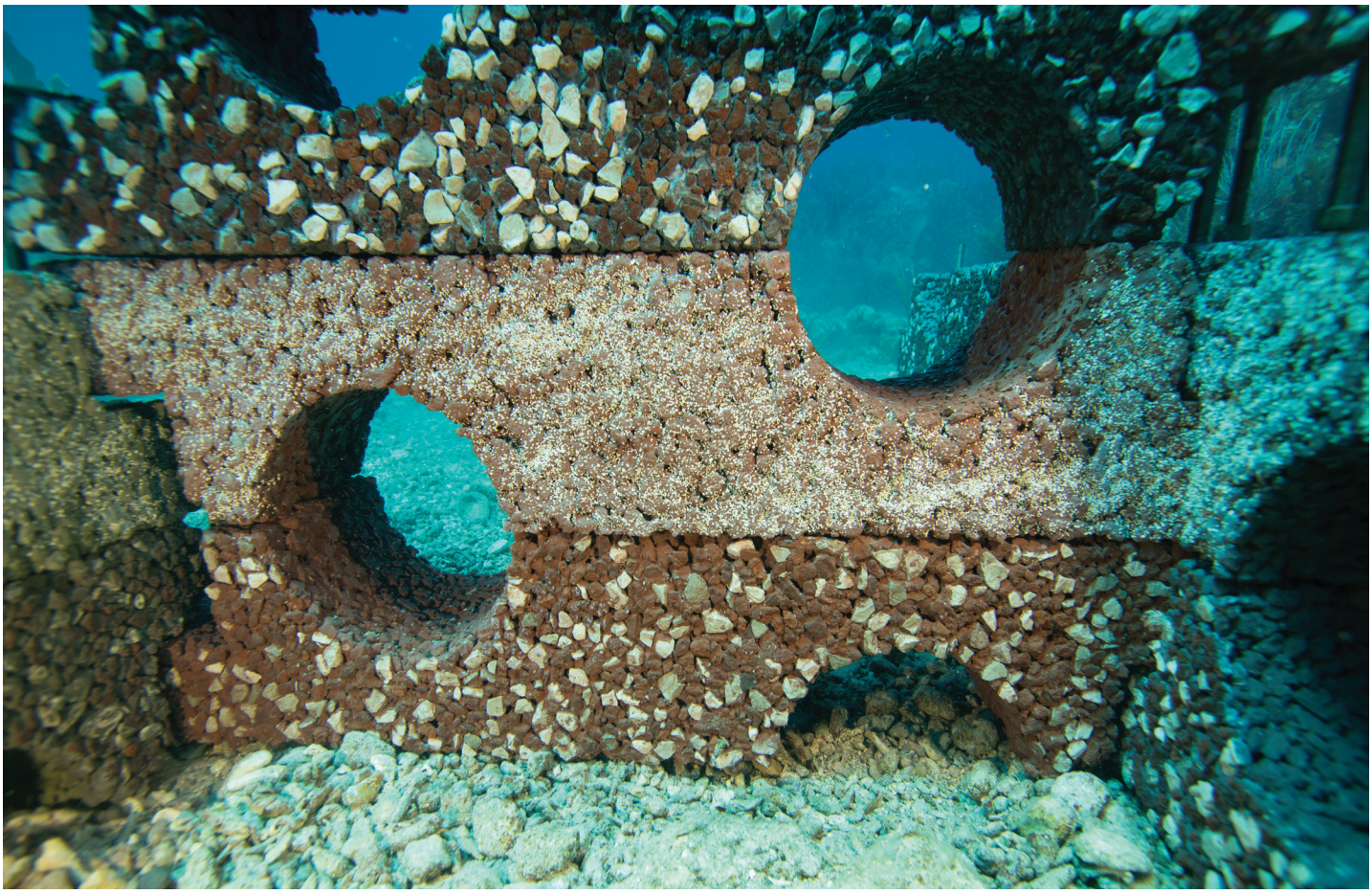
Reef Life Restoration's ability to cast and deploy large scale art and functional dive sites using IntelliReef technology to support current and future coral and marine plant growth. This allows for sustainable outplanting projects while engaging multiple stakeholders within the many facets of coral and coastal restoration methods. This conservation-based business model will play a vital role during the UN's Decade of Ocean Science, which demands that 30% of the oceans are protected by 2030. The long-term goal of this phase will be to install square kilometers of IntelliReefs in MPAs world-wide that foster collaboration between land based coral micro-fragmentation labs, business, tourism, community education, and research opportunities.

Developing our products for an eco-tourism launch, has been a compelling path towards bringing this material to market. We realized that with recent economic events affecting trade and long distance visitors for years to come; we have decided to focus on wave breaks, and research in design, materials and large scale deployment.

In the coming months, we will be seeking partners to develop aquaculture test rig systems for determining the needs of specific sponges and algae producing various modern anti-cancer and anti-viral compounds. We have requests for modular seawall systems; built for long distance generational impacts, to reduce future construction costs by growing with the rising sea.

"Break the wave and tumble into reef restoration"

With this modified trajectory, we are better able to interface with the exploding biotech and burgeoning climate change mitigation industries, to deliver products that save lives and reduce property erosion, while doing good for the ecosystems we serve. Moving forward, we will pursue a fiscal sponsor to be the managing multiple sources of funding and expectations.



Images 14 & 15. Immediately after deployment and then 14 months later

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Attachment 1: Research Authorization Nature Foundation

"Nature is Our Future"

January 28th, 2020

To whom it may concern

Letter of Research Authorization

For: Reef Life Foundation Ocean Science Team

The Nature Foundation St. Maarten, acting as the *de facto* and *de jure* Scientific Authority and Management Authority for biodiversity and ecosystems on Sint Maarten based on the Management Contract with the Ministry VROMI and acting under the authority of the Nature Conservation Ordinance AB 2008, hereby gives permission to the researchers of the Reef Life Foundation Ocean Science Team to conduct their research on the artificial reef structures called 'IntelliReefs, placed on the dive sites 'Mike's Maze', 'The Bridge' and 'Great Bay' in Sint Maarten waters from the 28th until the 30th of January 2020.
Their research will be focussed to understand the performance of the structures regarding marine life biodiversity settling on the structures and they will further photograph, and identify the marine biodiversity covered on the IntelliReefs prototypes, they will create and publish the photographs to global coral labs for analysis and quantification of species per sq. feet of substrate.

Abovementioned Science Team are permitted to do the following research activities; research which textures, coatings and minerals attracted and settled the most coral spawn during the recent spawning event in September. Count unknown marine organisms and identify the species on the IntelliReefs structures. Count and identify corals on the structures, count, size and identify sponges, algae, Crustose Coralline Algae and plankton species on the structures. In addition, they are authorized to conducting onsite evaluation and count of fish aggregation in on the structures, specifically which fish species entering the area and feeding of the IntelliReefs prototypes. The researches will also record increased fish aggregation in the locations of IntelliReefs deployment, this will contribute to the evaluation of beneficial economic and environmental impact.
Scuba diving activities are permitted from the Nature Foundation boat and the charter boat 'Random Wind', it is the responsibility of each diver to purchase their own Dive tag from sintmaarten.reefsupport.org.

This research is being done in close collaboration and under the auspices of the Nature Foundation Sint Maarten.

Hoping to have informed accordingly I remain

Cordially,

Melanie Meijer zu Schlochtern, MSc
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Attachment 2: Project Collaborators and Partners

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- Melody Brenna: Reef Life Foundation Executive Director
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- Konstantin Sobolev: Research and Materials Engineering Director
- Josh Hanes: Operations and Management Director
- Guyon Brenna: Architecture/Substrate Design Director
- Ian Kellett: Reef Life Ocean Project Advisor

Collaborators

- Colleen Flanigan: Island & Lab Species Photography for Identification
- Hugo Nobre: Filmmaker and Project Film Editor
- Michelle Sanders: On-Site Project and Interviews Videographer

Project Partners

- Waitt Foundaiton: Primary funders of Documentation trip 2019
- Nature Foundation: Sint Maarten MPA Management Organization
- Sea Legacy: Initial Deployment Sponsor and Video Documentation
- Random Winds Charter: Sint Maarten Catamaran Charter
- Sint Maarten Scuba Shop: Local Dive Shop and Dive Gear Sponsor
- Eco Blue Projects: Underwater Deployment and Recovery Specialists