DESIGN WITH DIPLORIIA

CORAL INFRASTRUCTURE FOR A NEW COASTAL FUTURE

MATTHEW GROSSER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT REQUIREMENTS FOR THE DEGREE OF

MASTER OF LANDSCAPE ARCHITECTURE

UNIVERSITY OF WASHINGTON

2020

COMMITTEE:

KEN YOCOM

JACQUELINE PADILLA-GAMIÑO

PROGRAM AUTHORIZED TO OFFER DEGREE:

LANDSCAPE ARCHITECTURE

UNIVERSITY OF WASHINGTON

ABSTRACT

DESIGN WITH DIPLORIIA

CORAL INFRASTRUCTURE FOR A NEW COASTAL FUTURE

MATTHEW GROSSER

CHAIR OF SUPERVISORY COMMITTEE:

KEN YOCOM (LANDSCAPE ARCHITECTURE)

THE GROWING STRESSORS OF GLOBAL CLIMATE CHANGE AND URBANIZATION HAVE BROUGHT ABOUT THE DECLINE OF ONE OF OUR PLANET'S MOST CRITICAL BIOMES - CORAL REEFS. AS CORAL REEFS VANISH, WE LOSE NOT ONLY THEIR SURROUNDING ECOLOGIES AND ECONOMICS, BUT ALSO THE STRUCTURAL COMPLEXITY THAT ALLOWS THEM TO EFFICIENTLY SERVE AS NATURAL BREAKWATERS, WHICH PROTECT COASTLINES FROM FLOODING AND EROSION. DESIGN WITH DIPLORIA SHOWCASES A MULTI-SITE EXPLORATION OF THESE ENTANGLEMENTS WITHIN MIAMI'S URBAN CONTEXT BY WORKING TO RESTORE AN ENIGMATIC, BUT DIMINISHED, LOCAL ECOSYSTEM AS AN INFRASTRUCTURAL AND SOCIAL RESILIENCE STRATEGY.

Acknowledgements

I'd first like to acknowledge my thesis committee, Dr. Ken Yocom and Dr. Jacqueline Padilla-Gamiño, I am so thankful for the encouragement and guidance you've provided along this fascinating journey.

Thank you to everyone who generously took time out of their schedules to meet with me: Colin Foord, Dr. Saki Harii, Dr. Frederic Sinniger, Dr. James Reimer, Dr. Jinkyu Yang, Gator Halpern, James Lee, and all of the members of the Jacqueline Padilla-Gamiño Lab, without your willingness to share your knowledge and experiences I would have certainly been lost.

I'd like to thank my cohort in the Landscape Architecture department continuously inspiring me for the past 3 years while acting as a sounding board for my ideas.

Thank you to my partner before and during quarantine Leah, who probably has gained more second-hand coral knowledge through my experience than she was expecting. As well as my good buds Chris Giamarino, Tim Cowan, and Salman Javed who provided some thoughtful outside perspective for my work.

I would also like to acknowledge both the Coast Salish peoples, the rightful owners of the land on which I worked, as well as the Tequesta people whose land hosted my design vision.

Contents

Author's Note

As I grew up upon the waters of The Great South Bay of Long Island, I became keenly aware of the interconnectivity of the global oceans and terrestrial processes. Through my adolescence, blooms of brown and red algae became more prevalent due to increased hardscape and agricultural runoff. Compounding this issue of eutrophication were depleted bivalve stocks. Over-extraction of shellfish led to large shifts in ecological baselines from what was considered bounty between the generations of my grandfather, my father, and myself. As the environment continued to degrade, you could observe a cultural shift in recreational activities from bay-life toward shopping malls, diminishing the once unique social and biotic ecology of the island. Less interest in recreation on, or dependence for subsistence from, these waters resulted in further ecological degradation due to social disinvestment in water quality. Providing me with an example of how capital can overtake ecologies of place and instilling in me a passion for environmental sustainability and politics from an early age.

While living in Brooklyn as an undergraduate at the time of Superstorm Sandy, I witnessed firsthand the destructive power that a storm event can unleash when urban infrastructure is unprepared. America's largest city and center of wealth was brought to a standstill by an act of nature that technically wasn't even fierce enough to be labeled a hurricane. This catalyzed an active dialogue within New York regarding how to approach urban resilience in the face of climate change. A few years later, while working as a green infrastructure project manager for New York City's Department of Design and Construction, the agency hosted a talk on resilience where SCAPE team members Gena Wirth and Pippa Brashear presented Living Breakwaters. I had never seen anything like this before, their work stirred something deep inside me. This project presented a design direction that not only fostered urban resilience but married it with the restoration of an integral, but diminished, local ecology.

Now after three years of pursuing a graduate degree in landscape architecture I am more passionate than ever about adaptive infrastructure and ecological reparations, but I am still left wondering how urban, social, and ecological resilience can be further nourished through design. I have felt for quite some time that coral reefs provide an obvious target for ecological design interventions due to the sheer urgency of their global struggle. Now with free reign to formulate a project of my choosing, I'm seeking to explore the potential solutions that my profession could work to provide.

Clammers on the Great South Bay
- Photo Courtesy of Newsday

INTRODUCTION

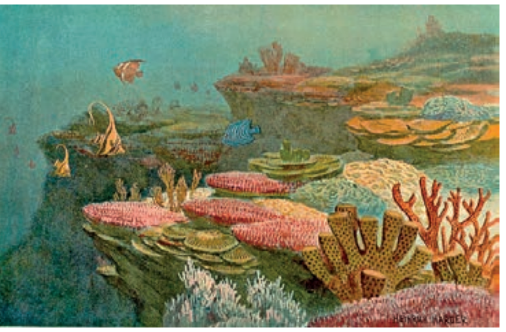
Still Image from "The Coral Reef are Dreaming Again" a short film by Coral Morphologic

"Corals were the first timekeepers of Planet Earth. For more than half a billion years, their internal clocks have been synchronized with the sun and the moon. However, it would take life several hundred million years of further evolution before finally crawling out from beneath the liquid lens of the ocean and into the open air where it would develop the consciousness necessary to ask the question, then the intelligence needed to invent the technology to empirically measure its objective reality. Thus, the purpose of life is to quantify the nature of the cosmos itself. The development of symbiosis between coral and humankind appears as a harbinger for the final stages of life on earth. Our ouroboros is nearly complete."
- Colin Foord (Coral Morphologic)

From Prehistory to Precarity

1 - Shick, J. M. (2018). Where Corals Lie: A Natural and Cultural History (Illustrated). London: Reaktion Books.

Coral reefs provide habitat and nutrients to over 25% of all documented marine species while directly supporting 500 million people globally, despite only covering less than 1% of the ocean's floor (1). Their complex structures form breakwaters, protecting our coastlines from erosion and flooding as nature-based tools of resilience. Yet, these vibrant hubs of biodiversity are extremely vulnerable to the threats of ocean warming and acidification catalyzed by global climate change. Our current period of rapid urbanization has resulted in the further degradation of these ecosystems as compounding stressors are introduced such as rigid coastal development activities, overfishing, and consistent pollution from urban surfaces. (1) With these conditions, it has been estimated that within the next two decades, there will be a widespread collapse of coral ecosystems. (1).



Above - Representation of an ancient coral reef by Heinrich Harder.

It is estimated that coral species (Anthozoans) first appeared in the world's oceans over half a billion years ago, making them far older than Homo sapiens (which arrived on the scene 7 million years ago).(1) As societies began to classify and quantify the world around us, coral eluded initial scientific classification. Exhibiting characteristics of plants, animals, and minerals, coral was an enigma until microscopic observation revealed corals to be marine invertebrates that consist of dense colonies of genetically identical polyps (1). These polyps have developed a symbiotic relationship with photosynthetic algae (zooxanthellae) that they house within their tissue in exchange for nutrients. As more was learned about the taxonomy of corals, more was understood regarding their importance in reef ecosystem dynamics. Most valuable to the composition of reefs are hermatypic corals, which build skeletons of calcium carbonate that provide the basic structure of a reef. These are also the corals most affected by global climate change, as ocean acidification inhibits their constructive abilities. (1)

There is growing public awareness regarding the severity of the declining condition of coral reefs globally, and 2018 was declared the International Year of the Reef by the World Underwater Federation in an effort to catalyze action. Likewise, multinational corporations like Pantone have pitched in with awareness campaigns like "Glowing, Glowing, Gone" a global competition that sought to use "colour and creativity to accelerate climate and conservation action." However, even as awareness grows solutions continue to materialize slower than necessary. Interdisciplinary collaboration toward solutions is needed now more than ever.

When discussing the destruction of global coral, the conversation is more about the dissolution of coral reefs as a functional ecosystem - coral as an organism will likely far outlast us on this planet. They have survived all kinds of planetary shifts in climate over the millennia of their evolution. However, coral's abundance and their ecosystem dynamics, as we know them, will become irreparably degraded if we do not mobilize swiftly and effectively.

Left - Pantone "Going Going Gone - Colors of the Climate Crisis" Highlighting the brilliant shades of color corals exude as they bleach.

Design for Aquatic Ecologies

What is design's role in the revitalization of corals? In order to navigate the impending climate crisis the dichotomy of "city" and "nature" must be deconstructed. We have reached a point where it may be too late for traditional views of ecological restoration alone to be successful. We must begin augmenting ecosystems to ensure their survival. The ability of designers to creatively layer added meaning, beauty, and legibility upon systems and processes provide us with a unique skill-set to aid in ecological reconciliation of this scale and magnitude.

Foundational works of landscape architecture theory such as the ideas that emerged from Ian McHarg's seminal thinking in his book, Design with Nature (1969), provide glimpses at a framework meant to elevate us toward more holistic ecological design approaches. McHarg exhibited an early understanding of ecological resilience and the need for biomimetic adaptivity through design, as he discussed the function of dune's along the New Jersey Coast and compared it to Dutch dike engineering design, proposing "that nature is process, that it is interacting, that it responds to laws, representing values and opportunities for human use with certain limitations and even prohibitions...May it be that these simple ecological lessons will become known and incorporated into ordinance so that people can continue to enjoy the special delights of life by the sea." (2) McHarg saw these dunes not as "nature" to be tamed, but rather "nature" to be replicated and augmented. When looking at protecting tropical shores, a similar approach and understanding of reef dynamics must be achieved.

2-McHarg, I., & American Museum of Natural History. (1969). Design with nature (1st ed.]. ed.). Garden City, N.Y.: Published for the American Museum of Natural History [by] the Natural History Press.

Randolph Hester's, more recent, Design for Ecological Democracy (2006) introduces the idea of "Ecological Think". A framework "not simply about natural ecology, [but] also about considering the consequences of urbanization actions and the inter-relationships that create vibrant self-sustaining habitats." Hester opines that "urban resilience doubtlessly depends on maintaining or creating diversity in many aspects of urban form, but ecological democracy most critically depends on overcoming landscape fragmentation and shortsighted interest-group divisions." (3) These sentiments ring true in any design project, monoculture-based conceptualization continually results in monotonous results. In order to reclaim the vibrancy of reef ecosystems, diversity and connectivity will undoubtedly have to play a crucial role.

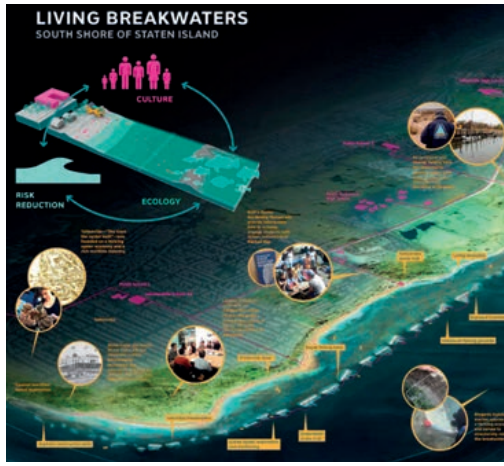
3 -Hester, R. (2006). Design for ecological democracy. Cambridge, Mass.: MIT Press.

We see these frameworks currently being expanded upon by an emerging group of contemporary landscape theorists, such as Kees Lokman and his concept of the "Cyborg Landscape". An idea structured around "the formulation of a landscape approach that integrates biotic and abiotic systems to envision more dynamic interactions among infrastructure, ecology, and urbanism" combatting the key issues of "climate change, population growth, resource scarcity, and environmental decline". (4) In my own thinking, reflected through the framing and development of this design research, there is no other path forward than the approach to process and adaptive design purported by luminaries such as McHarg, Hester, and Lokman. We must work beyond the nebulous boundaries of perception that continually seek to reinforce a separation of "human" from "nature" and both of these from "machine". In order to design strategies that address the complex issues we face as a society we cannot focus on these individual subcategories because of their high degree of interrelation.

4-Lokman, K. (2017). Cyborg landscapes: Choreographing resilient interactions between infrastructure, ecology, and society. Journal of Landscape Architecture, 12(1), 60–73. https://doi.org/10.1080/18626033.2017.1301289

Many design teams are materializing aspects of these theories within their practice. Kate Orff & SCAPE's work of resilience and oyster-tecture, Living Breakwaters, was conceptualized to advance "beyond a built environment conceived exclusively for human consumption and comfort (to) address the wider global ecosystem as a shared space for all species." (5) Their process of community engagement as well as their process of prototyping and experimentation with oyster growth techniques provide what is potentially the single greatest precedent for any kind of coastal design exploration. James Corner Field Operations' reimagination of the

5-Orff, K., & SCAPE. (2016). Toward an Urban Ecology (Illustrated). New York City: Monacelli Press.

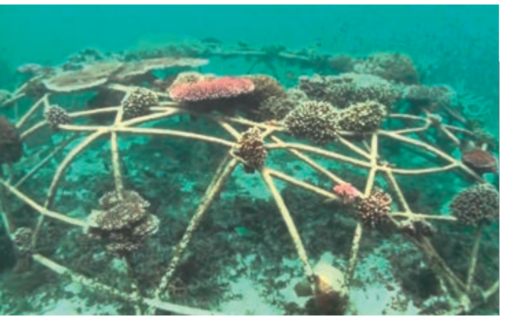


Above - A diagram from Living Breakwaters

Seattle Waterfront Seawall provides a similar case study for how we reconcile an urban social hub with ecological infrastructure through experimentation and a co-species approach to design.

These large infrastructural projects may feel new and exciting, but architecture has long engaged with the aquascape; and has specifically engaged with coral (albeit on a smaller scale) for decades. However, most of that work has been largely obscure and slowly built upon. In the mid 1970's, Wolf Hilbertz, a German architect and University of Texas professor found that running low voltages of electricity through a steel rebar cage could encourage the secretion of calcium carbonate by hermatypic corals. (6) This technique, though controversial due to a lack of independent studies, is being used in coral restoration today. One artist, Colleen Flanagan, has even applied it to her "Living Sea Sculpture" at an artificial reef site in Cozumel. (7)

6-Hilbertz, W. (1976). MARINE ARCHITECTURE: AN ALTERNATIVE. Architectural Science Review, 19(4), 84–86. https://doi.org/10.1080/00038628.1976.9697227



Above - Hilbertz's Biorock Design

7-Beans, C. (2018). Science and Culture: Artistic endeavors strive to save coral reefs. Proceedings of the National Academy of Sciences, 115(21), 5303–5305. https://doi.org/10.1073/pnas.1807178115

Michael Ezban's newly published Aquaculture Landscapes (2019) highlights some of these marvels of modern aquatic ecological design while comparing them to more traditional practices of aquaculture historically. Ezban appraises these works against relevant theory, and synthesizes the questions: "If urban infrastructure is designed to serve as loci of encounters between species in the city, can our intensified decentering experiences at these "constructured natures" foster recognition of fish and other animals as contributors to the "numerous, simultaneous, individual experiences" that comprise collectivity? Can granting fish and other animals subjectivity, recognizing our kinship with them, and planning for their success and ours, seed the emergence of "new ways of living in multispecies societies?" (8) This notion of kinship is an invaluable consideration when conceptualizing any design and needs to be explored further.

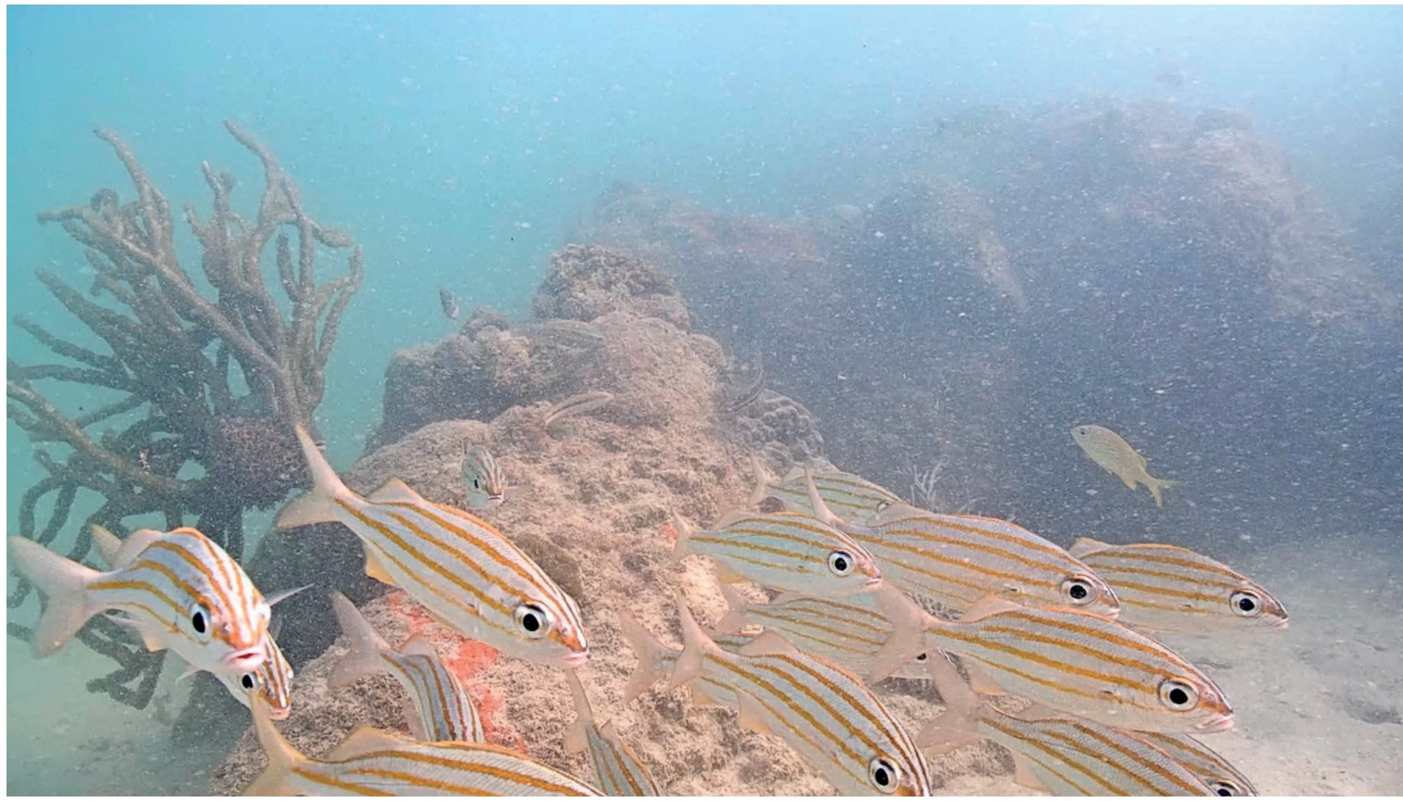
8-Ezban, M. (2019). Aquaculture Landscapes: Fish Farms and the Public Realm (illustrated). London: Routledge.

Not all works of design within the aquascape seek to catalyze systems, some simply allow existing systems to carve their own paths. Jason DeCaires Taylor, sculptor and marine conservationist, creates site-specific underwater sculptures that catalyze coral growth by encouraging settlement, while essentially creating reef museums as an elegy for ecology lost to climate change. Similarly, though not spatial designers, the art science collaborative Coral Morphologic provides another excellent example of how art and science can be wielded in the defense of corals through their audio-visual explorations of reef ecology. Most notably, their recently installed "Coral City Camera" provides a portal to an underwater world by livestreaming life among a small coral nursery and reef off of Port Miami.

Above - Some of Jason DeCaires Taylor's Work.

Design's role in the coralscape has certainly progressed over the last 5 decades, but this work must be expanded upon in order to fight back the planetary systems and forces that work to degrade these vital ecosystems.

Below - A Still from Coral Morphologic's Coral City Camera



Coral in the Capitalocene

Perhaps to better understand the decline of corals and facilitate their resurgence through design, we should begin by analyzing our current geologic age. This time period has not been kind to corals, as over 50% of coral globally has died within the last 30 years (9). Generally, this epoch has been defined as the "Anthropocene" due to the outsized influence of humans upon our environment through both industrialization and urbanization. When this period first began is a contested topic, with some arguing it started with the implementation of agriculture, others the European conquest of the Americas, others industrialization, and others still the first nuclear bombing (or it could all just be another human-centric articulation). Yet regardless of when this era began, the planetary damage wrought by anthropogenic activity continues to accelerate within an unsustainably short section of geologic time.

9 - Shick, J. M. (2018). Where Corals Lie: A Natural and Cultural History (Illustrated). London: Reaktion Books.

It could be argued that climate change and ecological ravagement by state and private industry was not committed by the entirety of our species, but rather those with the capital to influence large scale decisions. In this case, blaming all of humanity for climate change lets the capitalist system off the hook, suggesting that the proper name of the geologic age should be the Capitalocene. Environmentalist Naomi Klein suggests that we are paralyzed from truly combating climate change "because the actions that would give us the best chance of averting catastrophe — and would benefit the vast majority — are extremely threatening to an elite minority that has a stranglehold over our economy, [and] our political process." (10) There is still a chance for a hopeful future, as World-Ecology Research Network coordinator Jason Moore offers a way forward: "Weighing the injustices of centuries of exploitation can resacralize human relations within the web of life. Redistributing care, land and work so that everyone has a chance to contribute to the improvement of their lives and to that of the ecology around them can undo the violence of abstraction that capitalism makes us perform every day"(11)

10-Klein, N. (2014). This changes everything : Capitalism vs. the climate (First Simon & Schuster hardcover ed.). New York: Simon & Schuster.

11-Moore, J. (2015). Capitalism in the web of life : Ecology and the accumulation of capital (1st ed.). New York: Verso.

Donna Haraway builds upon the theorization of the Capitalocene through a more critical lens. "No species, not even our own arrogant one... acts alone; assemblages of organic species and of abiotic actors make history." (12) She offers another term to encompass this concept of re-worlding, the "Cthulucene", which she feels better encompasses the greater entanglement between geologic timescales and global actors. Haraway's advice as we face the future is to make kin by developing deeper relationships with the world around us. My thoughts on the future of coral and larger global ecologic health lie tied, again, to this idea of trans-species kinship. Though it seems that in order to completely reperate our ecological damage the capitalist model must be abandoned or greatly re-imagined, an initial step could be fostering equity and agency across species lines.

12-Haraway, D. (2016). Staying with the trouble : Making kin in the Chthulucene (Experimental futures). Durham: Duke University Press.

Capital threatens coral not only through the large-scale effects of global systems change that it has wrought, but also through localized threats such as dredging for shipping channels and overfishing. Further complicating matters is the fact that the conditions for coral proliferation is generally along the equatorial band that correlates to locales severely impacted by extractive colonial powers; thus leading to the materialization of added social inequities alongside ecological devastation. If we were to analyze coral through the existing lens of capital- the social, cultural and economic value held by coral reefs is estimated at $1 trillion US dollars; with projections showing that the climate-related loss of reef ecosystem services will cost US $500 billion per year or more by 2100 (13). Further breaking it down, reefs are estimated to have an economic value of $100,000 to $600,000 USD per km², making them one of the most high-value ecosystems on the planet. (13) With projected values like these it appears that a complete breakdown of the function of coral ecosystems, in tandem with the degradation of other essential ecologies during the capitalocene could potentially lead to a breakdown of the capitalist system itself. These considerations may

13- UNEP-WCMC (2006) In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs. UNEP-WCMC, Cambridge, UK 33 pp

14-Fry, T. (2011). Design as Politics (English ed.). New York: Berg.

15-Tsing, A. (2015). The mushroom at the end of the world : On the possibility of life in capitalist ruins. Princeton: Princeton University Press.

16-UN Secretariat of the Convention on Biodiversity (Various). (2011). Exploring the Potential of Satoumi for Implementing the Ecosystem Approach in the Japanese Archipelago. Montreal.

seem like they fall outside of design's purview, but the fact of the matter is that design is inherently political, and designers must further embrace politics in their practice (14). It is our responsibility to elevate the voices of local ecology and social context while moving decision makers away from purely bottom-line focused development.

What are the possible steps upward from this severe downturn? Anna Tsing's book, Mushroom at the End of the World (2015), provides the tangible example of the matsutake mushroom economy found in the Pacific Northwest. Matsutakes only grow in anthropogenically disturbed forests where logging has changed the ecological composition, creating forests that better support the relationship between the mushrooms and succeeding populations of lodgepole pines. The combination of this shift in ecology with a strong community of Asian immigrants created a perfect storm that gave rise to a new, more equitable, economy from the ashes of an over-commercialized resource. Can similar dynamisms emerge from our current coral crisis? (15)

The Japanese theory of Satoumi ("ocean village"), where prolonged contact between humans and their surrounding ecology create and sustain a distinct landscape hybridization, embodies this sentiment of human/landscape symbiosis. (16) Originating from coastal aquaculture practices in Southern Japan the term now "accommodates a wide range of conservation and restoration practices, including some involving human labour on the ecosystem, such as reforestation of watershed slopes, restoration of seagrass beds or maintenance of artificial habitats… (the) data is encouraging on their effectiveness and their potential to mobilize communities and fishers." Moving forward we must integrate ourselves into the landscape instead of distinguishing ourselves from it. Reflecting on traditional land ethics like Satoumi could provide the key to developing a comprehensive social and ecological approach to coral recolonization.

Asking Questions

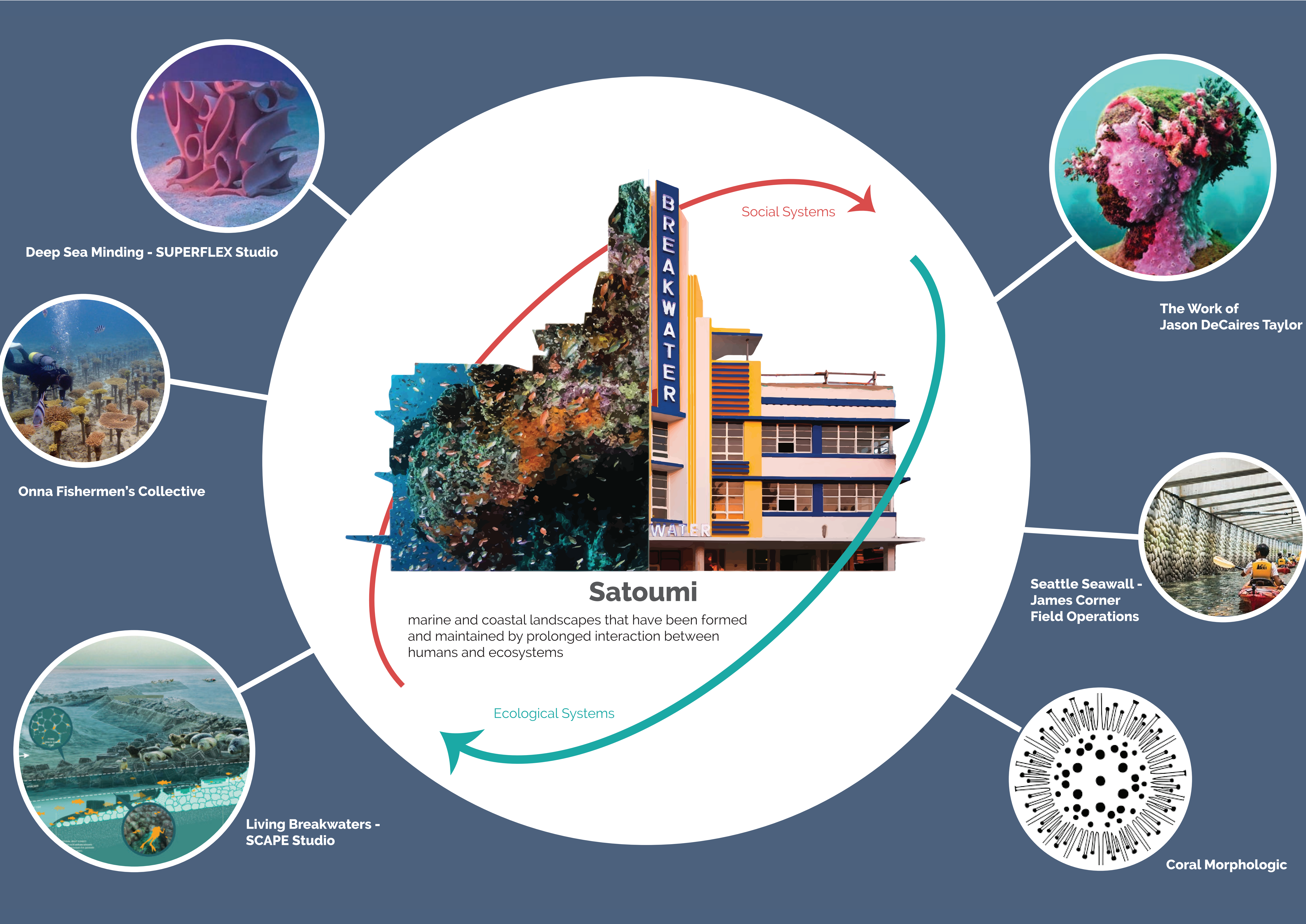
My research to this point has raised 3 primary questions that will influence how I approach and conceive my thinking of design's capacity to build greater understanding of the socioecological capital of coral ecosystems:

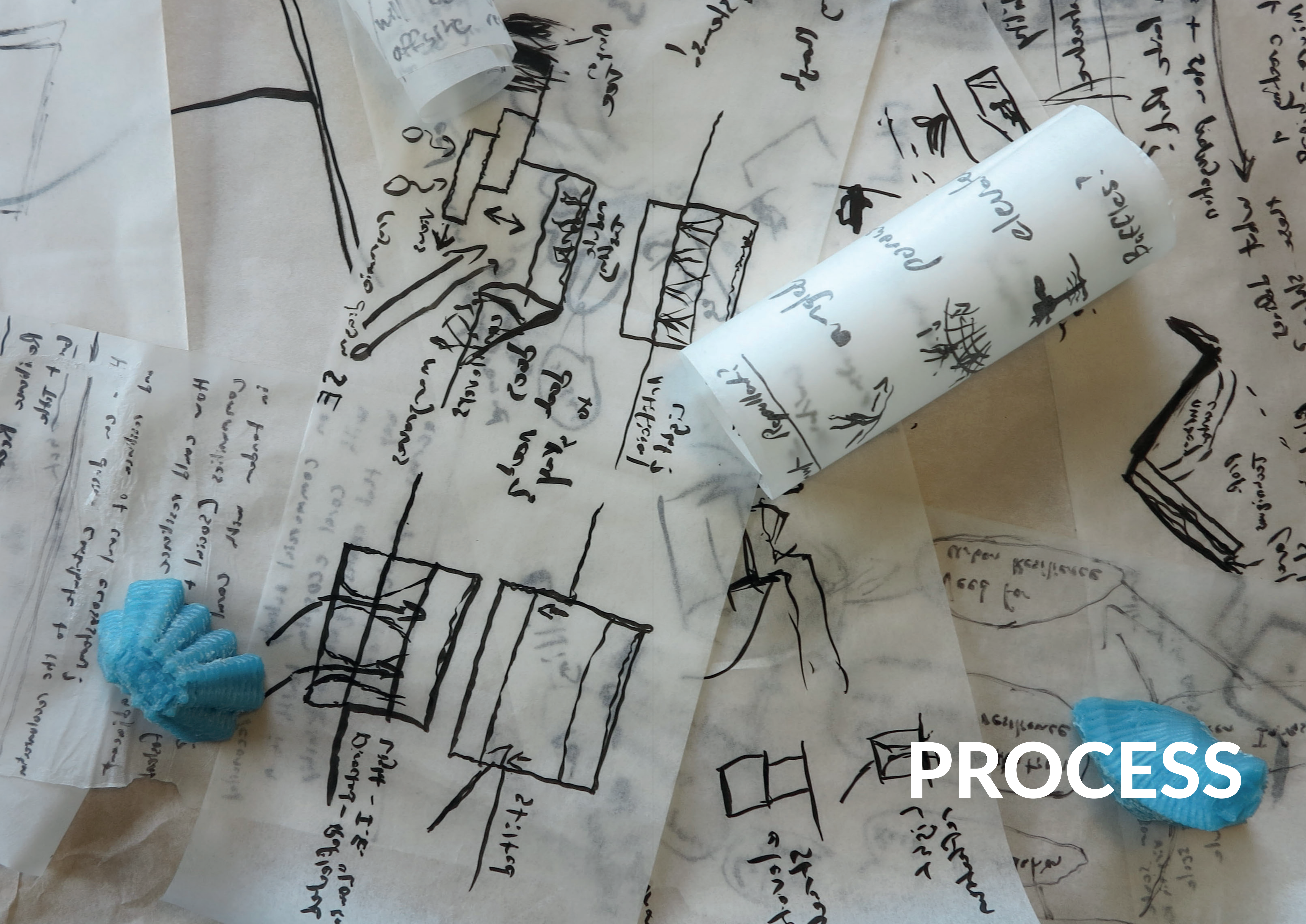
How can design contribute to the recolonization and resilience of coral ecosystems?

How could urban resilience be fostered in tandem with coral resilience?

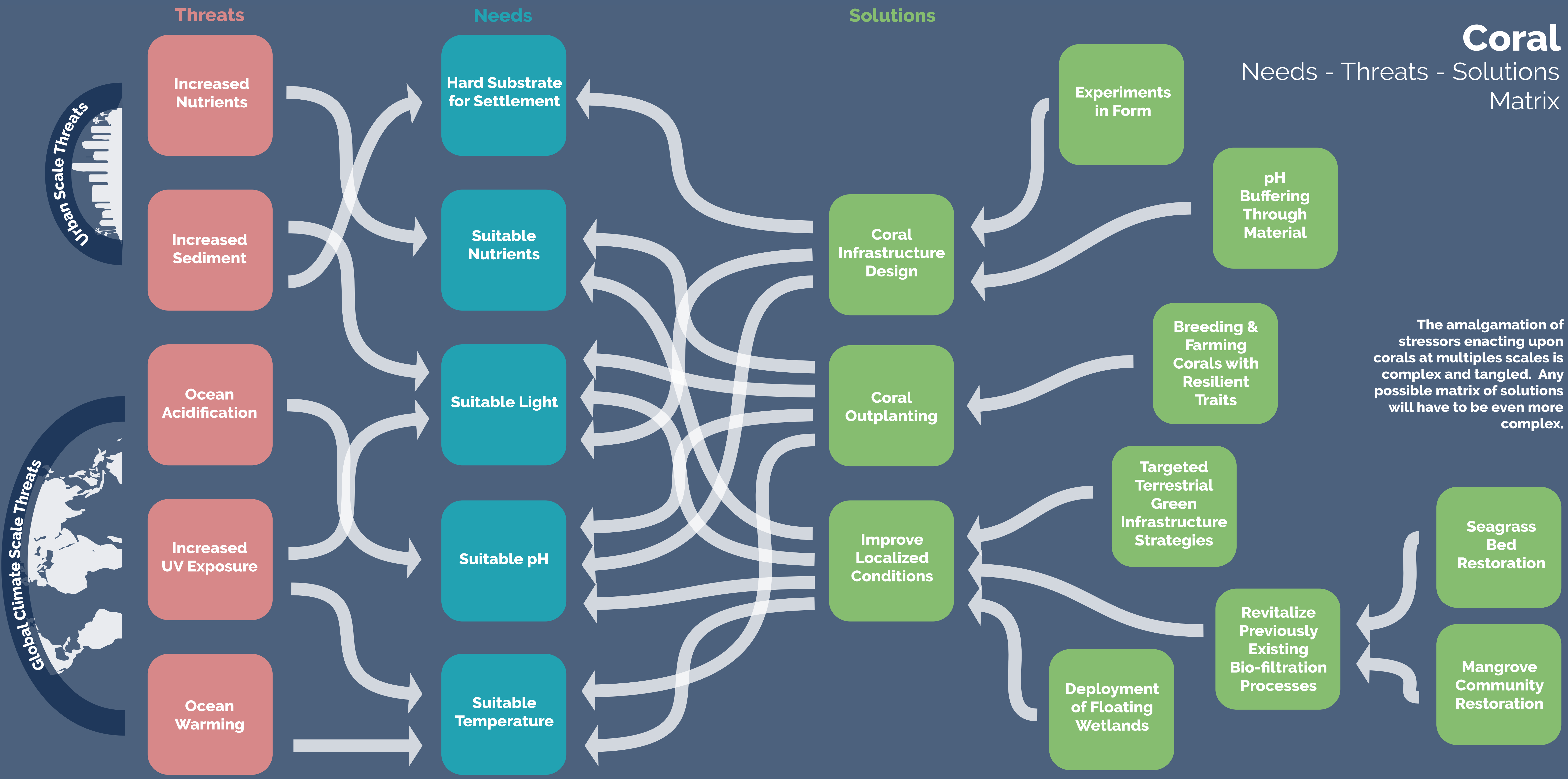
Can urban activity be reconciled with coral ecosystem health in a way that creates equity and kinship across species lines?

Pages 20/21 - Frameworks diagram illustrating the influences on my thinking.

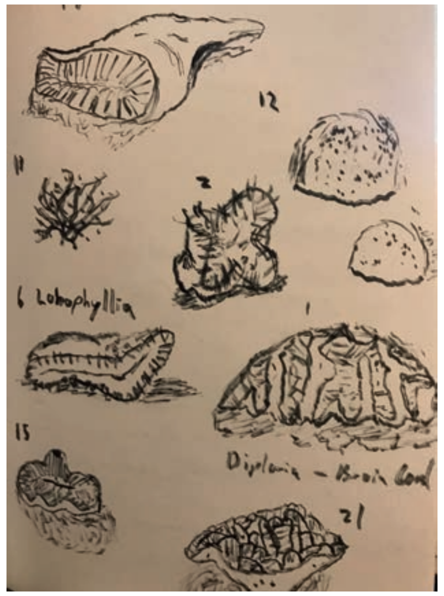

Deep Sea Minding - SUPERFLEX Studio
Onna Fishermen's Collective
Living Breakwaters - SCAPE Studio
BREAKWATER
WATER
Social Systems
Ecological Systems
Satoumi
marine and coastal landscapes that have been formed and maintained by prolonged interaction between humans and ecosystems
The Work of
Jason DeCaires Taylor
Seattle Seawall -
James Corner
Field Operations
Coral Morphologic



PROCESS



Coral
Needs - Threats - Solutions Matrix
Threats
Needs
Solutions
Urban Scale Threats
Global Climate Scale Threats
Increased Nutrients
Increased Sediment
Ocean Acidification
Increased UV Exposure
Ocean Warming
Hard Substrate for Settlement
Suitable Nutrients
Suitable Light
Suitable pH
Suitable Temperature
Coral Infrastructure Design
Coral Outplanting
Improve Localized Conditions
Experiments in Form
pH Buffering Through Material
Breeding & Farming Corals with Resilient Traits
Targeted Terrestrial Green Infrastructure Strategies
Seagrass Bed Restoration
Revitalize Previously Existing Bio-filtration Processes
Mangrove Community Restoration
Deployment of Floating Wetlands
The amalgamation of stressors enacting upon corals at multiples scales is complex and tangled. Any possible matrix of solutions will have to be even more complex.



Above - Some coral skeleton sketches of mine

Pages 24/25 - Coral Needs/Threats/ Solutions Matrix diagram illustrating coral's biotic needs and potential solutions

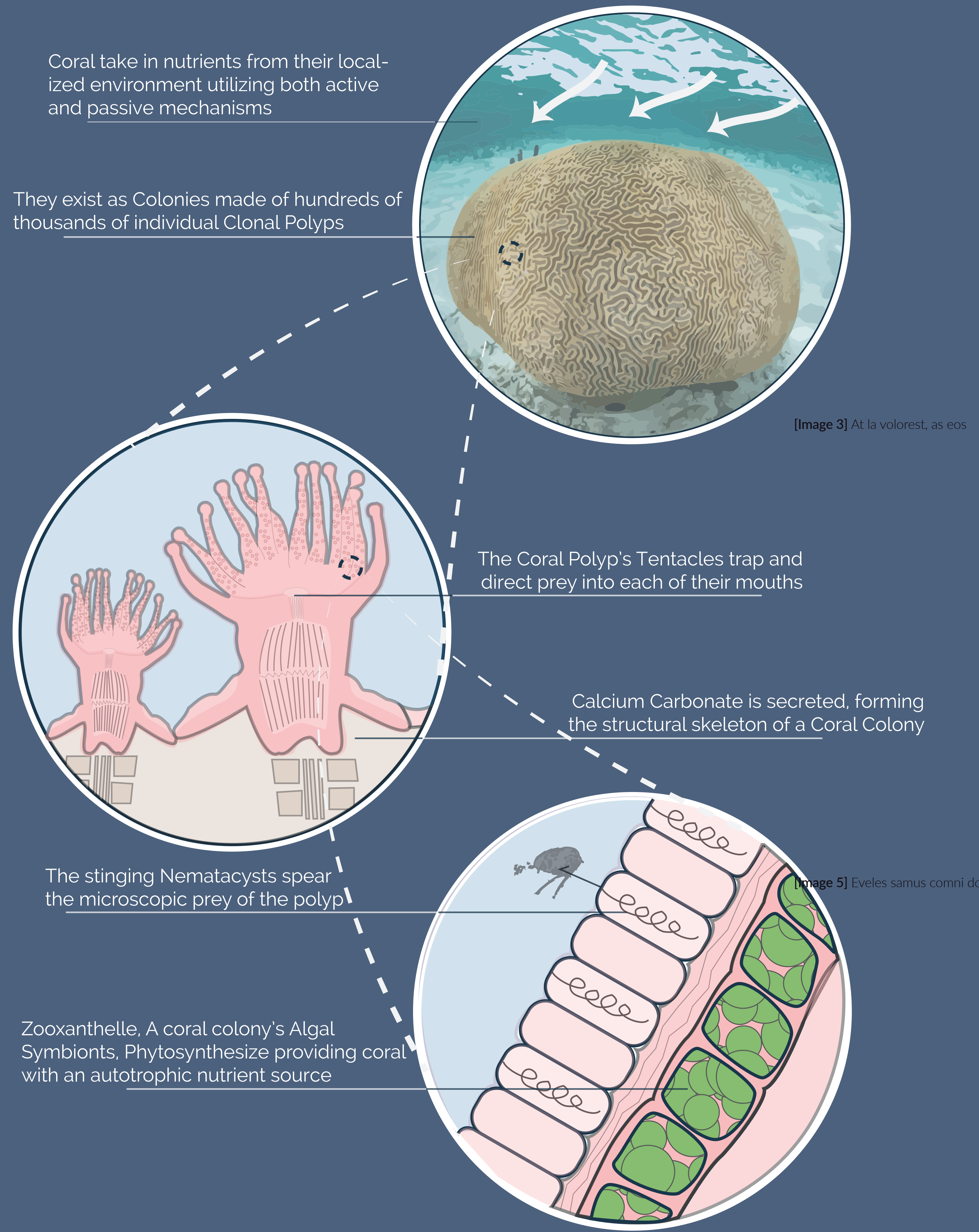
Page 27 - Diagram illustrating how corals intake nutrients.

17- Tebben, J., Motti, C. A., Siboni, N., Tapiolas, D. M., Negri, A. P., Schupp, P. J., .. Harder, T. (2015). Chemical mediation of coral larval settlement by crustose coralline algae. Scientific Reports, 5(1), 10803. https://doi.org/10.1038/srep10803

Coral as an Organism

To understand how to best restore and augment coral ecosystems, we must first recognize their biotic needs (as well as the global and localized processes that increasingly threaten those needs) before we can formulate possible solutions. (Illustrated on pages 24/25) Corals derive their nutrients through both autotrophic and heterotrophic means - relying on their algal symbionts to photosynthesize, while also actively feeding on tiny organisms living in the water column. As zooplankton come into contact with the tentacles of a coral polyp, the polyp releases stinging nematocysts that ensnare its prey. The tentacle will then retract bringing it's captured meal towards the "mouth" of the polyp. The plasticity coral organisms have to their nutritional intake also applies to their forms of reproduction. Corals can reproduce both sexually by releasing their eggs/sperm/ larvae into the water column and asexually by fracturing and then regrowing. Like some other anchored marine invertebrates, coral larval settlement is enhanced by the presence of "crustose coralline algae", a calciferous red algae whose chemical cues " steer" larvae toward solid substrate where they can begin their lifecycle as affixed reef armatures. (17)

In essence, corals have five environmental conditions that must be met in order for them to thrive and colonize: hard substrate for settlement, suitable levels of nutrients, suitable levels of light, suitable pH, and suitable temperature. Unfortunately, many of these variables are the ones most impacted by anthropogenic alterations on global climate and local urban scales. Increased nutrient loads and sediment are introduced from urban stormwater and agricultural runoff. At the same time, more carbon is released into our atmosphere causing our global temperatures and ocean acidification to rise. Ozone depletion from emissions leads to an increase in UV exposure and light intensity. As the environmental conditions around coral become more extreme their cells eject their algal symbiont as a sign of distress, essentially



18 - Shick, J. M. (2018). Where Corals Lie: A Natural and Cultural History (Illustrated). London: Reaktion Books.

starving themselves, this is known as coral "bleaching". Mass bleaching events, prolonged periods where the temperature and sunlight intensity are exceedingly high and the corals may not recover, are becoming both more frequent and more dramatic. (18)

To design for coral's future, we must look to stabilize the growing volatility of their environmental conditions; and though a single site design may not be able to adequately address these issues across the global scale, it can start to combat them on a localized one. A seminal document that begins to lay out some best practices in the fight against coral bleaching is the "Decision Framework of Interventions to Increase the Persistence and Resilience of Coral Reefs" by the National Academy of Sciences (19). This text explains relevant interventions while highlighting research priorities and existing case studies. Though this work is a fantastic first step, I believe more experimental solutions are out there and that the development of a more holistic design-based toolkit, that includes form-based recommendations, could further aid these pre-existing strategies. Designers should be exploring not only how to best facilitate coral settlement, but also how we could preemptively design coastal spaces to combat the stressors brought on by climate change and urbanization.

19- Committee on Interventions to Increase the Resilience of Coral Reefs; Ocean Studies Board; Board on Life Sciences; Division on Earth and Life Studies; National Academies of Sciences, E. and M. (2019). A Decision Framework for Interventions to Increase the Persistence and Resilience of Coral Reefs. https://doi.org/10.17226/25424

Coral Restoration Strategies

Over the past decades, marine and coral scientists have been deploying a wide range of restoration techniques to reinforce the structural and biological integrity of reefs. These methods have the potential to serve as a palette of tools to be explored, employed, and enhanced further by designers in aid of coral recolonization; yet they have yet to be implemented through interdisciplinary collaboration.

The propagation of coral for restoration purposes currently takes a wide variety of both land based and submerged forms. Most often coral propagation and restoration begins with "fragmenting" corals - where a coral colony is typically sliced with a band saw (or chiseled by hand on site) and the resulting fragments are put on small concrete plugs to grow. These "frags" are then placed in tanks to begin their growth. Though the frags can remain in this tank until being outplanted, they will have a greater chance of success if transferred onto a form of in-situ propagation to acclimate to localized environmental conditions. Frag size at outplanting can vary, but it has generally been found that corals have the greatest rate of survival when outplanted at 5-15 cm in size for branching corals and 4-5 cm for mounding corals. (20) An issue presented by solely relying on a fragment based approach is a lack of genetic diversity, because the corals are being reproduced asexually.

20- Edwards, A. J., & Coral Reef Targeted Research & Capacity Building for Management Program. (2010). Reef Rehabilitation Manual. St. Lucia QLD: The Coral Reef Targeted Research & Capacity Building for Management Program.

Corals can also be "seeded" onto structure since coral larvae, to settle, need a hard substrate to anchor onto. Where coral larvae are introduced into a tank with small structures for them to affix to, these structures are then cast onto the reef to continue their growth. This method has a much lower survival rate than "fragging", but because the corals are being reproduced sexually it maintains greater genetic diversity.

One area where we have seen design fields engage with coral most is on hard substrate settlement structures. Design studios like Real San Fratello and Super Studio have played with prototyping objects meant to accrue undersea biological growth. Perhaps the most successful product designer in this space is ECOncrete, the company that manufactures the reef building blocks for SCAPE's living breakwater. They have experimented with different products including mats and walls designed to facilitate marine settlement. Their products seek to replace shoreline armoring with a more hybridized approach to infrastructure that utilizes surface rugosity to encourage bio-genic buildup. The concrete mixes they use can also serve to buffer the local effects of ocean acidification due to their basic properties. (21) Experimenting with structure is the new expanding frontier of coral restoration.

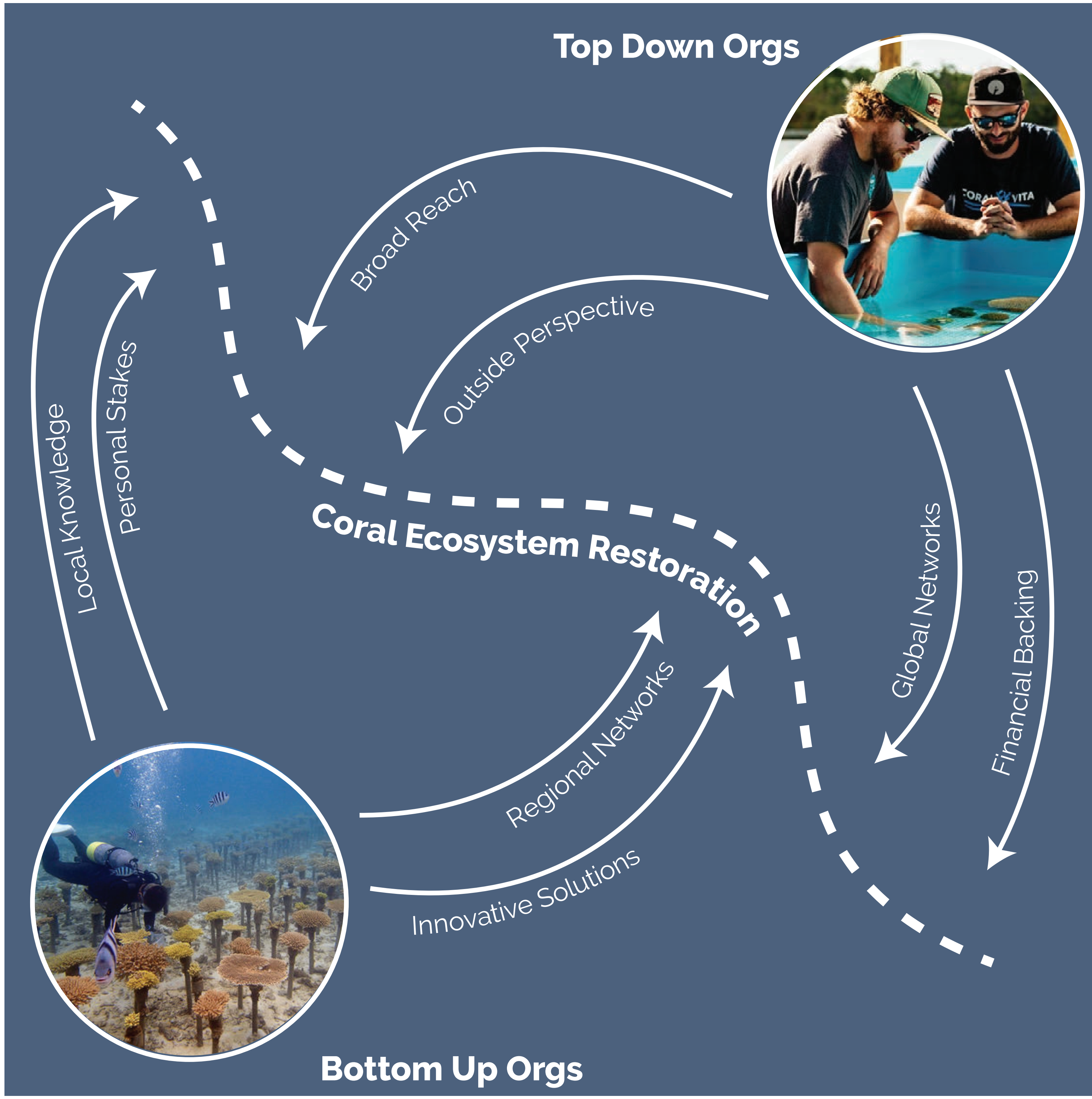
21- Sella, I. (2019, November) ECOncrete: Bringing Concrete to Life - Applying Principles of Reconciliation Ecology in Urban Waterfronts. Presented at the 2019 American Society of Landscape Architects Annual Conference, San Diego, CA.

22 - Shick, J. M. (2018). Where Corals Lie: A Natural and Cultural History (Illustrated). London: Reaktion Books.

Some of those restoring coral are trying to aid corals adaptive properties to changes in their environment. They do this either by studying zooxanthellae and selectively exposing corals to clades that are most stress tolerant, or by breeding particularly resilient colonies in an attempt to make heartier "super-corals". This form of assisted evolution may undoubtedly play a role in maintaining individual corals with a greater capacity for survival. (22)

There appears to be essentially two distinct types of coral restoration organizations, "Bottom Up" and "Top Down". "Bottom Up" groups form as grassroots community organizations combating a local scale problem. A good example is the Onna Village Fisherman's Collective in Okinawa, which is actively farming and outplanting corals on their local reef to maintain their coastal livelihood. "Top Down" organizations are usually not members of the community that they're working in and are instead backed by outside investment or philanthropy. One that is worth highlighting is Coral Vita, the world's first commercial coral farm. Their long-term vision is to create a network of their farms throughout the world that can help rehabilitate local reefs, making their mission feel almost colonial. Like similar "Top Down" organizations, they let people adopt a coral" to fund their work. Both organizational structures are necessary, and noble in their own ways, as pieces in the larger tapestry of a solution. These types of organizations each have their merits, but it is my belief that in order to truly develop a kinship with coral we need to emphasize the development of more "Bottom Up" organizations where communities take an active stake in their adjacent coralscape. Often the most successful solutions to complex entanglements arise from the diverse approaches cultivated through organic localized mobilization.

Opposite Page - Diagram illustrating how both "Top Down" and "Bottom Up" organization is needed to tackle coral ecosystem restoration



Siting for Impact

Where might a design intervention focused on coral recolonization have a maximum impact on both urban and coral resilience? Undoubtedly the best location would be an urban center that is as threatened by changing climate conditions as much as the adjacent coral. The sea level around Southeast Florida is rising faster than anywhere else in the continental U.S. due to the subsidence and porousness of its geology. Lying directly within "hurricane alley" the six million people living in Miami's metropolitan area know that it is a matter of when, not if, the next big storm will hit. (Illustrated on pages 34/35)

As a municipality, Miami is currently investing 500 million dollars into complex feats of engineering like raising street grades and developing a network of stormwater pumps in order to ensure the city endures the impacts of rising seas in combination with the increasing frequency and intensity of hurricanes and tropical storms. (23) However, this seems to be a stiff and antiquated approach, just as Thomas J. Campanella notes in his commentary Saved by a Salt Marsh:

"Engineered hard-structure solutions are costly to build and maintain and - because they are fixed and inflexible - are ultimately prone to catastrophic failure. They also produce unanticipated side effects. [Mitigation strategies that take a living shoreline] approach to the problem of coastal resilience - conciliatory, synthetic, mediated - [are] a categorical rejection of the testosteronic hard-structure defensive tactics we have traditionally used to defend cities from the sea - dikes, seawalls, floodgates, bulkheads, revetments, jetties. Captain Ahab has set aside his harpoon in effect to negotiate with the troublesome whale." (24)

Urban centers have been relying on rigid civil engineering practices alone for far too long and the results have far too often left little to no room for adaptation, while ecological focused infrastructure projects present a new more integrative and flexible direction forward. Restoring the diminished ecology of Miami's shoreline could serve as a large piece of the city's resilience puzzle (just as it may for Staten Island if Living Breakwaters is implemented with conviction and commitment).

Miami's predicted 100 year flood event leaves the majority of the city underwater, and a 500 year event completely submerges it. It would be foolish to think that we could fortify the urban environment so completely that it can survive the effects of climate change unaltered. Instead the answer lies in being adaptive to the increasing temporalities of the sea. We cannot stop the water from encroaching upon Miami's urban landscape, but perhaps we can try to fortify some of the city's most critical infrastructure to weather these changes.

Miami's Coralscape

Southeast Florida is coral embodied. The region's oolite limestone foundation is the result of corals continually accreting on each other's skeletons for millions of years. Along this coastline coral reefs annually contribute $324 million (U.S.)while maintaining 70,000 jobs within the local economy. (25) Most importantly, Florida's coral reefs (and adjacent mangrove ecosystem), provide an existing source of resilience infrastructure buffering wave action while preventing coastal erosion and flooding. The function of these ecosystems should be considered exceedingly critical considering the extremely porous oolite foundation which effectively renders traditional measures of resilience like large-scale seawalls and green infrastructure infeasible.

The mangrove/reef ecotone along the coastline has been greatly reduced over time, yet anthropogenic changes are giving coral opportunity to claim new frontiers. Biscayne Bay, Miami's interior water body, has historically had limited to no coral growth because of its low level of salinity. Corals only began to pioneer the

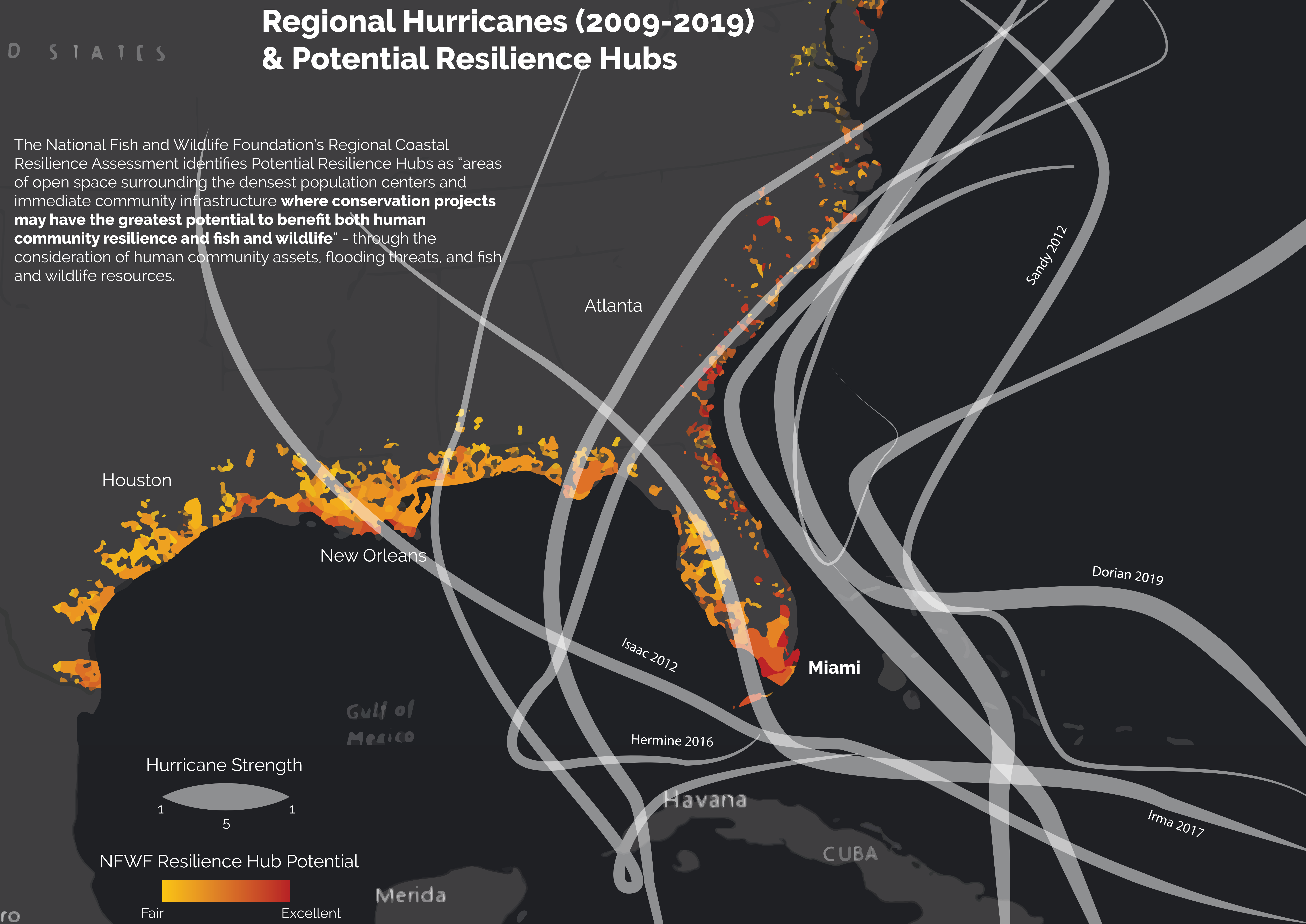
23-Harris, A. (2018, April 19). Miami Beach's future is 'uncertain,' experts say, but sea rise pumps are a good start. Retrieved from https://www.miamiherald.com/news/local/community/miami-dade/miami-beach/article209328849.html

24- Steiner, F., & McHarg, Ian L. (2019). Design with Nature Now. Cambridge, Massachusetts: Lincoln Institute of Land Policy, published in association with the University of Pennsylvania Stuart Weitzman School of Design and The McHarg Center

25- Johns, Leeworthy, Bell, & Bonn. (2001). Socioeconomic Study of Reefs in Southeast Florida: Final Report. Retrieved from http://coralreef.noaa.gov/Library/Publications/valuemetaanalysis.pdf

Regional Hurricanes (2009-2019) & Potential Resilience Hubs

The National Fish and Wildlife Foundation's Regional Coastal Resilience Assessment identifies Potential Resilience Hubs as "areas of open space surrounding the densest population centers and immediate community infrastructure **where conservation projects may have the greatest potential to benefit both human community resilience and fish and wildlife**" - through the consideration of human community assets, flooding threats, and fish and wildlife resources.



26- Lynn Wingard, G., South Florida Water Management District, & Biscayne National Park. (2004). Changing Salinity Patterns in Biscayne Bay, Florida. Retrieved from http://sofia.usgs.gov/projects/remote_sens/sflsatmap.html

27- Voss, G. (1988). Coral reefs of Florida (1st ed.). Sarasota, Fla.: Pineapple Press.

28-Frank, Andrew K. (2017). Before the Pioneers: Indians, Settlers, Slaves, and the Founding of Miami. Gainesville: University Press of Florida.

landscape as processes of sea-level rise and geologic subsidence shifted the halocline. The bay continues to grow saltier due to water control measures and upland agricultural practices. (26) Walking along the over-water causeways and the armored urban edges you can clearly identify coral species exercising their right to the city. These urban corals grow in adaptive orientations (I personally observed a few growing sideways on a vertical concrete wall) and could also be adapting in other ways - behaviorally, genetically, they may have different clades of algal symbionts. The answers to each of these questions could prove key in driving coral restoration globally, more research is warranted.

The "natural" configuration of a Floridian coral ecosystem begins upland with a tropical hardwood hammock that serves to mitigate soil erosion and moderate understory temperature. This gives way to a mangrove wetland, where the levels of inundation correlate to the species of mangrove - Red Mangroves are most submerged, then black, and white. Their tangled pneumatophores provide habitat while passively filtering water, trapping detritus that breaks down through microbial action and makes nutrients available to the ecosystem. Next, seagrass meadows that provide additional habitat and nutrients - supporting charismatic megafauna like Manatees and Sea turtles. The roots and broad leaves of seagrasses trap sediment, reducing the turbidity of the water.. Heading seaward in these seagrass beds are patches of coral growing on exposed oolite before reaching a healthy reef. (27) This shoreline condition can provide so much abundance that the indigenous Tequesta people of this region were able to rely on these coastal ecosystems alone, without actively practicing agriculture. They exhibited a historic regional presence of the principles of Satoumi through their subsistence on fish, reptiles, shellfish and coastal plants. (28) (illustrated on page 38)

Along today's urbanizing coastlines of Florida, you will find an increasing amount of hardscape. Shoreline armoring is widely prevalent, typically in the form of a vertical concrete/steel seawall sometimes augmented with rip-rap. Developers here are constantly trying to fortify their properties from the ocean, not integrate it as part of their site. Despite this, the largest anthropogenic impact to the coralscape of Miami will always be the island building and channel maintenance activities that are overseen by the Jacksonville District Office of the Army Corps of Engineers ("USACE"). These alterations have irreversibly altered the benthic characteristics of the area. Disturbed sediment and placed dredge spoils bury and drown corals, robbing them of the light needed for their symbionts to photosynthesize. In the most recent phase of channel maintenance, completed in 2015, the USACE contracted the Great Lake Dredge & Dock company to remove more than five million cubic yards of rock, limestone and sand in order to widen and deepen the port channel ("Government Cut"). This engineering decision was made to accommodate larger commercial and passenger vessels as a response to similar alterations made at the Panama Canal. However, the implementation of the project created a large sediment plume that has been shown to have effects on coral more than 15 miles distant from the Cut, while also leaving behind a hydrous deposit of dredge spoils that will continue to migrate. (29) (Illustrated on pages 40/41)

The forces that maintain the rigidness of Miami's coastal edges continuously value economics over ecological dynamics, without regard to how ecological processes provide services that support regional economics. Tourists flock to the city and its port because of the sun, sand, and the vibrance of the marine ecology. As this ecology is threatened, wouldn't the income generated by tourism grow threatened as well? Maybe then we should be striving for a new approach toward ecotourism that prioritizes these precious ecosystems. As I write this during the pandemic of COVID-19, we are seeing the cruise industry that the Port of Miami so heavily relies on economically, breakdown before our eyes. However, though commerce is breaking down, the environmental damage has not ceased. Cruise ships based out of Port Miami, still filled with workers, will come to port to refuel and restock and then head 3 miles offshore in order

Above - Sediment engulfing coral - photo by Miami Waterkeeper

29- Miller, M. W., Karazsia, J., Groves, C. E., Griffin, S., Moore, T., Wilber, P., & Gregg, K. (2016). Detecting sedimentation impacts to coral reefs resulting from dredging the Port of Miami, Florida USA. PeerJ, 2016(11). https://doi.org/10.7717/peerj.2711

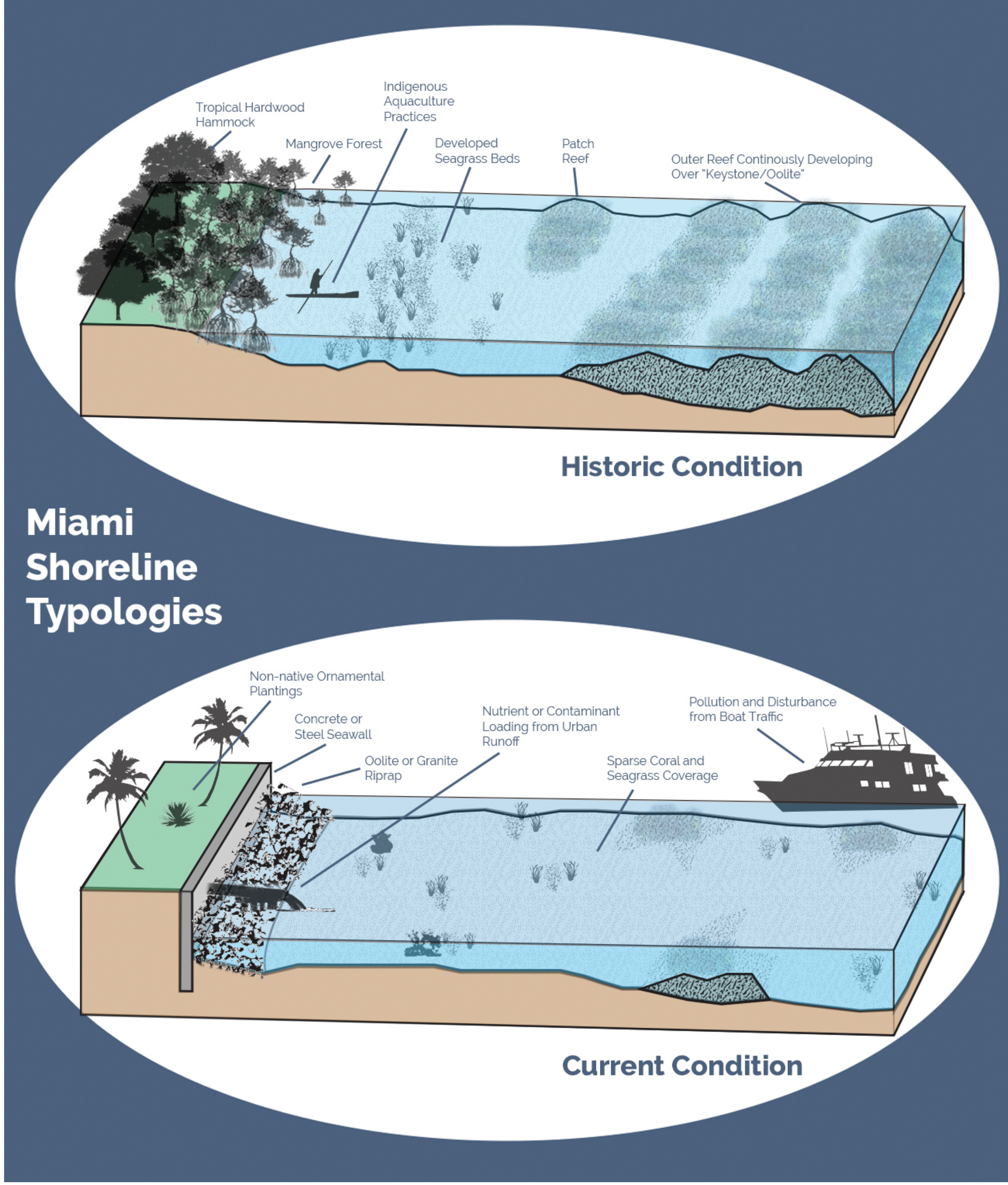
Below - Aerial of the sediment plume outside Government Cut- photo by Miami Waterkeeper

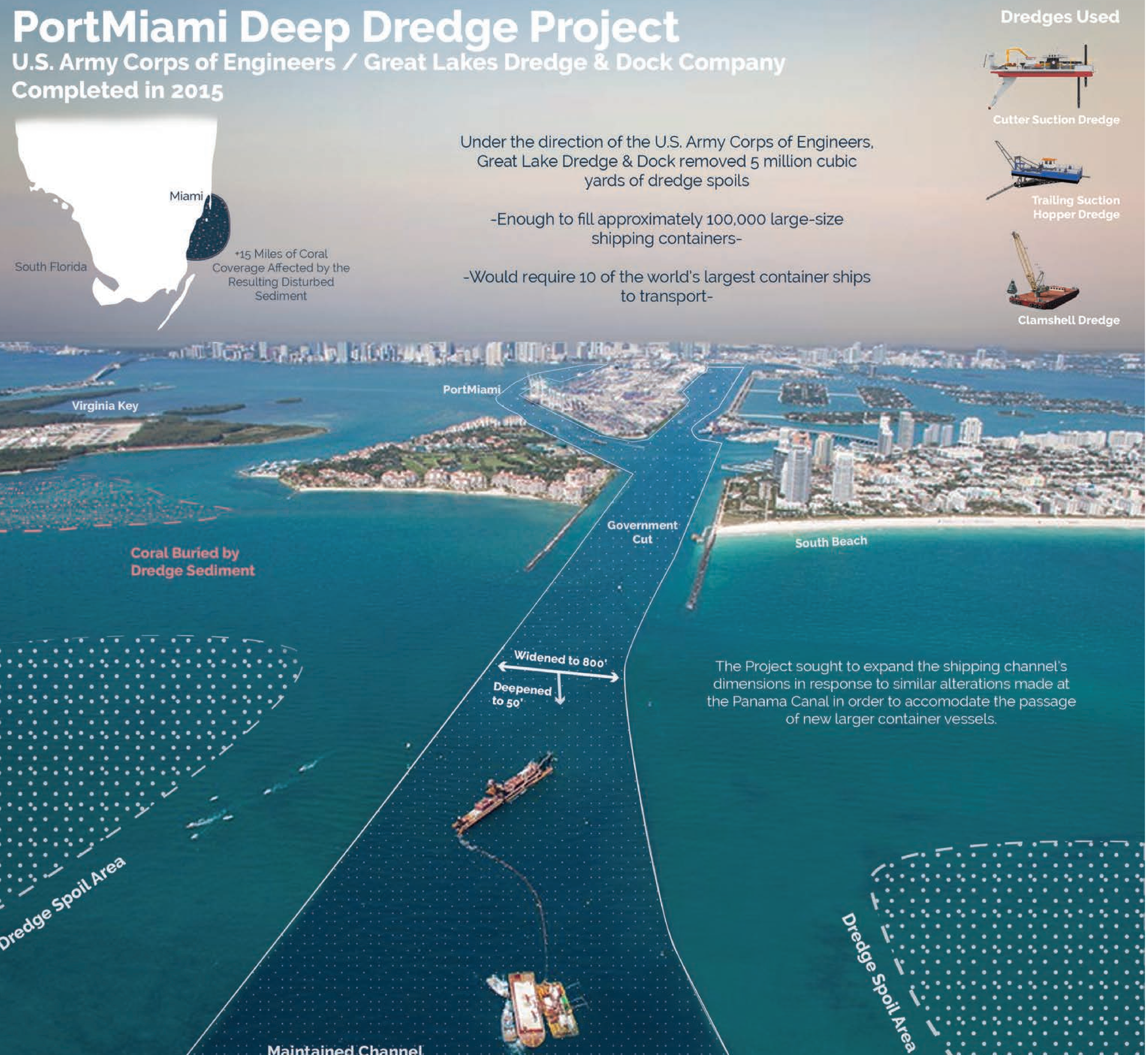
to dump their sewage in an approved location. These vessels are continuing to burn massive amounts of fuel while nutrient loading reefs with their sewage discharge. More easily observable via Coral Morphologic's Coral City Camera, are the disruptions this boat traffic causes the benthos. It is disturbing how much ecological degradation those with capital tolerate in order to resume the commercial status quo.

Miami's conscious connection to its adjacent coralscape could be defined as tenuous. The oolite or "Florida Keystone" can be readily found in the vernacular of Miami's built environments, serving as material for building facades, benches, tree pits, and pathways. However, the majority of both the citizenry and tourists have no idea that there are astounding urban corals actively pioneering the urban edges of Biscayne Bay. To build the public opinion necessary to halt the deconstruction of the natural environment for economic gain, and invest in the city's ecology, people must be made aware of how baselines are shifting.

Miami's coastline hosts a few locations where coral, though perhaps currently obscured and unnoticed, is already intertwined with the built environment and social dimensions of place. Analyzing these sites serves as a prerequisite for any potential design vision.

)pposite Page - Illustrations of Miami's historic and current shoreline conditions.





Left - An analysis of the approach and the effects of the PortMiami Deep Dredge Project that was completed in 2015.

Above- An illustration showing the spatial relationship between Virginia Key and its surrounding context.

Virginia Key

Virginia Key is a five-mile by one-mile barrier island south of Miami Beach that is only accessible by Rickenbacker Causeway. On the southern end of the island sit research stations for the University of Miami's National Marine Fisheries Service and the National Oceanic and Atmospheric Administration. However, the largest feature on the island is Miami's Central District Sewage Treatment Plant, constructed in 1950, it is the oldest and largest sewage treatment plant in the country. Currently the effluence from the plant is dispersed through a collection of combined sewage outfalls housed within erosion control groins on a public beach front (though there are future plans to begin dispatching the wastewater into a 10,000 foot deep injection well). The island hosts opportunities for public recreation with a dirt bike trail and the beachhead. In an obvious display of environmental racism, this beach first opened as a "colored only" beach from 1945 to its desegregation in 1960 (as the sewage treatment plant was implemented). It has remained a popular, and almost revered, destination for the local African American community. (30)

Sparse coral and seagrass coverage can be found in the shallow waters that extend out from the beachhead. The Army Corps dumps the dredge spoils from their port channel maintenance in an offshore area just Northeast of

30- Shell-Weiss, M. (2009). Coming to Miami : A social history (Sunbelt studies). Gainesville: University Press of Florida.

Virginia Key. Due to the prevailing north-south longshore current and east-west wave action, this sediment flows toward these shallow near-shore waters and chokes out the continuity of these vital ecosystems. Along the southern end of the shallow water off Virginia Key lies the Half Moon Underwater Archaeological Preserve, the wreck of a German racing yacht that sank in 1908, which supports coral growth and serves as a popular dive site. Virginia Key presents a site in dire need of ecological reparations, where critical infrastructure could be fortified through the revitalization of its diminished local ecology.

South Beach - South Pointe

When most people think of Miami their minds may go straight to the lively streets of South Beach. When development began on the barrier island of Miami Beach in 1910, this was the first neighborhood to emerge. Today this hotbed of nightlife sees over 20 million tourists a year and many of them walk along the waterfront of "Government Cut" (the primary inlet to Biscayne Bay) at South Pointe Park. A 17-acre public park designed by Hargreaves & Jones and completed in 2009. The project features a prominent serpentine Hargreavian landform that "serves as a place for viewing, a path for walking, and [an] artful, iconic feature of the park." However, outside of including modest dune restoration and night lighting that was "detailed so as not to disrupt sensitive turtle habitat", the design does little to engage with the environment it finds itself in. (31)

31- Hargreaves & Jones (2009) South Pointe Park Retrieved from http://www.hargreaves.com/work/south-pointe-park/

Two graduate students at Florida International University, Elizabeth Cornejo and Lillian Marin-Seanz, explored this lack of ecological visibility with their graduate thesis in architecture - Bajio: Research Center for Coral Reefs (2017). They proposed and conceptualized the design of a coral research center along the jetty on the ocean side of the cut that wisely played off Hargreave's iconic form South Pointe Park. Their design is mostly form-based, but also had a stated goal of bringing people closer to coral through interactive programing and small-scale exhibitions of aquaculture. (32) Siting their design inside Government Cut, while at the same time bordering an existing artificial reef was a good decision, but it also led to a major missed opportunity by not responding to the dredge condition that has so impacted this area. For a topic that is innately tied to local ecology, it's interesting that they tied their design only to the form of the adjacent park, without exploring the reverberations from the adjacent dredged channel.

32- Cornejo, E. Marin-Saenz, L. (2017) Bajio: Research Center for Coral Reefs (Master's thesis, Florida International University, Miami, USA) Retrieved from https://issuu.com/lillianms/docs/thesis-liz_lilli

The faculty advisor for their project, Eric Goldemberg (of MONAD studio), has also taught a Reef Module studio over the past few years. One project that stood out due to its organic structural aesthetic is "Biomorphic Sanctuary" by Paula Castel, a project that aimed to "immerse the community of Miami into a collective process of healing one of the most biodiverse ecosystems on earth by redefining the edge to dissolve land/water boundary, working with grain at a multi-scale, and layering systems that synergize and adapt to rapidly increasing climate change effects". In an improvement on "Bajio", "Biomorphic Sanctuary" considered the interrelated coastal gradient of mangroves and seagrass beds, however I would have still liked to see how the temporal cycles of these ecosystems develop and interact over time. In a dramatic move, the design erases a large portion of South Beach from the map (including Hargreaves' South Pointe Park) in order to reinvent the shoreline. This feels to be an unbuildable and overly complex approach to ecological design which does a disservice to interdisciplinary collaboration due to its lack of accessibility for those outside of the design fields.

Pages 46/47 - An illustration showing the spatial relationship between Southe Pointe and its surrounding context.

In order to have effective urban coral infrastructure that establishes Human-Coral Kinship, a city's citizenry must be aware of the systems and processes happening just below the water's surface. South Beach's South Pointe is the perfect location to sow the seeds of this awareness due to its high foot traffic and visibility for both locals and tourists alike.

Coral in the Built Environment

Though coral exists just under the surface of the waters' of Biscayne Bay, you may have to strain before finding any acknowl-edgement of that within the urban environment. These construction details that utilize oolite (or Florida Keystone) reveal that coral plays a larger role in the city's built vernacular than most may realize.

1

Urban Corals - Beneath our Feet

Many residents and visitors may not notice, but coral is actively colonizing the rip-rap and other forms of shoreline armoring around Miami. Highlighting this bold urban ecology is the first step toward a Human-Coral kinship.

2

3

4

South Pointe Context I

Government Cut

The Old Harbor-Pilot Slip

An old slip for the harbor pilot's vessel sits at the western ter-minus of South Pointe Park. Aside from serving as a shoreline promenade, this prime location sits under utililized - until its reimagining as the South Pointe Coral Nursery & Research Center

South Pointe Park

Designed by Hargreaves and Jones and completed in 2009. This 17 acre park is a hotbed of local and touristic activity in South Beach. In true Hargreavian fashion, the strong froms of the park have created a neighborhood landmark that can provide inspiration to my adjacent site

South Pointe Context II

Government Cut

DESIGN

The Modules

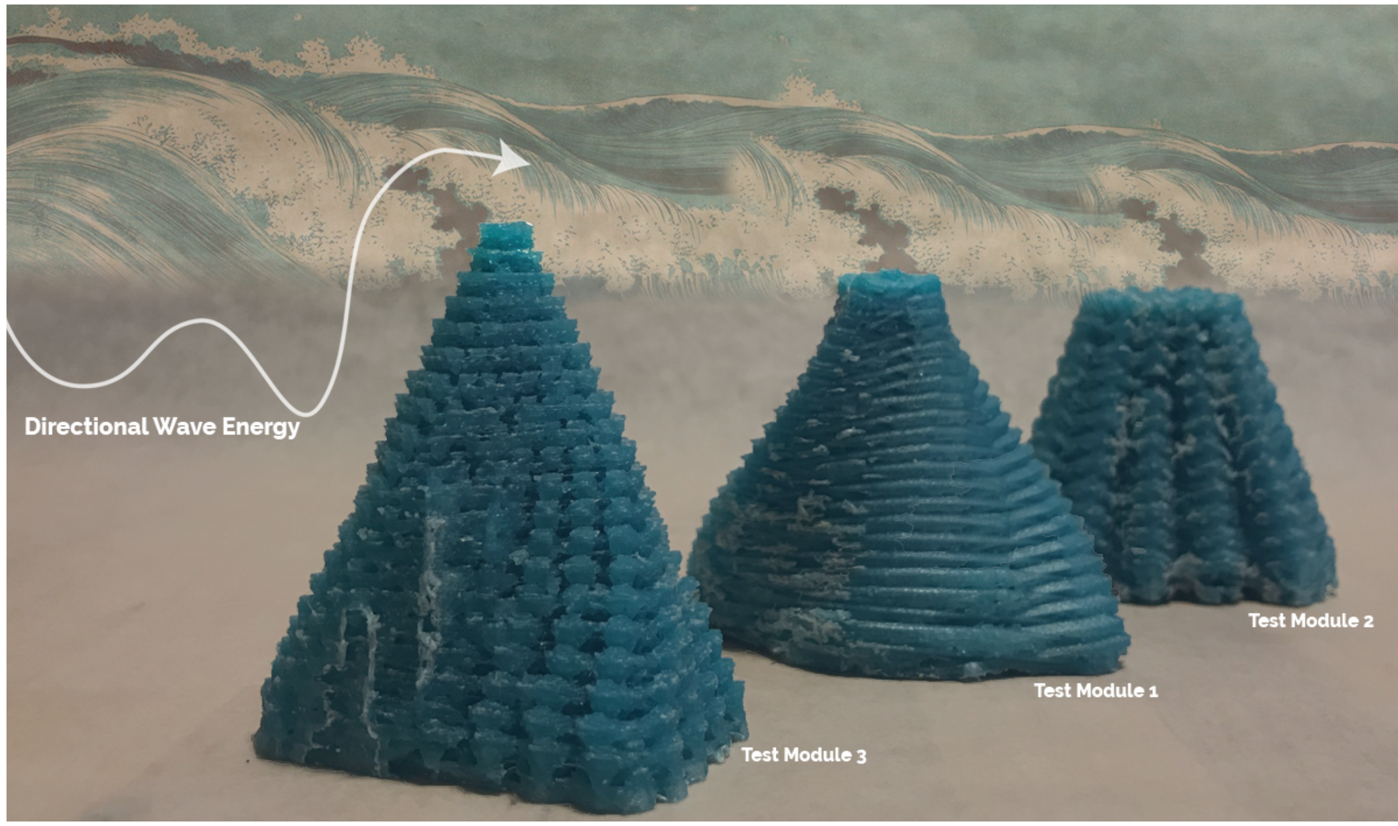
I began my design work by considering the smaller scale design possibilities around the mitigation of global and site-specific coral stressors. Direct UV intensity on corals could be reduced through shading, angled surfaces, and the creation of dappled light conditions. Sediment can be kept from burying corals by increasing the verticality or porosity of the reef structure, as well as by angling substrate surfaces. (Shown on Pages 52-53) To encourage coral settlement as ocean acidity rises a more basic concrete mix could be used that would work to buffer the localized acidity (low pH) of water around the structure. Another structural attribute that is needed to both effectively diffuse waves and encourage coral growth is surface complexity. With all of this in mind I set out to design a modular piece of infrastructure that could be utilized both as a tool for coastal resilience and an efficient structure for coral outplanting and settlement. I began by coding different parameters, namely porosity, verticality, and surface complexity into a parametric modeling script that allowed me to iterate different potential module designs. (Shown on the opposite page)

I 3D printed PLA prototypes of a few of the resulting designs to examine their surface complexity in physical form. If implemented the designs could easily be upscaled and printed in concrete with the modeled void space. Concrete 3D printing companies like MadCO 3D have developed non-toxic binding concrete additives that allow them to print concrete structures with complex voids and gaps.

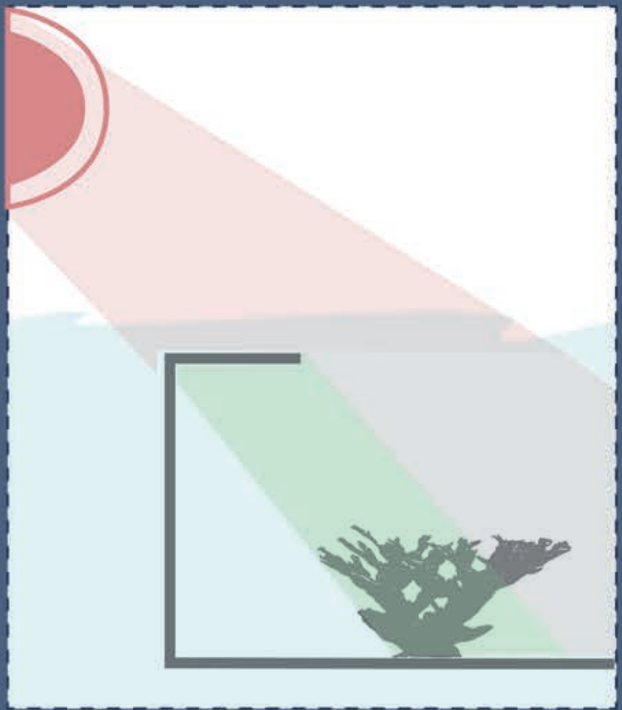
With my final iteration, I settled on a woven tall-twisting structure that provides the most dynamic combination of complexity and porousness that I could extract from my script. The surface of each module has notches that allow for the outplanting of coral fragments sourced from a related nursery site, amplifying their structural complexity over time and reinforcing the breakwaters' efficiency. (Shown on pages 54/55)

At a landscape scale these modules could assemble in a variety of configurations that would alter the ways in which they interact with the longshore current, wave action, sediment flow, and tidal action. Groupings of hundreds of modules would direct and channel water flow in conflicting ways that would diffuse wave action and cause suspended sediments to settle. Scattered placement of modules allows for coral to settle and colonize new territory, while creating a flow condition that still disrupts wave action and forms added micro currents that further diffuse wave action along the shoreline. Lastly, a Complex breakwater condition can be created when sediment begins to fill in the module groupings by adding further modules to create reef fringes that will further increase breakwater capacity and habitat function. These breakwater configurations should be more efficient than the traditional "Uniform" breakwaters that are most often utilized today, which often create a condition where wave energy is forced around an object without much opportunity for diffusion.
(Shown on Pages 56/57)

Below - Three of my 3D printed module prototype iterations.



UV Reduction Strategies

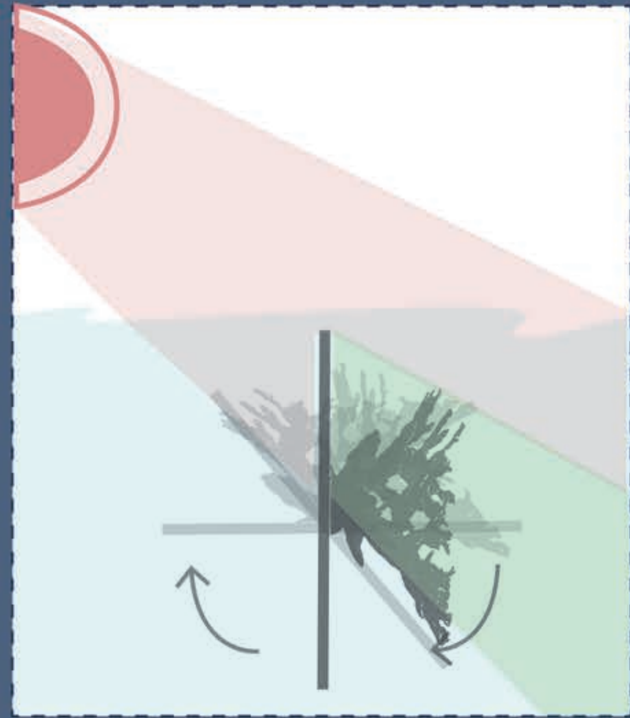


Shading

Angular shading structures could also expose coral to less direct light

Dappled Light

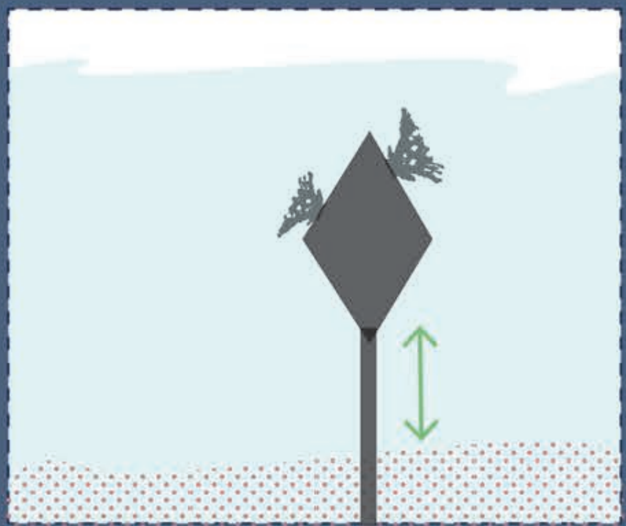
Overhead structure that creates a more dappled light condition could reduce stress on the coral's photosynthetic symbionts



Angularity

Adjusting surface directionality would expose the coral to less direct sunlight

Sediment Mitigation Strategies

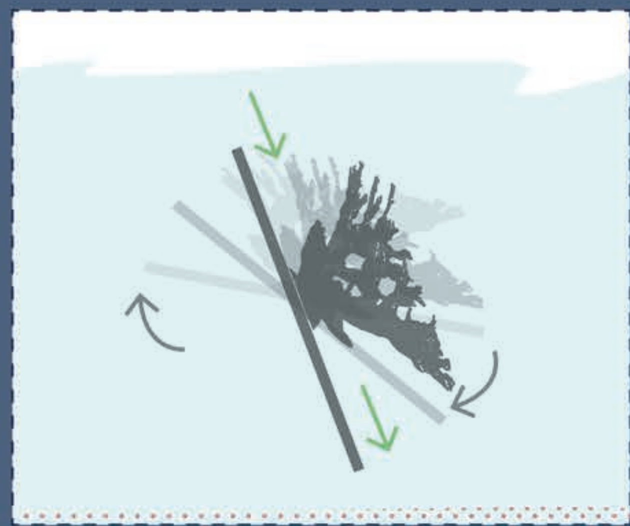


Verticality

Elevating the reef itself would allow sediment to accumulate over time below the reef structure

Porousity

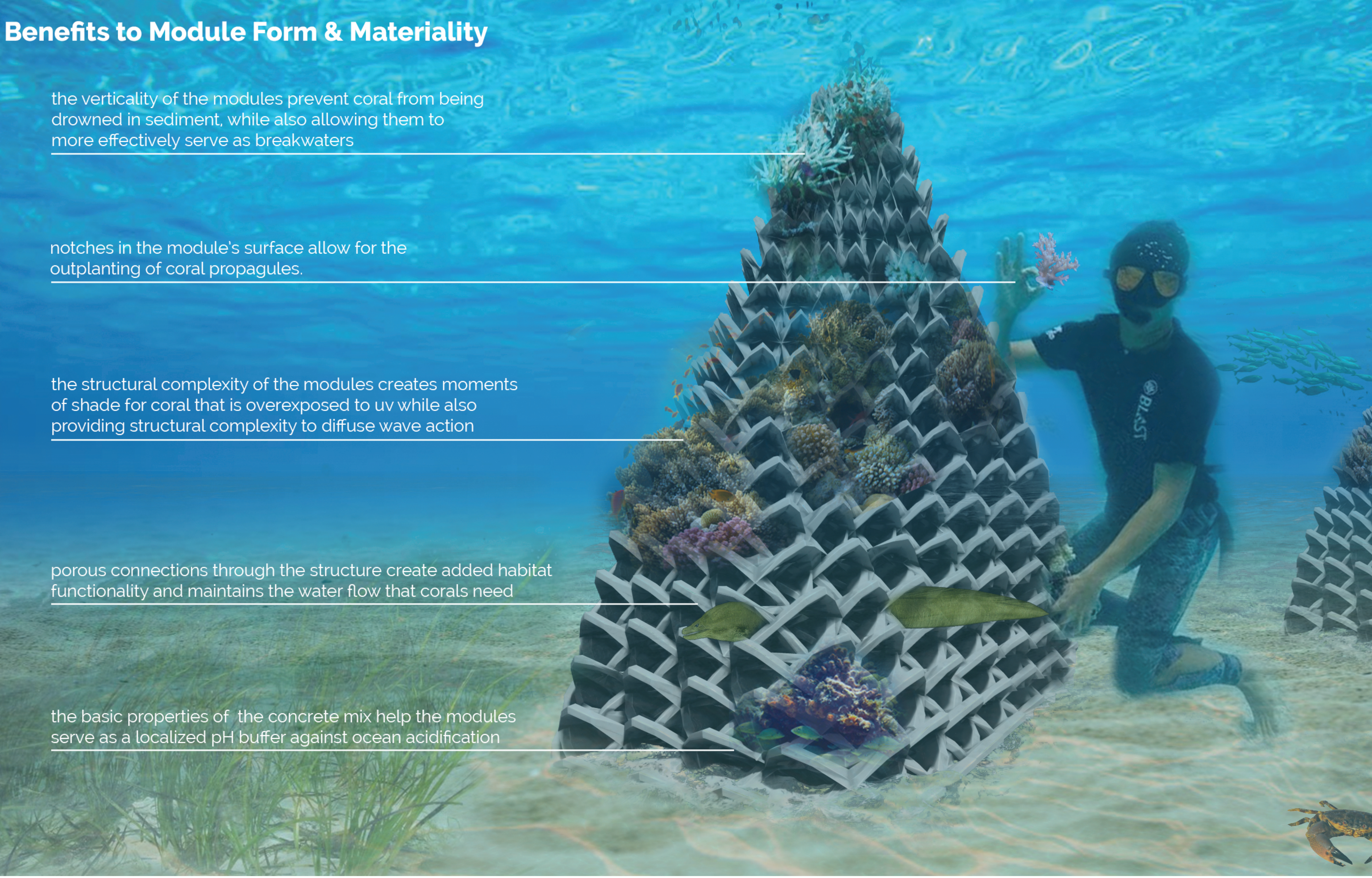
Porous structures would allow sediment to freely travel and not bury colonizing coral



Angularity

Adjusting surface directionality allows for the redirection of settling sediment

Benefits to Module Form & Materiality



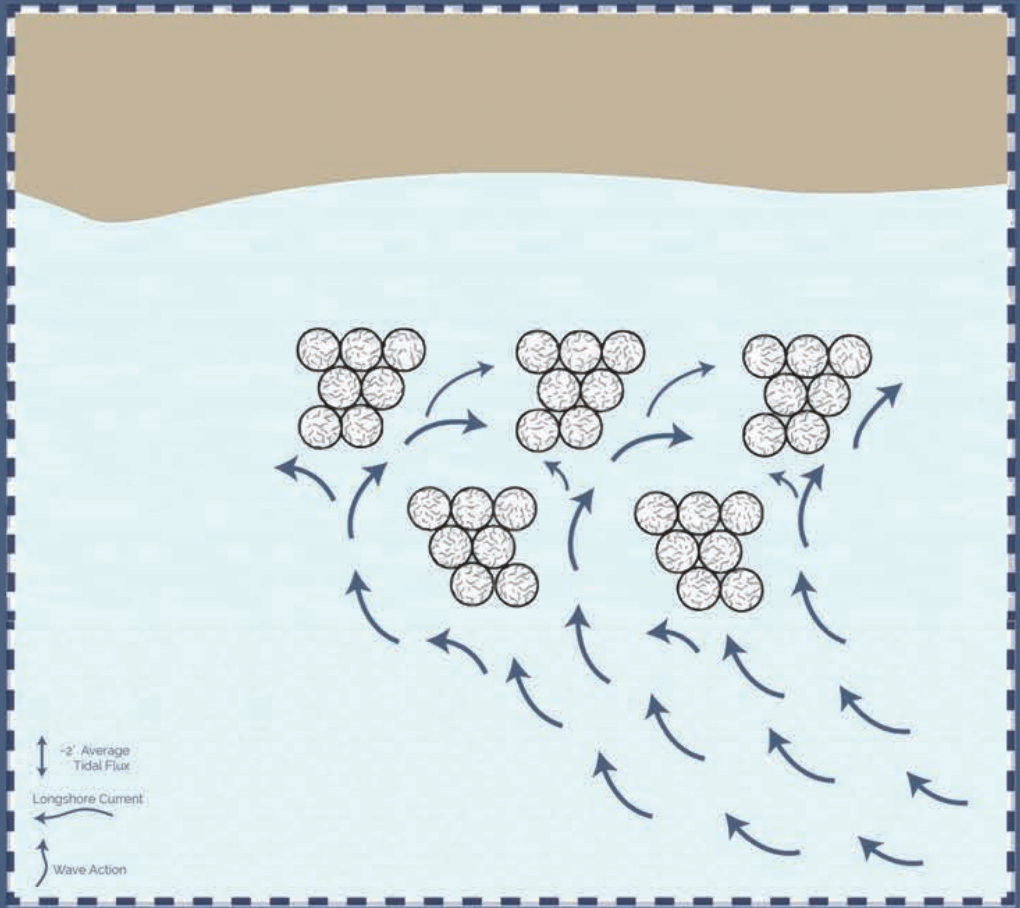
the verticality of the modules prevent coral from being drowned in sediment, while also allowing them to more effectively serve as breakwaters

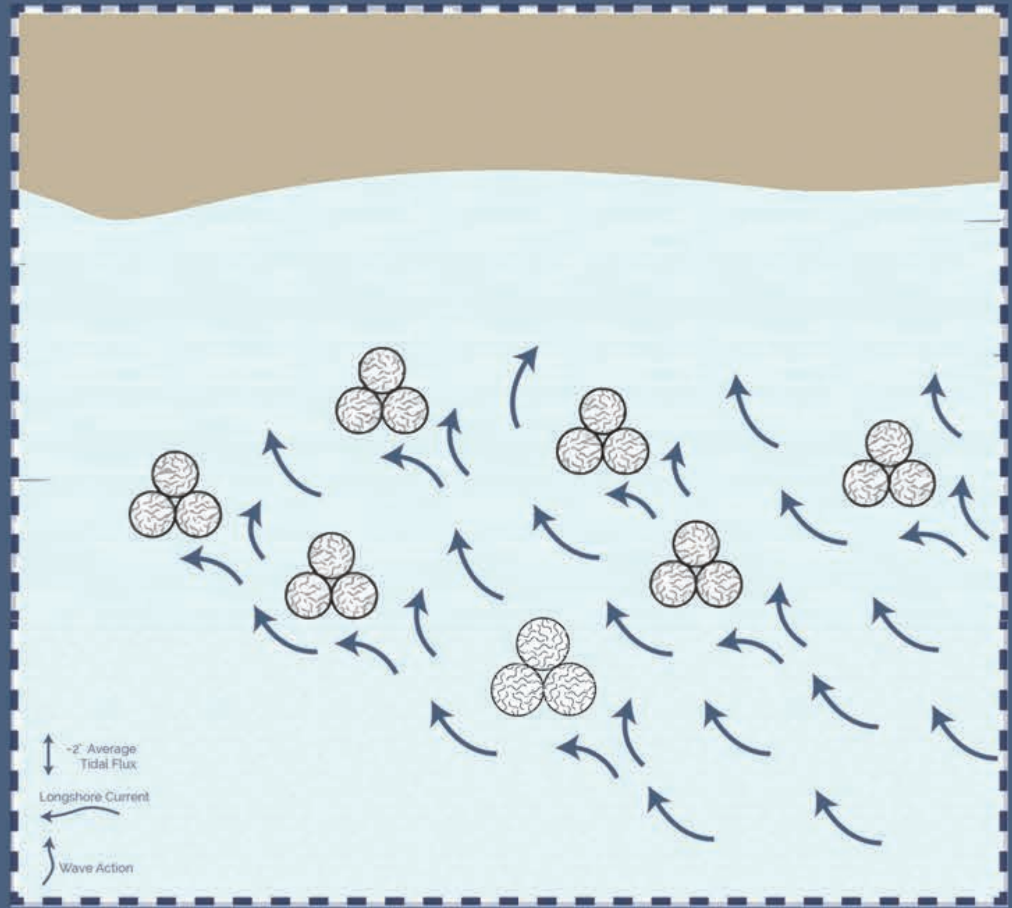
notches in the module's surface allow for the outplanting of coral propagules.

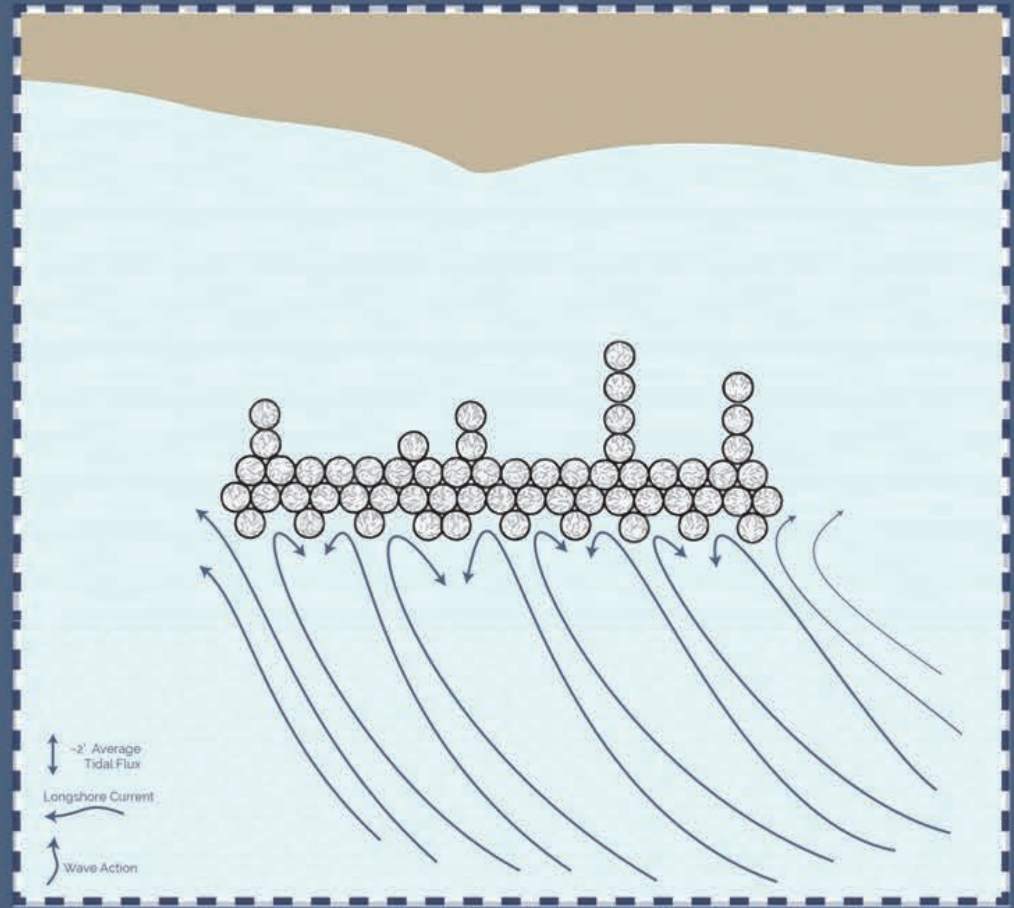
the structural complexity of the modules creates moments of shade for coral that is overexposed to uv while also providing structural complexity to diffuse wave action

porous connections through the structure create added habitat functionality and maintains the water flow that corals need

the basic properties of the concrete mix help the modules serve as a localized pH buffer against ocean acidification







Groupings

Groupings of modules can the same functions of a traditional "uniform" breakwater while also providing more structural complexity and allowing for the greater water flow that corals need. This configurations channels and directs sediment inward forming deposits.

Scattered

Scattered Modules can encourage coral growth while working to dampen localized coastal erosion - while also creating footholds of hard substrate for coral to establish themselves onto among the influx of sediment. This configuration allows water to flow through freely while increasing possible micro-currents

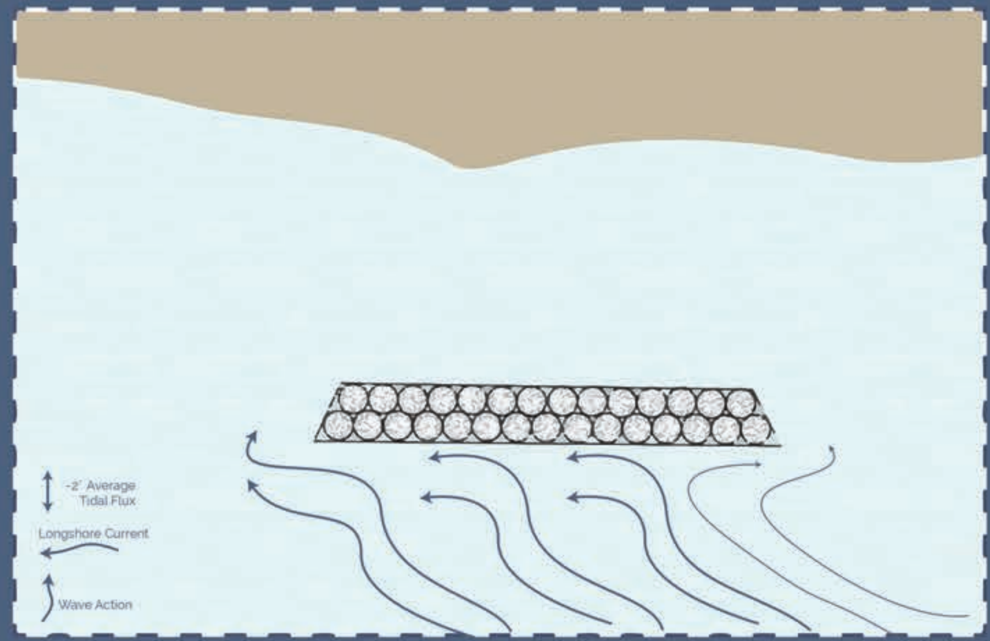
Complex

The complex condition is created once the primary spine of module groupings becomes inundated with sediment, forming a complex seawall that can effectively dampen wave action. Module "fingers" are extended from the groupings in order to further increase complexity and provide fringe reef habitat.

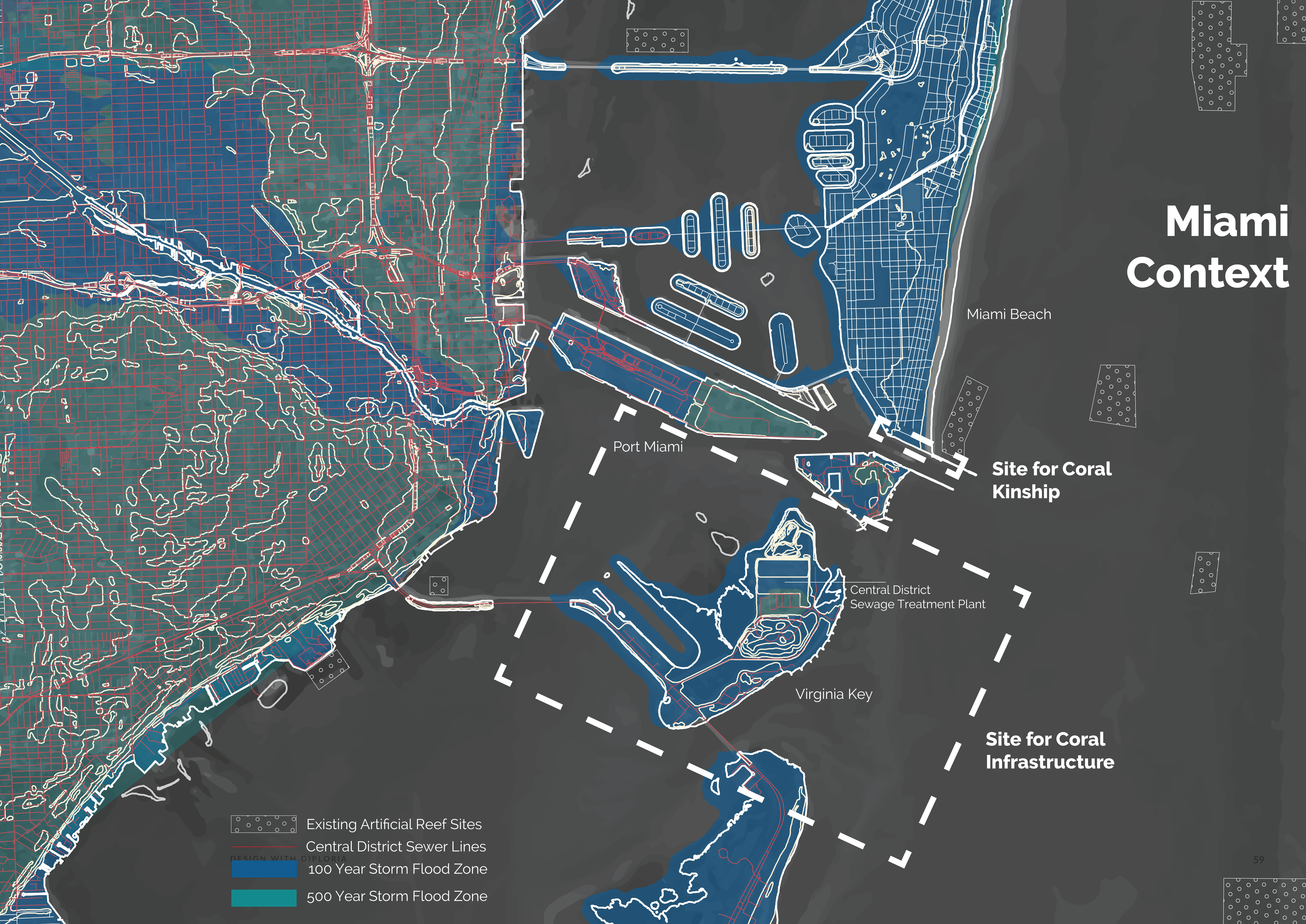
Detached Breakwater Module Configurations

Uniform

The typical detached breakwater is an armored uniform surface that works to stop wave action, hold back flooding and accrue sediment. Because the surface is uniform and not structurally complex, it reflects wave action instead of diffusing it.



Miami Context



Early implementation - Phase 1

Sediment Buiild up Along Coral Module Grouping.

Site for Coral Infrastructure - Virginia Key Coastal Augmentation

Determining where in Miami these modules would most effectively be deployed was fairly simple after analyzing where the city's critical infrastructure appears most threatened. Virginia Key's sewage treatment plant was sited with little foresight or ecological consideration, but it is a critical urban infrastructure that must be fortified, and the dredge spoils advancing upon sparse existing coral coverage offer an opportunity to fortify and augment a critical ecosystem. The proposed module design could be strategically located here.

In this proposal, I have arranged three dense clusters of module groupings to form a ridge on the far end of the existing coral coverage, where the water depth dramatically shifts from an average of 5 ft. to upwards of 15 ft. These groupings will intersect with and concentrate the incoming dredge sediment, allowing it to deposit over time and transform from a fringe reef (pg 60/61) to a sandbar (pg 62/63) and finally a barrier island condition (pg 64/65) that will continue to fortify the three module clusters as structural breakwaters.

Once the sediment engulfs the module clusters the sandbars could potentially evolve into barrier islands as mangroves are outplanted. Following this evolution, I propose more modules to be placed as "Reef Fringes" in the deeper waters seaward from the newly created islands, creating a new venue for coral outplanting and maximizing habitat capacity. I envision an aquascape that

will surely serve to support a diverse marine ecology while serving as a source of interest to underwater recreation enthusiasts. (pg 70/71)

The exterior breakwater groupings would create a lagoon condition shoreward, where scattered modules are strategically placed to maximize coral growth and reduce impact on existing intact colonies. This would develop into a dynamic environment where snorkelers and kayakers can navigate this field of scattered infrastructural modules being outplanted with coral, allowing them to get up close and personal with the ecological infrastructure that protects their city, in addition to the charismatic megafauna that migrate through this location. The concrete structures teeming with life will provide a tactile encounter with a thriving "cyborg landscape".(pg 68/69)

In order to maintain localized nutrient levels, provide ancillary habitat functions, and complete a healthy coral microbiome restoration of the mangrove and seagrass biomes along the shoreline is also necessary. The groins that extend from the eastern coast of Virginia Key can be augmented as "mangrove fingers" that work to biologically filter some of the sewage outfall from the central district treatment plant. Improving both the water quality for localized ecosystems as well as for visitors to the recreational beach-head who will now have the opportunity to enjoy this historic beachfront for years to come while the mangroves serve to reinforce the infrastructure and improve aquatic conditions. (pg 68/69)

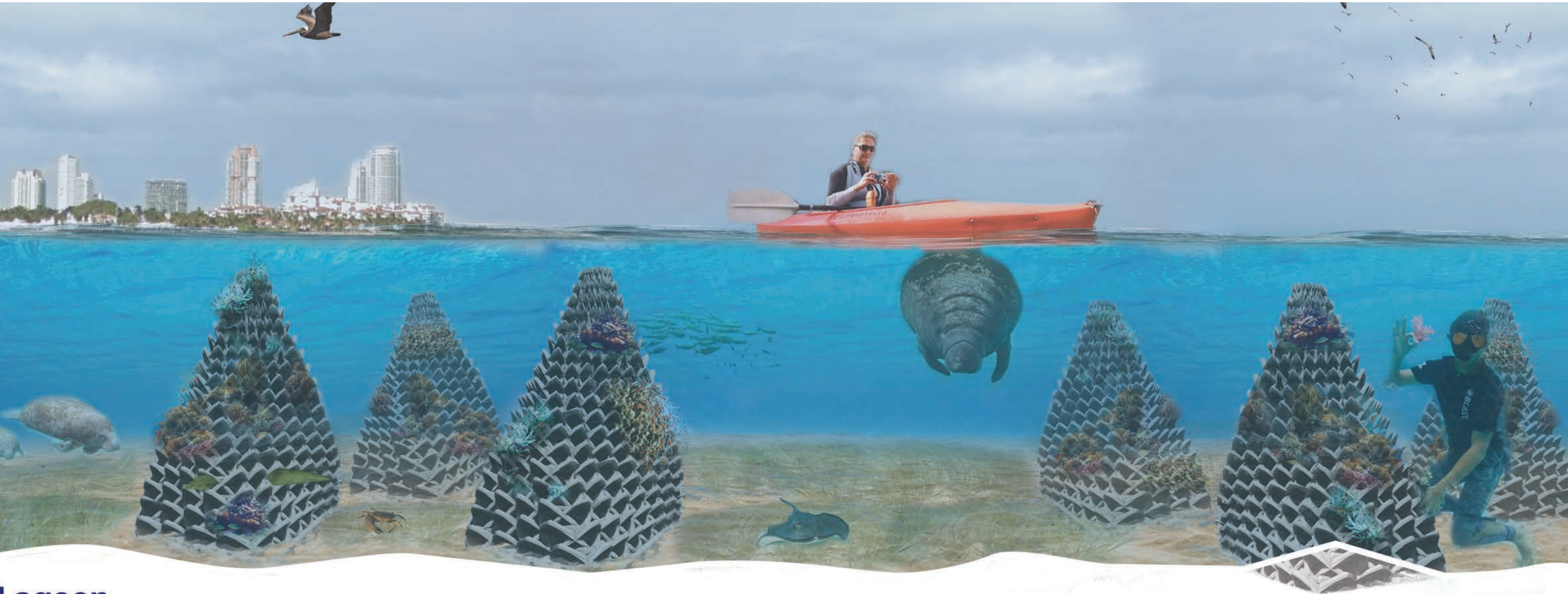
Pages 60-65 reveal how the dredge spoils resulting from the PortMiami Deep Dredge Project will interact with the different configurations of infrastructural breakwater modules placed off of the coast of Virginia Key..

Left - A section through the entirety of The Site for Coral Infrastructure showing the three landscape typologies created.

Infrastructure Site Sections

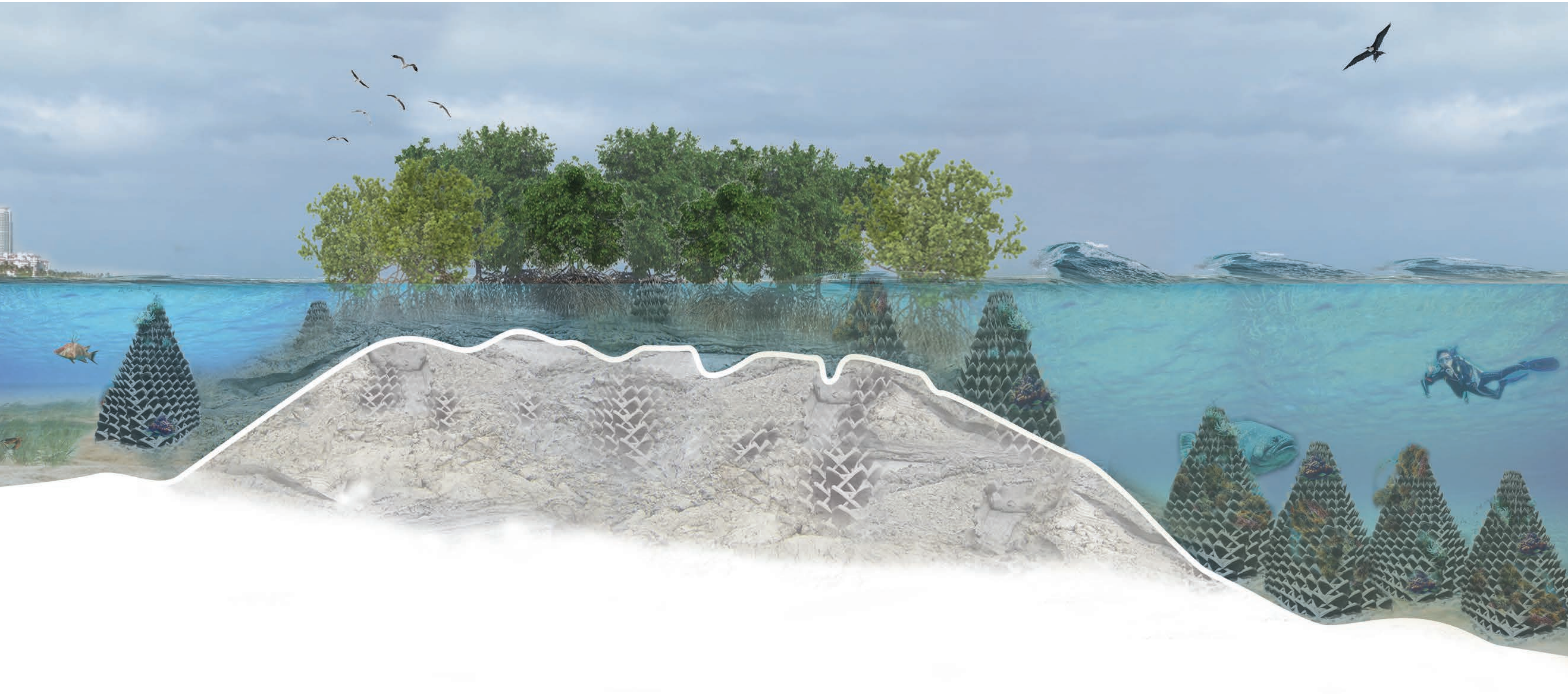
Shoreline

Above - The Shoreline of Viginia Key, where mangrove and seagrass bed restoration aid in the revitalization of the water quality and the ecology of the public beachhead.



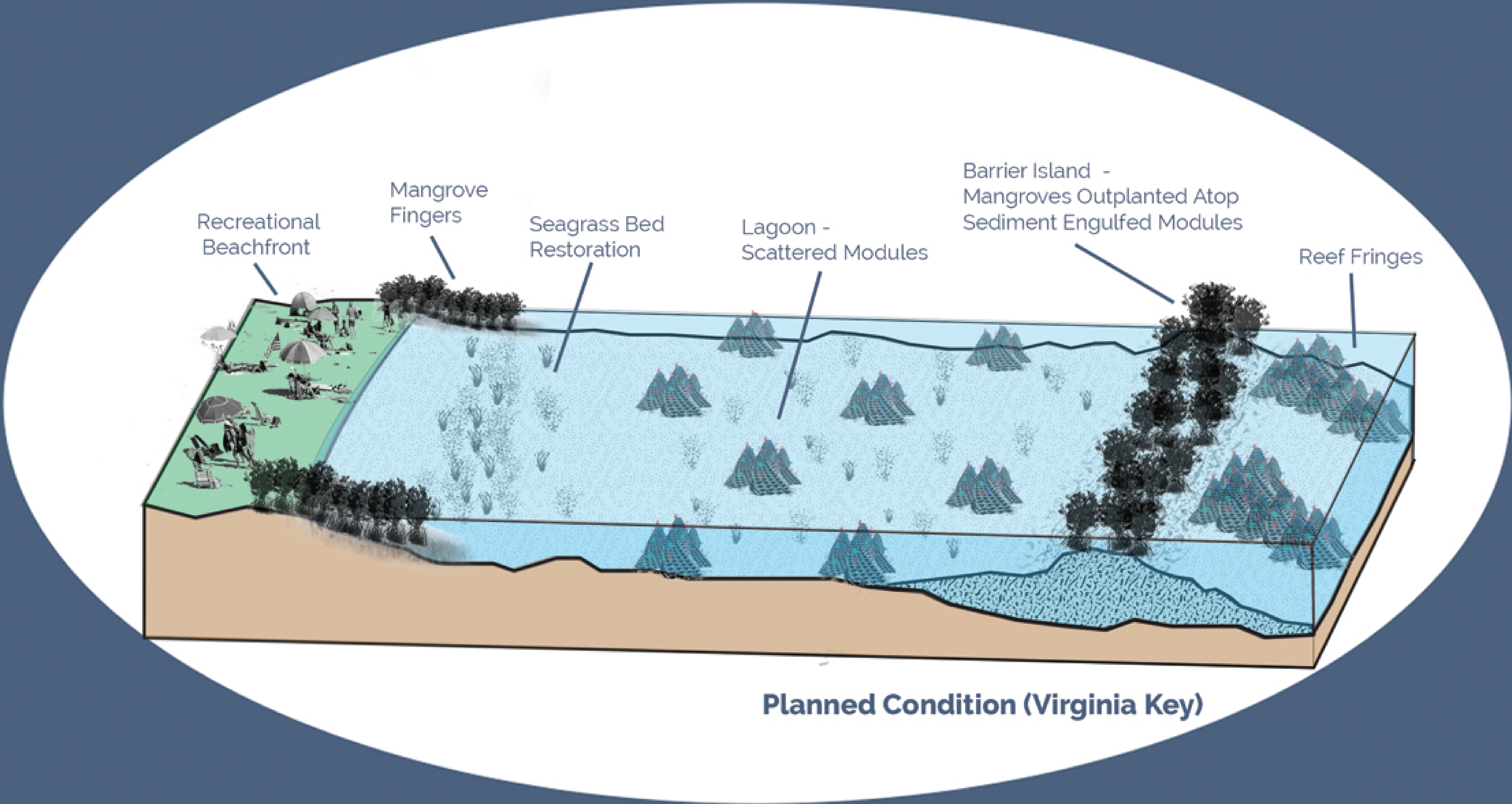
Lagoon

Above - A glimpse at the Lagoon condition, where ecology retakes the shallows waters among scattere modules off of Virginia Key



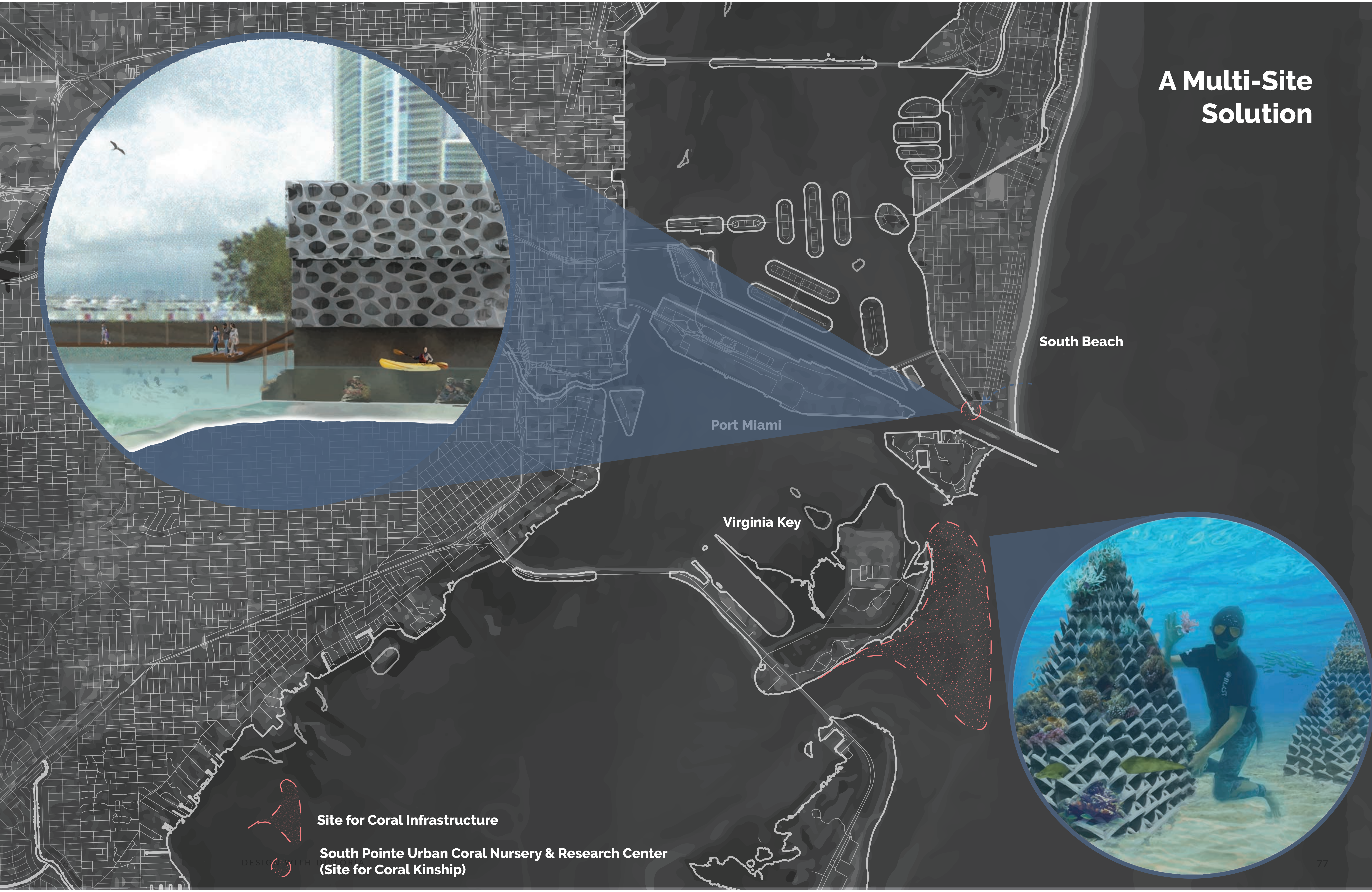
Barrier Island

Above - The Barrier Island condition created once the groupings modules become inundated by the dredge spoils and mangroves are outplanted.



Above - The planned shoreline typology for Virginia Key, which recalls and augments the most vital aspects of the historic and current conditions.

A Multi-Site Solution



Site for Coral Kinship - South Pointe Coral Nursery & Research Center

Pages 74/75 - Map showing the spatial relationship between The Site for Coral Kinship and The Site for Coral Infrastructure

In order to facilitate this massive ecological infrastructure operation, support will be needed in the form of positive public sentiment as well as extensive coral research and farming capabilities. To achieve these goals I selected a site just inside the channel of Government Cut at the old harbor pilot's slip. This location affords the opportunity to cap Hargreaves & Jones' South Point Park, symbolically extending their revolutionary approach to landscape into the aquatic realm.

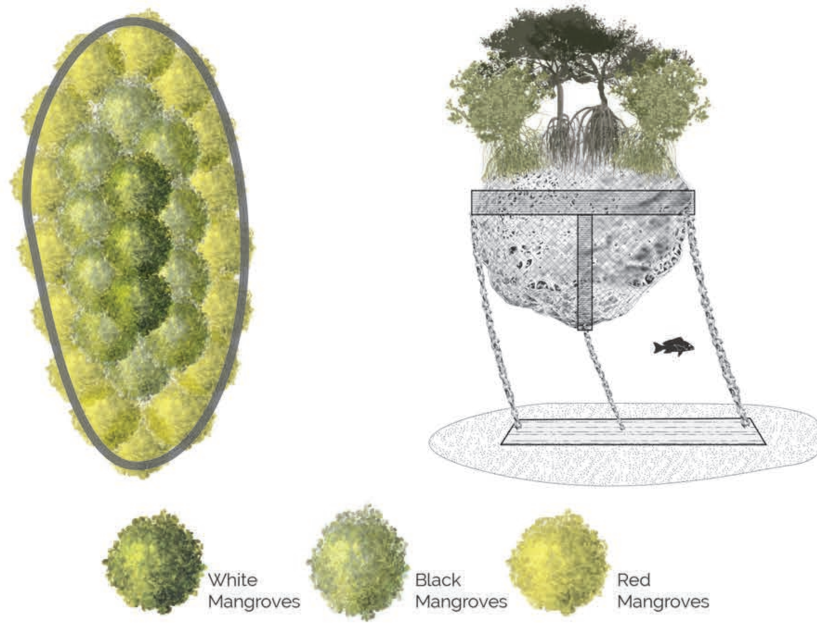
I propose an exposure of the public to the coral beneath the surface of Miami's urban waterways by utilizing the interior of the slip as a module test site. Here new designs could be tested and where the public can view the ecological infrastructure being deployed in defense of the city. I've also conceptualized a "coral shelf" along the edge of the promenade that would work to highlight any coral that will naturally settle there. Here, tour guides could take people on illuminating nighttime journeys into the world of urban corals while providing background information and identifying species as they wield their UV lights to expose their fluorescence. (pg 78/79)

I have designated locations for three methods of coral farming to be comparatively employed: "Coral Trees", "Benthic Tables", and "Rope Nurseries". These propagation techniques will acclimatize frags to water conditions, after being first produced in the on site Research Center and placed in raceway tanks. The donor corals used to create the frags would be sourced from other existing artificial reef sites since those individuals may be better adapted to growing on artificial substrates. The coral nursery would rear up to nine distinct coral species in order to maintain biodiversity both in the nursery and out on the reef. They would be out-planted on different cycles in accordance to the rates they grow. Branching corals like Acropora cervicornis (100- 200mm per year) and Acropora palmata (50-100mm) grow the fastest, allowing them to be outplanted in bi-yearly and yearly cycles. Comparatively, large mounding coral species, Porites porites (5- 20mm), Orbicella annularis (6-11mm), Siderastrea siderea (4-6mm) Porites astreoides, Montastrea cavernosa, Diploria labyrinthiformis, Diploria strigosa (3-5mm), take much longer to develop, forcing them to be outplanted in two to five year cycles, respectively. Branching corals are only acclimatized on "Coral Trees" and "Rope Nurseries", as the "Benthic Table" propagation typology is reserved specifically for mounding species. The tables create flow conditions at the bottom of the water column that those species prefer. (Shown on pages 82-86)

To maximize the ecological benefits on site and improve the coral nursery's microbiome, seagrass and mangrove communities can again be introduced. I've allocated space for seagrass bed restoration in the center of the site utilizing seagrass stake boxes. These boxes, constructed with a ballasted wood frame, allow for some accretion of sediment without burying the planted manatee and turtle grasses. I further propose large scale floating wetlands that would facilitate the naturally occurring gradient of mangrove species from red to black to white, where each requires a different level of inundation. These floating wetlands will be anchored to the seabed at low tide levels, allowing them to experience tidal inundation despite their buoyancy. To allow for some degree of shoreline mangrove restoration, the southernmost edge of the harbor pilot slip is drawn back. This allows for a kayak launch and more mangrove habitat that will facilitate employees and volunteers with easy access to the waters of the nursery. (pg 78/79)

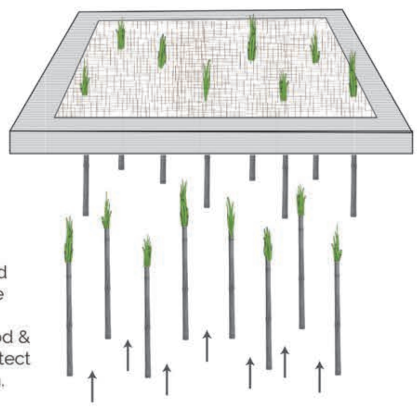
The site's research center building is cantilevered over the slip to interplay with the water, while still allowing light to hit the coral module testing grounds. The armature on its facade recalls a coral skeleton of calcium carbonate and provides shading to the large glass windows in the Miami heat. On the first floor, visible to the public, the corals are fragged and reared through their early stages. This public outreach section of the building also hosts the opportunity for guests to design their own breakwater module in virtual reality with a program that allows them

2 Floating Wetlands



Large-scale Floating Wetlands create the range of innundation levels needed to facilitate the grow of Red, Black, and White Mangroves- surrounding coral with its traditionally occurring Microbiome.

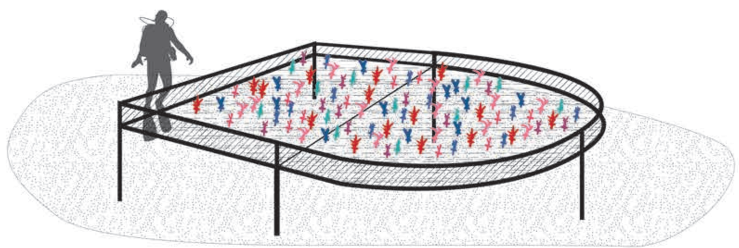
7 Seagrass Stake Boxes



Seagrass is restored on-site by using live stakes fastened to bamboo within wood & jute frames - to protect from sedimentation.

6 Rope Nursery

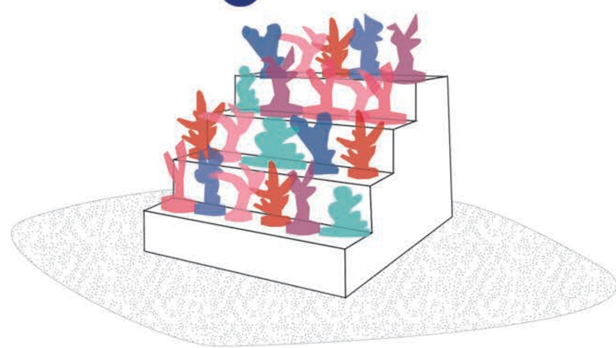
5 Benthic Tables



Benthic Tables are more focused on developing mounding corals, opposed to the other propogation methods, since these species prefer less water movement

4 Coral Trees

3 Coral Shelves



Coral Shelves highlight the natural settlement of corals within the urban center to pedestrians along the floating dock and the promenade to alter the parameters of the structure, modify the coral species outplanted upon it, and then see how it changes their wave- breaking effectiveness. Upstairs is dedicated to research focused on genetic information from urban corals. Their microbiome and their symbiotic zooxanthellae are analyzed here to study their potential for adaptation. (Shown on pages 88-91)

A citizen science organization will operate in conjunction with the research center and farm. This group can assist with outplanting, propagation processes, and the collection of coral larvae/sperm/eggs during spawning season. This will help bring interested individuals into the fold, laying groundwork of a coral-kinship for the citizenry of Miami.

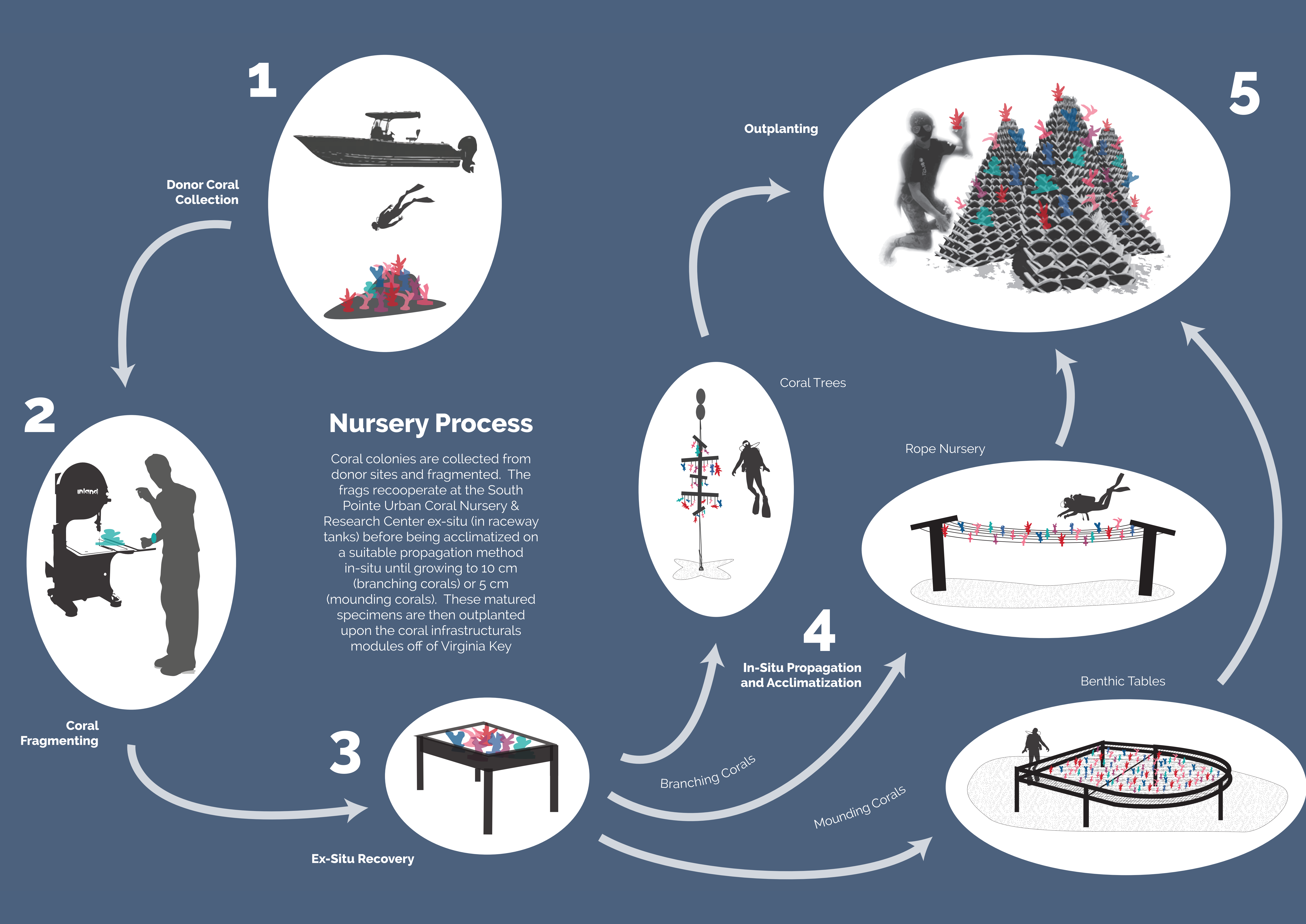
Below - A section through The Site for Coral Kinship

Floating Wetlands and Seagrass aid in an ecosystem based approach at Coral Farming

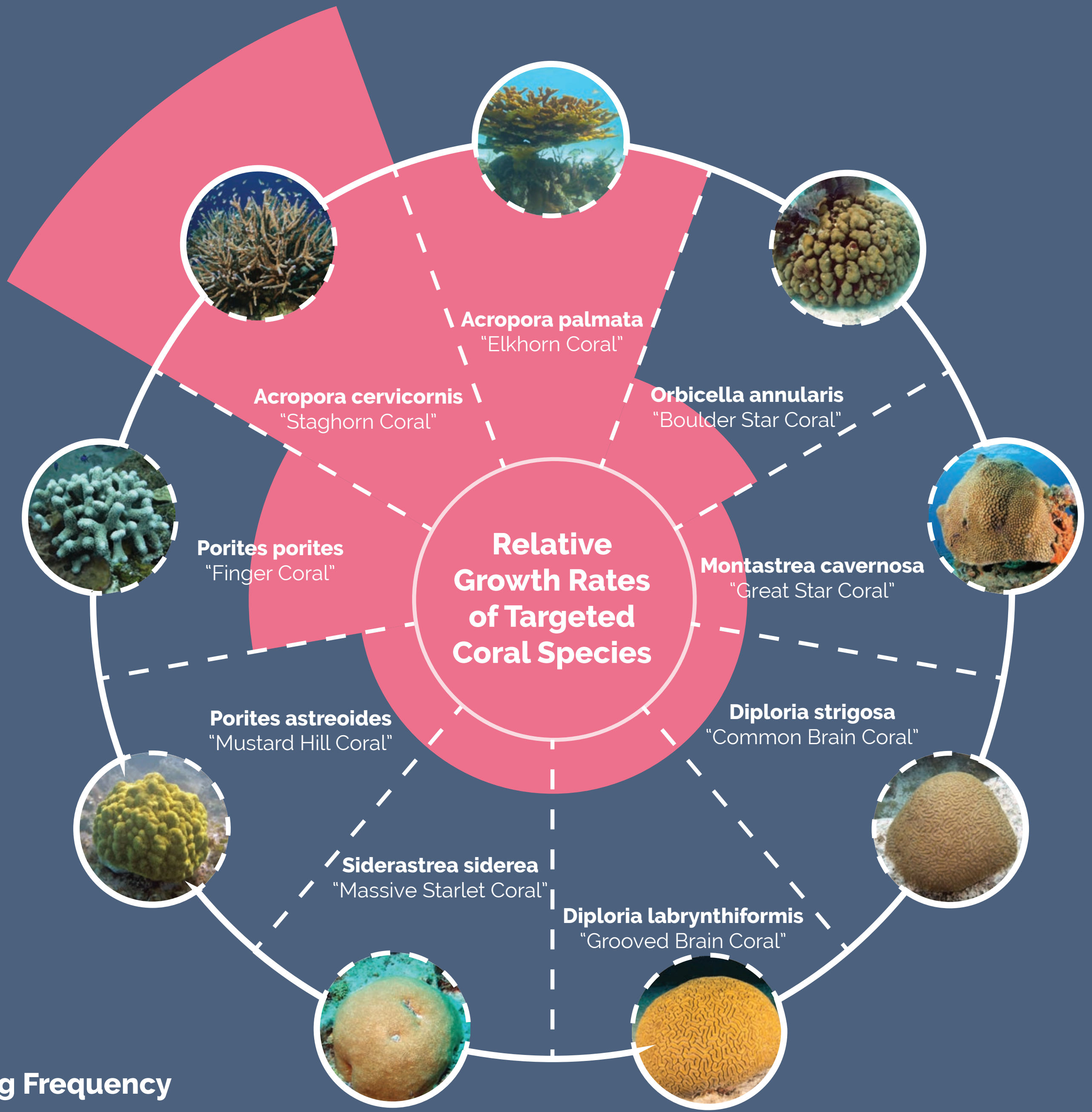
The center of the site - where open space is needed to accomodate outplanting boat traffic - provides ample room for a restored seagrass meadow. Allowing visitors to get a closer look at visiting manatees.

The Module test area provides passerbys with a glimpse of the ecological infrastructure designed to protect their city.

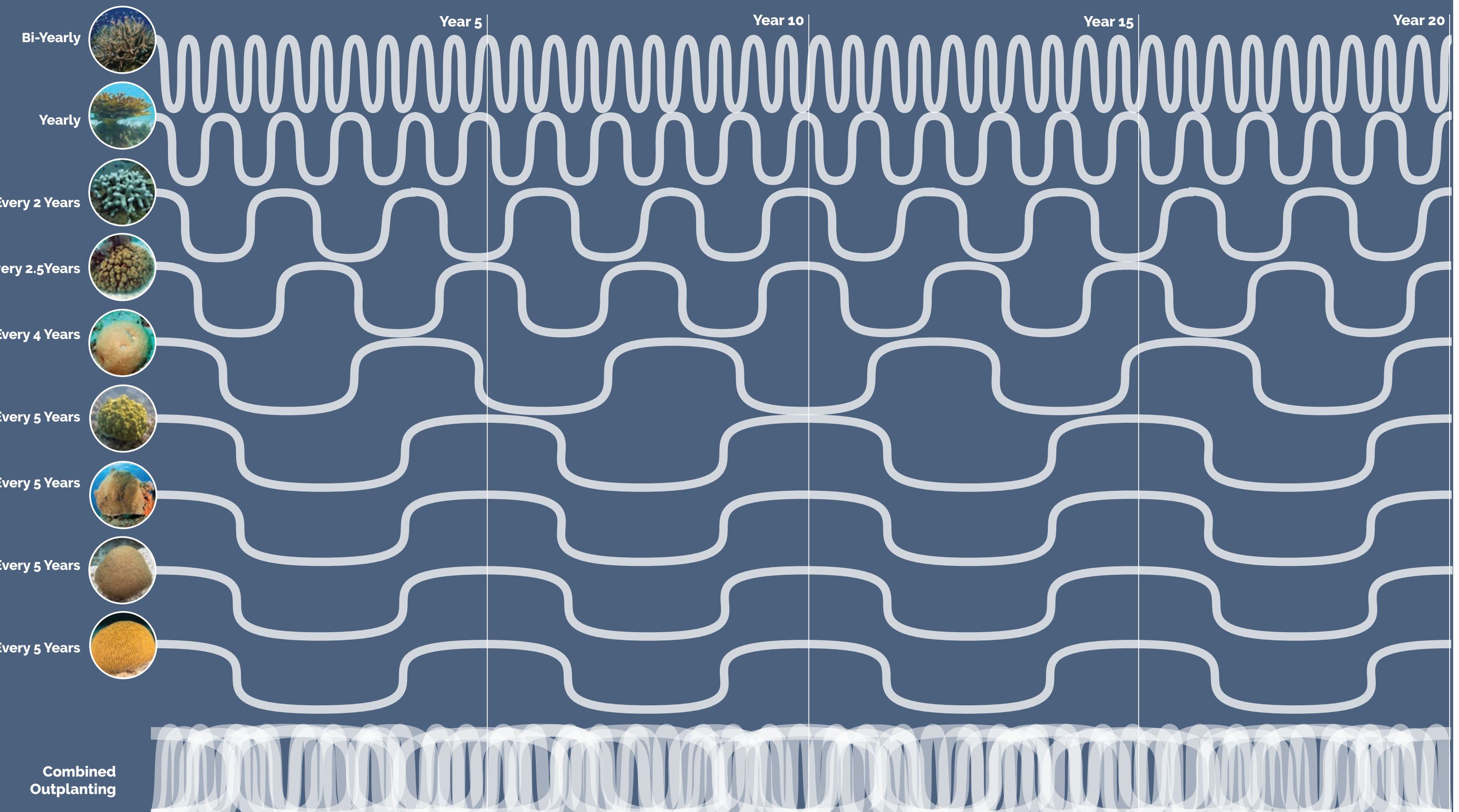
Donor Coral Network
South Beach
Port Miami
Central District
Sewage Treatment Plant
Virginia Key
Donor Sites (Existing Artificial Reefs)
Site for Coral Infrastructure
South Pointe Urban Coral Nursery & Research Center
(Site for Coral Kinship)



Nursery Process
Coral colonies are collected from donor sites and fragmented. The frags recooperate at the South Pointe Urban Coral Nursery & Research Center ex-situ (in raceway tanks) before being acclimatized on a suitable propagation method in-situ until growing to 10 cm (branching corals) or 5 cm (mounding corals). These matured specimens are then outplanted upon the coral infrastructurals modules off of Virginia Key
1
Donor Coral Collection
2
Coral Fragmenting
3
Ex-Situ Recovery
Branching Corals
Mounding Corals
4
In-Situ Propagation and Acclimatization
Coral Trees
Rope Nursery
Benthic Tables
5
Outplanting



Outplanting Frequency



Above- Coral Trees deployed in the Bahamas, photo by the Bahamas Reef Environment Education Foundation

Pages 82/83 - A map showing where the artificial reefs where donor corals are sourced from.

Pages 84/85 - A diagram showing the donor collection, propagation, and outplanting process.

Page 86 - A diagram showing how the growth rates of the coral species on site compares to the frequency at which they'll be outplanted

Left - A Rope Nursery at work in the Seychelles, photo by Science Magazine

Below - An example of a Benthic Table in French Polynesia, photo by Coral Gardeners

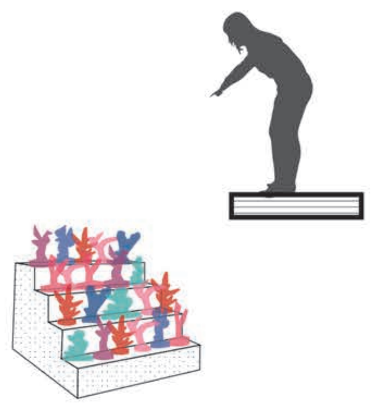
Left - A look at some of the programming elements to be housed within the South Pointe Urban Coral Research Center.

1 Opportunities for Citizen Science

Community members can partake in the operation of the coral farm and collection of coral spawn.

2 Nighttime Coral Tours

Nighttime coral tours will be led highlighting the wide variety of present species and their bioluminescence



3 Design Your Own Breakwater

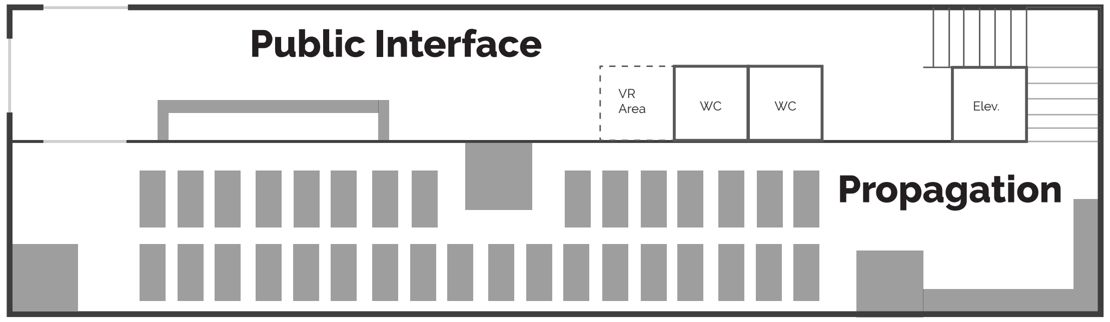
Visitors can design their own breakwaters using VR technology. Allowing them to experiment with both form and outplanted species

4 Coral Fragging & Ex-Situ Care

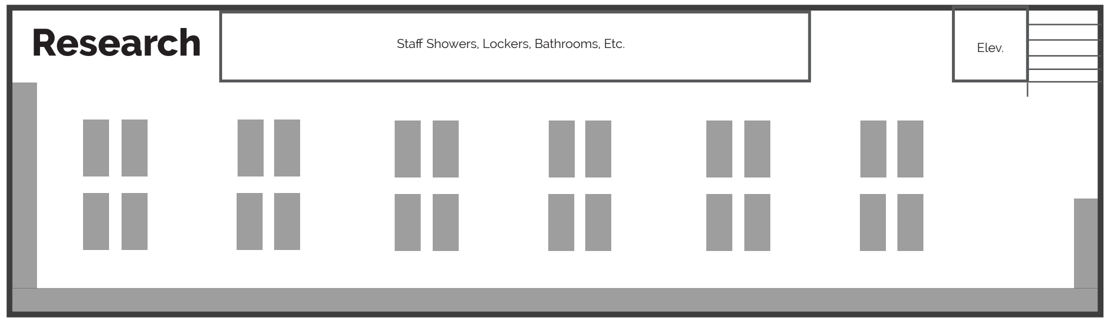
Inside of the research center coral is fragmented hrough the use of a wet bandsaw. The fragments are then affixed to plugs and are briefly cared for in tanks before their growth continues through in-situ propagation methods.

5 Coral Symbiont & MicroBiome Research

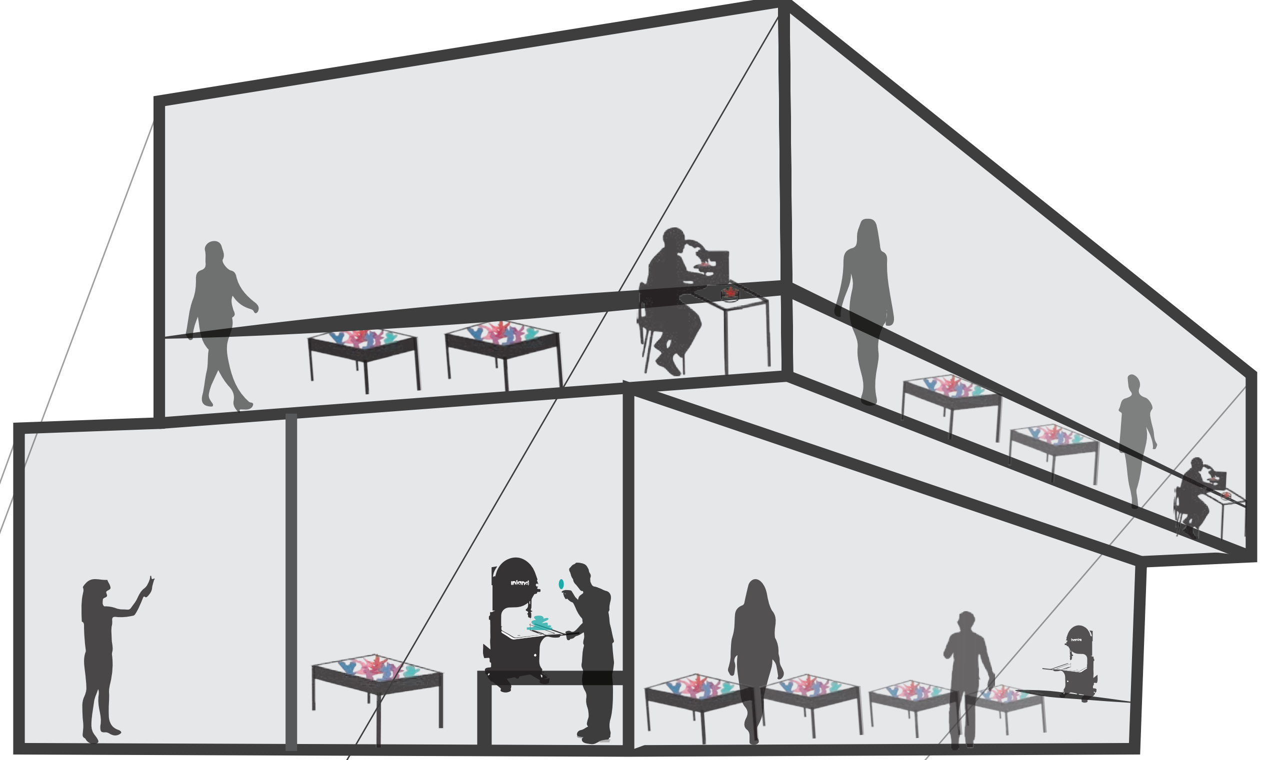
The Center's primary research mission is three-fold: To study the genetics of the urban corals of biscayne and the complexities of their relationship with Symbodinium and their MicroBiome.



First Floor



Second Floor



RIght - A glimpse at how those programming elements would be accomodated within the structure of the Research Center

EXTRAPOLATION

Image from Anastasia Samaloyova's Flood-Zone showing a hazy Miami morning.

Reflection/Questions Answered

Through my exploration of multiple sites and scales (The Modules, The Site for Coral Infrastructure, and The Site for Coral Kinship), it seems I have only begun to scratch the surface of design's potential to aid in the restoration of coral ecosystems. I feel fairly fulfilled with both the direction and depth of my design exploration. However, I wouldn't say my research in this arena is completely finished, there are many more avenues that I would like to explore in the future as an extension of this work. I would love to keep iterating on infrastructural modules - testing them in situ, studying and iterating upon designs in order to maximize their potential. I would also love to spend more time on the ground in Miami talking to urbanites about the level of consideration they give to the coral around them. Despite having so many different potential directions left to explore, I was still able to illuminate a few answers to the initial questions I posed:

How can design contribute to the recolonization and resilience of coral ecosystems?

As an enthusiastic designer with much to learn, I need to recognize my personal bias in response to this question - but I believe there is so much that design can begin to accomplish through further interdisciplinary collaboration. The best landscape architects in practice are able to take the science and break it down into a more easily digestible format for public consumption; while at the same time abstracting these complex ideas and providing them form. Through these skills we can build coalitions and bring disparate disciplines together while pulling back the veil on unseen processes (which is especially helpful for underwater ecologies). To aid coral, design needs to focus on systems, not just form. We must use our ability to consider multiple scales in a way that helps us bridge the gaps between local and global processes. These are all qualities that could undoubtedly be put to good use when paired with scientific experts who bring the knowledgebase and passion needed to make any ecological design a success.

How can urban resilience be fostered in tandem with coral resilience?

In reality there should be no dividing line between ecological resilience and urban resilience, as cities and ecosystems are entities that have naturally been matrixed together. Coral reefs' inherent function as breakwaters serve as an obvious tool for urban resilience and designing nature-based coral infrastructure for Miami can undoubtedly play a role in the city's defense against increased storms and flooding. However, a climate resilient city requires so much more than that, it requires identity, forming communal bonds, and opportunities for mutual aid. In this way resilience is just as defined by bringing people together as it is about infrastructural capabilities. I believe broadcasting the plight of coral in tandem with the plight of our coastal cities has the ability to mobilize individuals to reconsider the anthropogenic damage to these ecologically rich locales, perhaps inspiring them to take direct tactical action.

Could urban activity be reconciled with coral ecosystem health in a way that creates equity and kinship across species lines?

It's undeniable that exposure helps breed empathy and connection and it appears that Miami's community members and visitors alike have never been fully exposed to the enchanting world of coral that exists just below their feet. Hopefully, once the dwellers of this sub-tropical coastal urban center are re-exposed to the ecology beneath the waves they'll become more invested in its preservation.

I understand that this is all easier said than done, cities are full of distraction, it is hard to worry about the survival of marine invertebrates, when you yourself are just trying to survive. That is why policy is a necessary approach as well. However through design tactics, we can imbed reminders into the built environment that represent the plight of coral ecosystems around the city. It is part of the intent of the South Pointe Coral Nursery & Research Center to serve as this form of a reminder. It's unfair to imagine that the entirety of a city's populace can immediately be bonded to their long ignored adjacent ecology, but we can begin taking steps toward equality by building relationships. Relationships take time and patience, but by providing a platform for them to develop, we are taking the necessary first steps. If we are to successfully design to combat the capitalist forces that have brought about the degradation upon coral reef ecosystems it is going to take a movement of motivated individuals at local and global scales. A mobilized citizenry is always required to truly enact change and perhaps the common goal of coral restoration can aid in the counter movement of community against capital.

What's Next?

IIt is encouraging to see the scientists and designers converging around potential solutions such as the proposal of the Green New Deal "a generational investment in planning and design that will radically transform the social and physical landscape of the United States." Marine scientists have begun to band together, collectively calling on governmental decision makers to balance the green with the blue, stating "A terrestrial ocean integrated climate policy is part of a larger changing narrative about oceans and the recognition of their untapped potential for climate regulation, mitigation and adaptation... Investing in integrated climate solutions has the potential to provide needed economic stimulus and empowerment to vulnerable communities, who often contribute the least to climate change yet bear the brunt of its consequences" (33) This very call to action shows a willingness to embrace innovative design solutions that would repair and strengthen the connection between society and our surrounding ecologies. Historically , it has seemed that the field of conservation, often discounted design for fear of disrupting the "natural" ecology of a locale (Conservationists are by definition "conservative"). However, this fails to recognize that ecological dynamics on this planet are constantly shifting, nothing remains static and unchanged. Design gives us a proactive way forward as people are beginning to notice the irreversible changes we've enacted on the environment around us and realize there is no path backward, only forward.

33- Dundas, S. J., Levine, A. S., Lewison, R. L., Doerr, A. N., White, C., Galloway, A. W. E., ... White, J. W. (2020). Integrating oceans into climate policy: Any green new deal needs a splash of blue. Conservation Letters. https://doi.org/10.1111/conl.12716

Though critical of landscape architecture's "entire genre of self-important design writing and advocacy [that] has emerged from the premise that social and ecological crises are best addressed through design in general and landscape architecture in particular", Billy Fleming's 2019 article Design and the Green New Deal outlines a path forward for our profession. Fleming declares that "If landscape architects wish to remake the world we must first reconstitute our discipline as something more than a client-driven enterprise...Political leaders will lay out the broad strokes: investments in clean energy research, a new federal industrial policy, public spending for climate adaptation in vulnerable communities, but landscape architects are in a position to realize the projects necessary to the Green New Deal - the retrofitting of vulnerable cities with green infrastructure... the managed retreat from coastal areas - and to argue that success will depend on our ability to plan, design, and administer radical transformations." (34)

34- Fleming, B. (2019). Design and the Green New Deal. Places Journal, (2019). https://doi.org/10.22269/190416

I certainly agree that this bold government vision needs to be achieved in order to make these kinds of projects successful. We must expand the designation and management of marine protected areas in addition to similar area-based conservation strategies. Fleming's indictment of addressing crises through design seems to be more of a criticism of our profession's refusal to embrace both the political nature of our practice and the policies necessary to make our design capabilities effective, rather than a call for us to completely abandon large-scale design work. No one solution will do the trick, we will need a matrix of governmental action in tandem with both large-scale and small-scale design visions in order to combat the anthropogenic degradation of all ecosystems, not just coral reefs. I contend that there is indeed still a need for us to cater to a "client". However, now our clients must be coral reefs and the other ecologies deconstructed by inconsiderate industry and development, as well as the communities whose lives and livelihoods are far too often considered below the value of capital.

Perhaps most importantly, these projects require follow through and long-term commitment since their outcome can not be truly determined until the end of their life cycle. The future will always be hazy, and without those supporting factors these grand visions are useless. We can formulate a wide range of brilliant and inspiring ideas, but if we don't invest in understanding change and adaptively managing conditions these ideas are for nought. Even with the best execution of adaptive management, a landscape that deals with the complexities of coral ecosystems and the indeterminacy of sediment will have a high degree of uncertainty. Yet, if we embrace this uncertainty and engage with the ecology around us, we will begin to take the vital first steps toward an interspecies future.

Works Cited

Beans, C. (2018). Science and Culture: Artistic endeavors strive to save coral reefs. Proceedings of the National Academy of Sciences, 115(21), 5303–5305. https://doi.org/10.1073/pnas.1807178115

Committee on Interventions to Increase the Resilience of Coral Reefs; Ocean Studies Board; Board on Life Sciences; Division on Earth and Life Studies; National Academies of Sciences, E. and M. (2019). A Decision Framework for Interventions to Increase the Persistence and Resilience of Coral Reefs. https://doi.org/10.17226/25424

Cornejo, E. Marin-Saenz, L. (2017) Bajio: Research Center for Coral Reefs (Master's thesis, Florida International University, Miami, USA) Retrieved from https://issuu.com/lillianms/docs/thesis-liz_lilli

Dundas, S. J., Levine, A. S., Lewison, R. L., Doerr, A. N., White, C., Galloway, A. W. E., … White, J. W. (2020). Integrating oceans into climate policy: Any green new deal needs a splash of blue. Conservation Letters. https://doi.org/10.1111/conl.12716

Edwards, A. J., & Coral Reef Targeted Research & Capacity Building for Management Program. (2010). Reef Rehabilitation Manual. St. Lucia QLD: The Coral Reef Targeted Research & Capacity Building for Management Program.

Ezban, M. (2019). Aquaculture Landscapes: Fish Farms and the Public Realm (illustrated). London: Routledge.

Fleming, B. (2019). Design and the Green New Deal. Places Journal, (2019). https://doi.org/10.22269/190416

Frank, Andrew K. (2017). Before the Pioneers: Indians, Settlers, Slaves, and the Founding of Miami. Gainesville: University Press of Florida.

Fry, T. (2011). Design as Politics (English ed.). New York: Berg.

Haraway, D. (2016). Staying with the trouble : Making kin in the Chthulucene (Experimental futures). Durham: Duke University Press.

Hargreaves & Jones (2009) South Pointe Park Retrieved from http://www.hargreaves.com/work/south-pointe-park/

Harris, A. (2018, April 19). Miami Beach's future is 'uncertain,' experts say, but sea rise pumps are a good start. Retrieved from https://www.miamiherald.com/news/local/community/miami-dade/miami-beach/article209328849.html

Hester, R. (2006). Design for ecological democracy. Cambridge, Mass.: MIT Press.

Hilbertz, W. (1976). MARINE ARCHITECTURE: AN ALTERNATIVE. Architectural Science Review, 19(4), 84–86. https://doi.org/10.1080/00038628.1976.9697227

Johns, Leeworthy, Bell, & Bonn. (2001). Socioeconomic Study of Reefs in Southeast Florida: Final Report. Retrieved from http://coralreef.noaa.gov/Library/Publications/valuemetaanalysis.pdf

Klein, N. (2014). This changes everything : Capitalism vs. the climate (First Simon & Schuster hardcover ed.). New York: Simon & Schuster.

Lokman, K. (2017). Cyborg landscapes: Choreographing resilient interactions between infrastructure, ecology, and society. Journal of Landscape Architecture, 12(1), 60–73. https://doi.org/10.1080/18626033.2017.1301289

Lynn Wingard, G., South Florida Water Management District, & Biscayne National Park. (2004). Changing Salinity Patterns in Biscayne Bay, Florida. Retrieved from http://sofia.usgs.gov/projects/remote_sens/sflsatmap.html

McHarg, I., & American Museum of Natural History. (1969). Design with nature (1st ed.]. ed.). Garden City, N.Y.: Published for the American Museum of Natural History [by] the Natural History Press.

Miller, M. W., Karazsia, J., Groves, C. E., Griffin, S., Moore, T., Wilber, P., & Gregg, K. (2016). Detecting sedimentation impacts to coral reefs resulting from dredging the Port of Miami, Florida USA. PeerJ, 2016(11). https://doi.org/10.7717/peerj.2711

Moore, J. (2015). Capitalism in the web of life : Ecology and the accumulation of capital (1st ed.). New York: Verso.

Orff, K., & SCAPE. (2016). Toward an Urban Ecology (Illustrated). New York City: Monacelli Press.

Shell-Weiss, M. (2009). Coming to Miami : A social history (Sunbelt studies). Gainesville: University Press of Florida.

Sella, I. (2019, November) ECOncrete: Bringing Concrete to Life - Applying Principles of Reconciliation Ecology in Urban Waterfronts. Presented at the 2019 American Society of Landscape Architects Annual Conference, San Diego, CA.

Shick, J. M. (2018). Where Corals Lie: A Natural and Cultural History (Illustrated). London: Reaktion Books.
Tsing, A. (2015). The Mushroom at the End of the World : On the Possibility of Life in Capitalist Ruins. Princeton: Princeton University Press.

Steiner, F., & McHarg, Ian L. (2019). Design with Nature Now. Cambridge, Massachusetts: Lincoln Institute of Land Policy, published in association with the University of Pennsylvania Stuart Weitzman School of Design and The McHarg Center.

Tebben, J., Motti, C. A., Siboni, N., Tapiolas, D. M., Negri, A. P., Schupp, P. J., … Harder, T. (2015). Chemical mediation of coral larval settlement by crustose coralline algae. Scientific Reports, 5(1), 10803. https://doi.org/10.1038/srep10803

UN Secretariat of the Convention on Biodiversity (Various). (2011). Exploring the Potential of Satoumi for Implementing the Ecosystem Approach in the Japanese Archipelago. Montreal.

UNEP-WCMC (2006) In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs. UNEP-WCMC, Cambridge, UK 33 pp

Voss, G. (1988). Coral reefs of Florida (1st ed.). Sarasota, Fla.: Pineapple Press.

Works Considered

Beck, M. W., Losada, I. J., Menéndez, P., Reguero, B. G., Díaz-Simal, P., & Fernández, F. (2018). The global flood protection savings provided by coral reefs. Nature Communications, 9(1). https://doi.org/10.1038/s41467-018-04568-z

Bélanger, P. (2017). Landscape as infrastructure : A base primer. Abingdon, Oxon ; New York, NY: Routledge.
Carson, R. (1937). Undersea. Atlantic Monthly, (78), 55–67. https://doi.org/10.7401/visions.03.06

Cunning, R., Silverstein, R. N., Barnes, B. B., & Baker, A. C. (2019). Extensive coral mortality and critical habitat loss following dredging and their association with remotely-sensed sediment plumes. Marine Pollution Bulletin, 145, 185–199. https://doi.org/10.1016/j.marpolbul.2019.05.027

Curt Storlazzi, B. D., Reguero, B. G., Cole, A. D., Lowe, E., Shope, J. B., Gibbs, A. E., … Beck, M. W. (2019). Rigorously Valuing the Role of U.S. Coral Reefs in Coastal Hazard Risk Reduction Prepared in cooperation with the University of California Santa Cruz and The Nature Conservancy.

Daniels, A., Stevenson, R., Smith, E., & Robblee, M. (2018). Faunal and Vegetation Monitoring in Response to Harbor Dredging in the Port of Miami. https://doi.org/10.3133/ofr20181052

del Tredici, P. (2014). The Flora of the Future. Places Journal, (2014). https://doi.org/10.22269/140417

Deming, M. (2015). Values in landscape architecture and environmental design : Finding center in theory and practice (Reading the American landscape). Baton Rouge: Louisiana State University Press.

Fabricius, K. E. (2011). Factors determining the resilience of coral reefs to eutrophication: A review and conceptual model. In Coral Reefs: An Ecosystem in Transition (pp. 493–505). https://doi.org/10.1007/978-94-007-0114-4_28

Hall, A. E., Herbert, R. J. H., Britton, J. R., & Hull, S. L. (2018). Ecological enhancement techniques to improve habitat heterogeneity on coastal defence structures. Estuarine, Coastal and Shelf Science, 210. https://doi.org/10.1016/j.ecss.2018.05.025

Hametz, I.R., Holmes, R., Seavitt Nordenson, C. (2019, November) Beyond Barriers: Engineering, Ecology, and Design at the Water's Edge. Presented at the 2019 American Society of Landscape Architects Annual Conference, San Diego, CA.

Heron et al. (2017). Impacts of Climate Change on World Heritage Coral Reefs: A First Global Scientific Assessment. Paris, France: UNESCO World Heritage Centre.

Jaap, W., National Coastal Ecosystems Team, & United States. Minerals Management Service. Gulf of Mexico OCS Region. (1984). The ecology of the south Florida coral reefs : A community profile (FWS/OBS ; 82/08). Washington, D.C.: U.S. Dept. of the Interior, Fish and Wildlife Service, Minerals Management Service.

Karlson, R. H. (1999). Dynamics of coral communities. Kluwer Academic Publishers.

Leal, M. C., Ferrier-Pagès, C., Petersen, D., & Osinga, R. (2016). Coral aquaculture: applying scientific knowledge to ex-situ production. Reviews in Aquaculture, 8(2), 136–153. https://doi.org/10.1111/raq.12087

Leong, W., & Pawlik, J. R. (2010). Fragments or propagules? Reproductive tradeoffs among Callyspongia spp. from Florida coral reefs. In

Source: Oikos (Vol. 119). Retrieved from https://www.jstor.org/stable/20779065?seq=1&cid=pdf-reference#references_tab_contents

Malm, A. (2018). The Progress of this Storm : On Society and Nature in a Warming World (Verso futures). London: Verso.

Mathur, A., Cunha, Dilip da, & University of Pennsylvania. School of Design. (2014). Design in the terrain of water (First ed.). United States] : [Philadelphia, Pennsylvania]: Applied Research Design Publishing ; University of Pennsylvania School of Design.

Mathur, A., & Cunha, Dilip da. (2009). Soak : Mumbai in an estuary. New Delhi: Rupa & CO.

Marshall, N., Adger, W. N., Benham, C., Brown, K., I Curnock, M., Gurney, G. G., … Thiault, L. (2019). Reef Grief: investigating the relationship between place meanings and place change on the Great Barrier Reef, Australia. Sustainability Science, 14(3), 579–587. https://doi.org/10.1007/s11625-019-00666-z

Marshall, N., Marshall, P., Curnock, M., Pert, P., Smith, A., & Visperas, B. (2019). Identifying indicators of aesthetics in the Great Barrier Reef for the purposes of management. PLoS ONE, 14(2). https://doi.org/10.1371/journal.pone.0210196

Mos, B., Dworjanyn, S. A., Mamo, L. T., & Kelaher, B. P. (2019). Building global change resilience: Concrete has the potential to ameliorate the negative effects of climate-driven ocean change on a newly-settled calcifying invertebrate. Science of The Total Environment, 646, 1349–1358. https://doi.org/10.1016/j.scitotenv.2018.07.379

Orff, K. (2020). The Great Mother of Life. Journal of Architectural Education, 74(1), 8–9. https://doi.org/10.1080/10464883.2020.1693816

Patel, R., & Moore, Jason W. (2017). A history of the world in seven cheap things : A guide to capitalism, nature, and the future of the planet. Oakland, California: University of California Press.

Parenti, C., & Moore, Jason W. (2016). Anthropocene or capitalocene? : Nature, history, and the crisis of capitalism (Kairos (PM Press (Firm))). Oakland, CA: PM Press.

Porter, J., & Porter, Karen G. (2002). The Everglades, Florida Bay, and coral reefs of the Florida Keys : An ecosystem sourcebook. Boca Raton, Fla.: CRC Press.

Price, N. N., Muko, S., Legendre, L., Steneck, R., van Oppen, M. J. H., Albright, R., … Edmunds, P. J. (2019). Global biogeography of coral recruitment: Tropical decline and subtropical increase. Marine Ecology Progress Series, 621, 1–17. https://doi.org/10.3354/meps12980

Reopanichkul, P., Schlacher, T. A., Carter, R. W., & Worachananant, S. (2009). Sewage impacts coral reefs at multiple levels of ecological organization. Marine Pollution Bulletin, 58(9), 1356–1362. https://doi.org/10.1016/j.marpolbul.2009.04.024

Samoylova, A. (2019). FloodZone (1st Edition). Göttingen: Steidl Verlag.

Staley, C., Kaiser, T., Gidley, M. L., Enochs, I. C., Jones, P. R., Goodwin, K. D., … Chun, C. L. (2017). Differential impacts of land-based sources of pollution on the microbiota of southeast Florida coral reefs. Applied and Environmental Microbiology, 83(10). https://doi.org/10.1128/AEM.03378-16

Todd, P. A., Heery, E. C., Loke, L. H. L., Thurstan, R. H., Kotze, D. J., & Swan, C. (2019). Towards an urban marine ecology: characterizing the drivers, patterns and processes of marine ecosystems in coastal cities. Oikos. https://doi.org/10.1111/oik.05946

Veron, J. E. N. (2000). Corals of the World, Vol. 1-3 (Mary Stafford-Smith, Ed.). Townsville, Queensland: Austrailian Institute of Marine Science.

Zaneveld, J. R., Burkepile, D. E., Shantz, A. A., Pritchard, C. E., McMinds, R., Payet, J. P., ... Thurber, R. V. (2016). Overfishing and nutrient pollution interact with temperature to disrupt coral reefs down to microbial scales. Nature Communications, 7. https://doi.org/10.1038/ncomms11833

Collage of Miami's Coralscape

Design with Diploria

Coral Infrastructure for a New Coastal Future

Matt Grosser
Landscape Architecture - College of Built Environments
University of Washington
Seattle, WA