X-REEFS: Next-generation hybrid coral reefs

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE, ATMOSPHERIC & EARTH SCIENCE

Prof. Andrew Baker
University of Miami, Rosenstiel School
abaker@miami.edu
@coralprof

CORAL REEF FUTURES LAB MIAMI

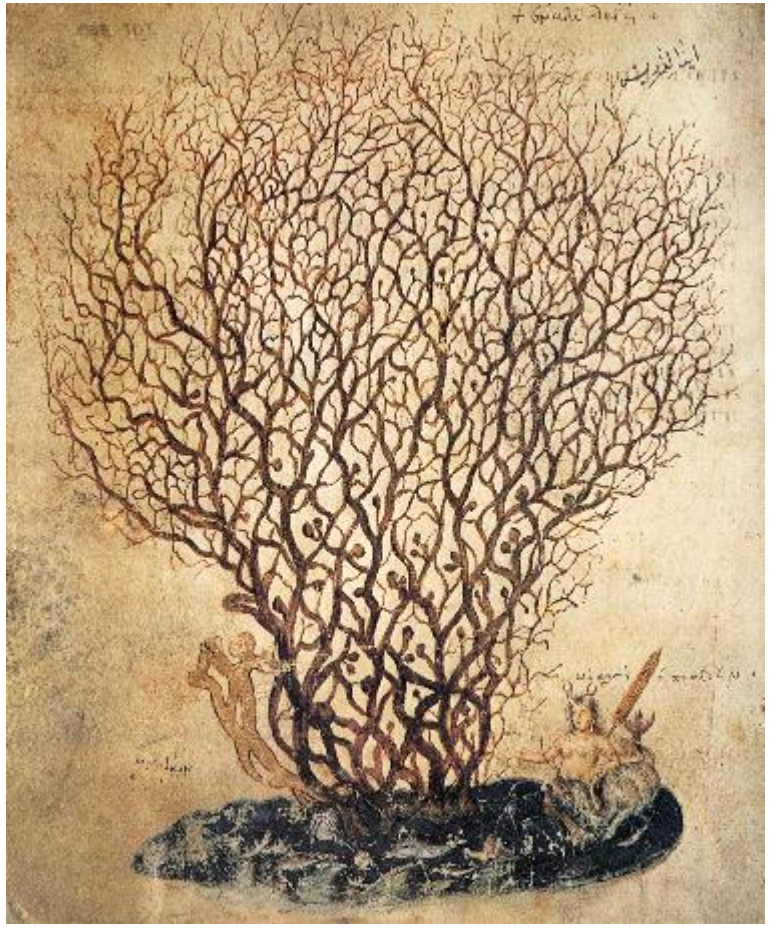

60
MINUTES
produced by Andy Court
Rescuing
Reefs

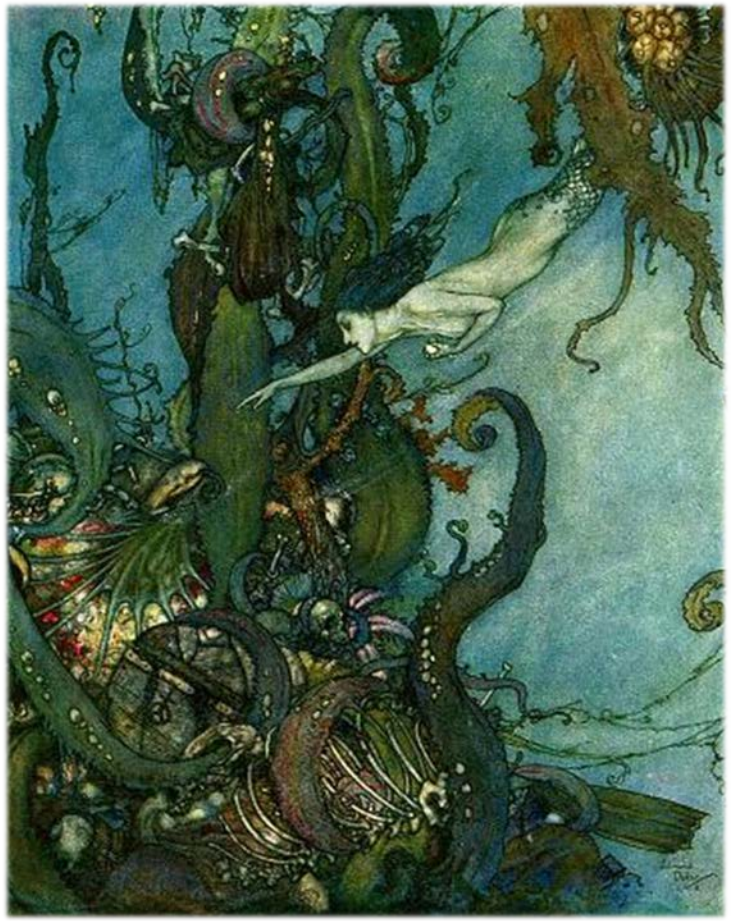
VP Kamala Harris visits Miami, announces $562M to deal with climate change impact

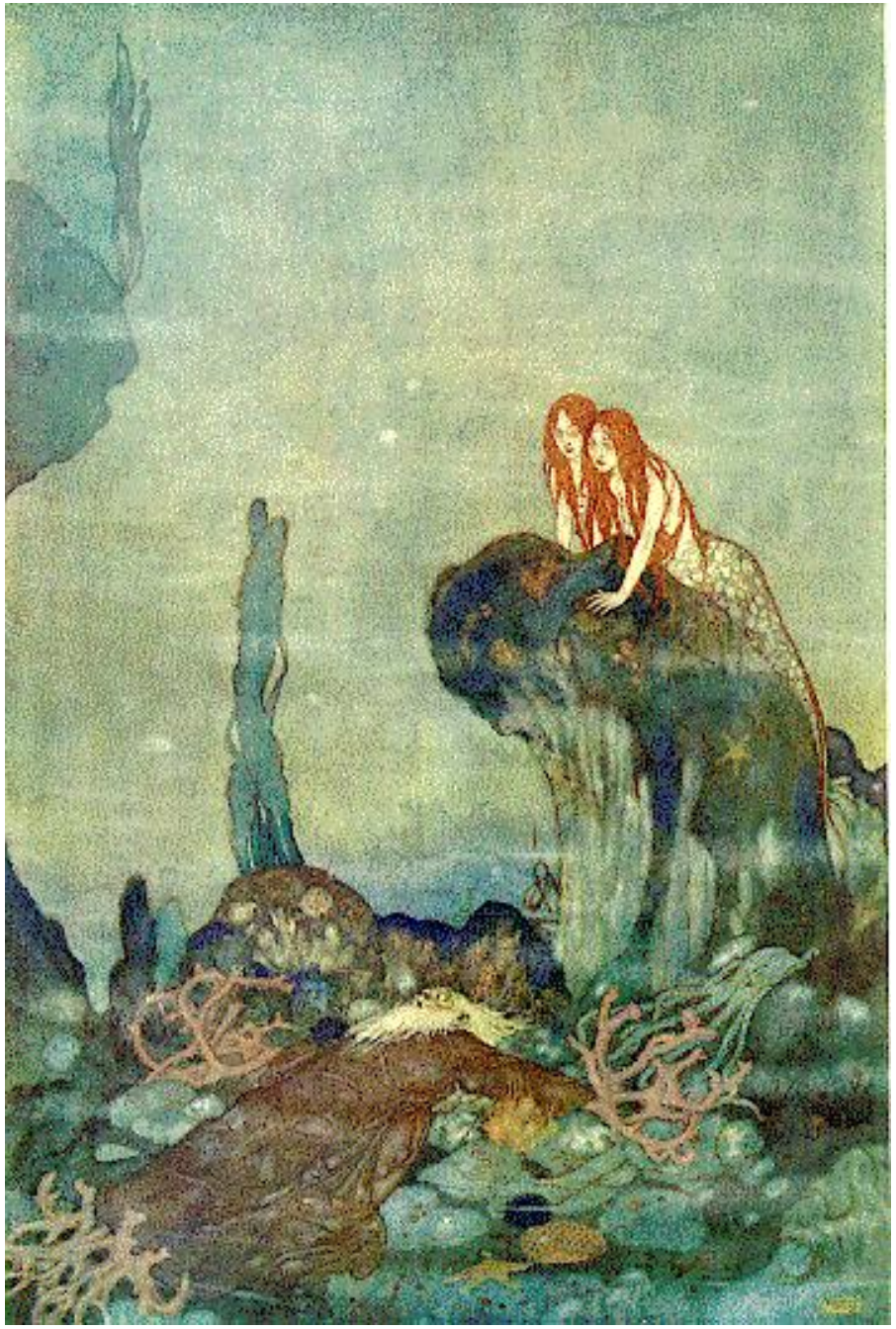
local10.com

Something Rich and Strange:

The Life, Death, and Resurrection of Coral







Edmund Dulac

Full fathom five thy father lies.
Of his bones are coral made.
Those are pearls that were his eyes.
Nothing of him that doth fade,
But doth suffer a sea-change
Into something rich and strange.

William Shakespeare,
The Tempest

Edmund Dulac

"An ocean without its unnamed monsters would be like a completely dreamless sleep" – John Steinbeck

Coral: cor·al [kawr-*uh*l] Noun.

Origin: Middle English, but derives from Old French

Latin (*corallium),* Greek (*korallion)*,
Hebrew *gōrāl (pebble)* + *ion* (diminutive suffix)
= “Small pebble or rock”

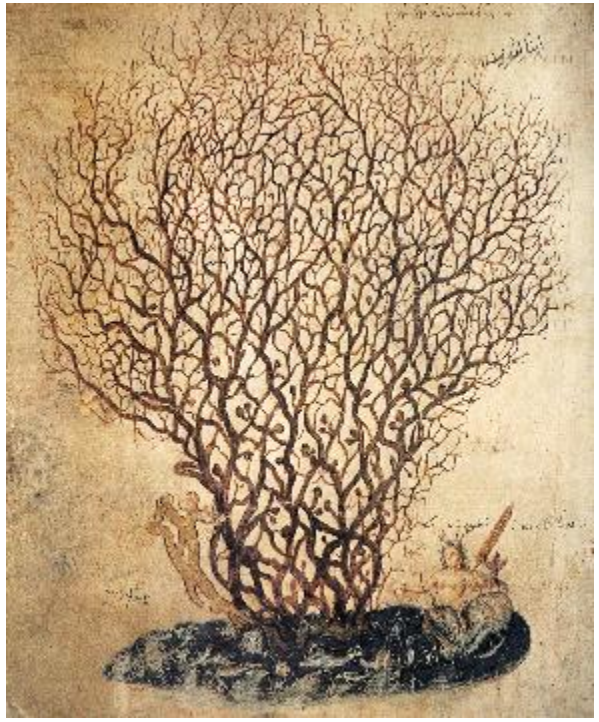
Originally referred to the precious Mediterranean red coral with an attractive red or pink skeleton and dense texture that has been used in jewelry, medicine, and trade for thousands of years (perhaps even from Paleolithic times)

Spectacular array of different “corals”

Red corals, pink corals, white corals, blue corals, gold corals, organ-pipe corals, fire corals, stony corals, soft corals, black corals, thorn corals, horny corals, leather corals, gorgonian corals….

Perseus Disarming and the Origin of Coral, by Peter Paul Rubens (1577-1640)

Corals as potent symbols of *transformation…*



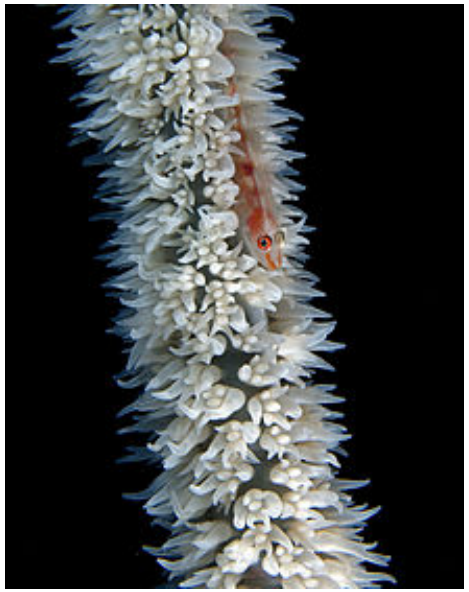
"Its form is that of a scrub, its color is green…
when removed from water its color is red….
when touched by a person it turns to stone"

Pliny the Elder, on corals

Even now, corals have the same nature, hardening at a touch of air. What was alive under the water, above water is turned to stone.

Metamorphoses, Ovid

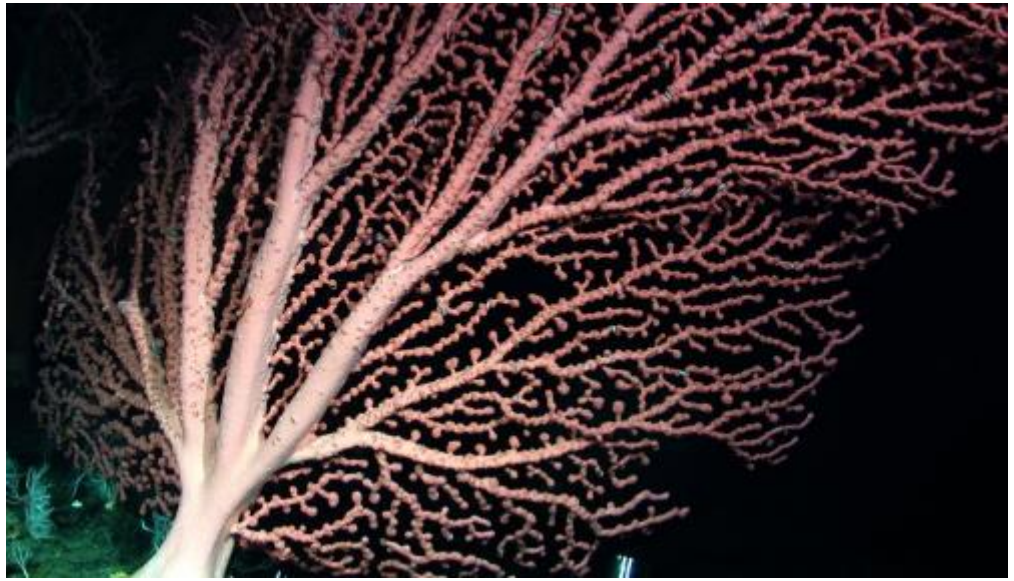
Black (or “thorn”) corals – “Antipatharians” (greek: “against disease”)

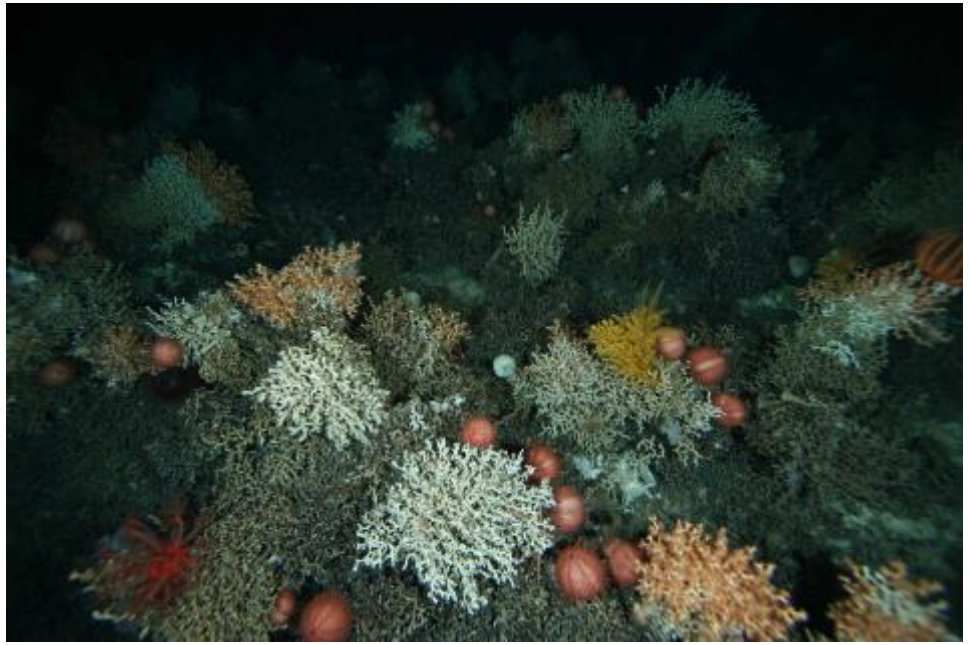


Japanese *umimatsu* snuff bottle

Madonna de la Vittoria
Andrea Mantegna, 1496

Cold water (deep sea) corals



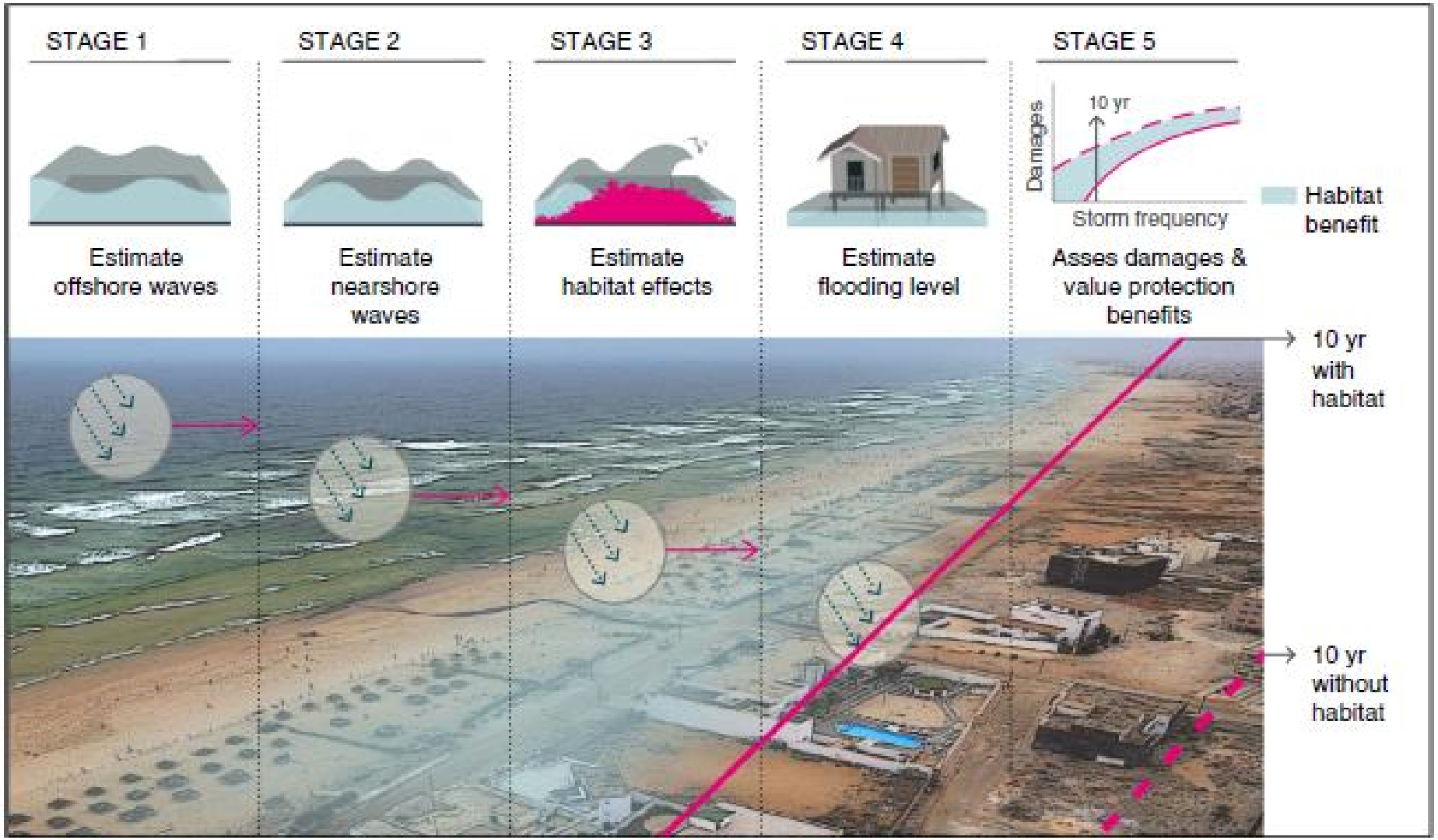


Antarctic corals

One group of corals, the **stony corals**, have hard internal skeletons made of limestone and build **coral reefs** in shallow tropical seas…

But they are threatened by climate change, which cause coral “bleaching” during increasingly frequent and intense “marine heat waves”

Coral reefs built by these corals can develop into enormous submerged offshore structures that can be seen from space



Florida's Coral Reef

Florida's Coral Reef provides more than $355M in annual flood protection benefits to buildings and protects nearly $320M in annual economic activity

Beck et al. 2018

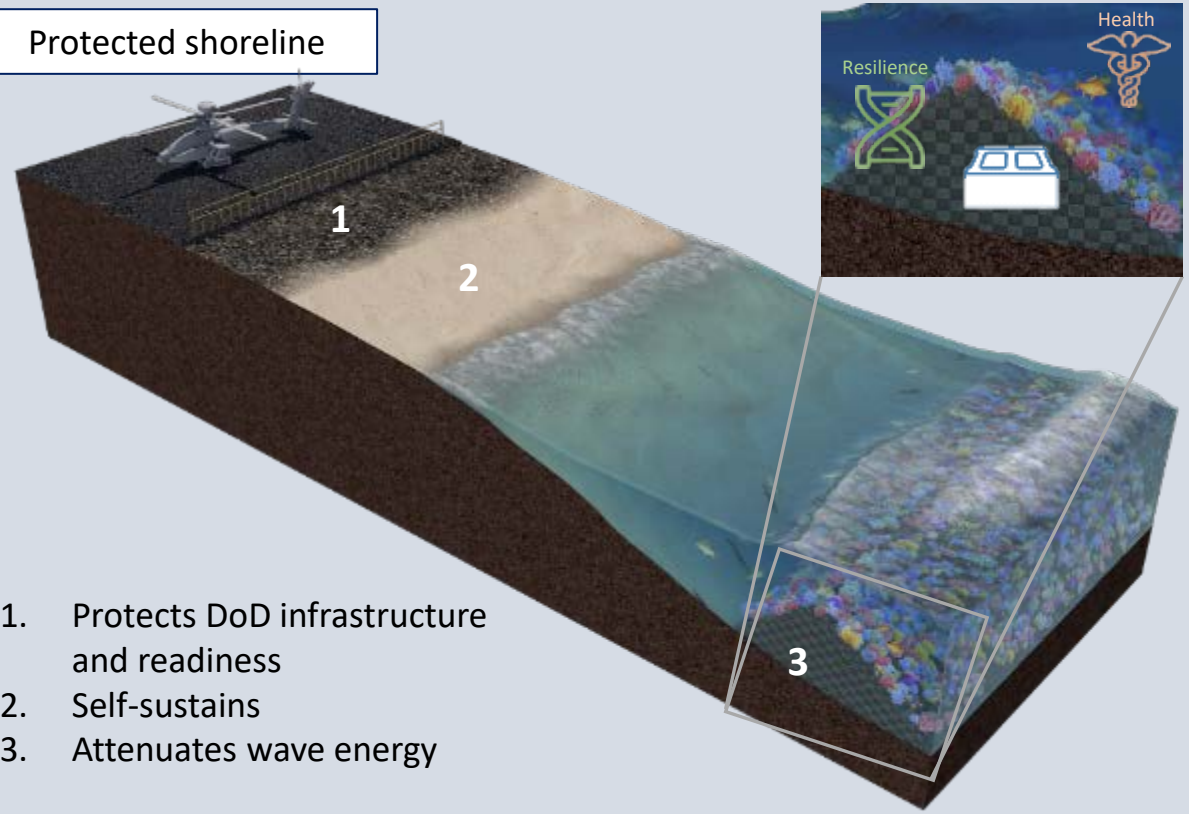
Storlazzi et al. 2019

Department of Defense Problem: Globally, coastal DoD installations and civilian infrastructure are at risk for damage from inundation and beach erosion due to sea level rise-associated flooding and increased storm intensity

Vulnerable shoreline

1. Threatens DoD infrastructure and readiness
2. Requires maintenance
3. Reflects wave energy

Protected shoreline



1. Protects DoD infrastructure and readiness
2. Self-sustains
3. Attenuates wave energy

Defense Advanced Research Projects Agency (DARPA) “Reefense” Program

Vision: Develop hybrid biological and engineered reef-mimicking structures to mitigate wave and storm damage that increasingly threaten sustainability and DoD personnel and infrastructure, and provide economic and environmental stability

Goal: Next-generation hybrid reefs designed to build both coastal and coral resilience

University of Miami X-Reefs Project

Hybrid reefs that combine the immediate wave-protection benefits of artificial structures with the ecological benefits of coral reefs, and which also incorporate:

Ecological engineering approaches to help promote coral recruitment and dominance, and

Adaptive biology approaches to increase coral resilience and growth in warming climate

Technical Approach and Goals of X-REEFS

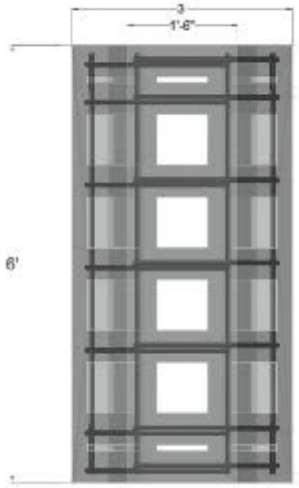
Overview. Develop and deploy a 100-m hybrid engineered and biological coral reef-mimicking structure that is fast-growing, resilient, and provides immediate protection from waves.

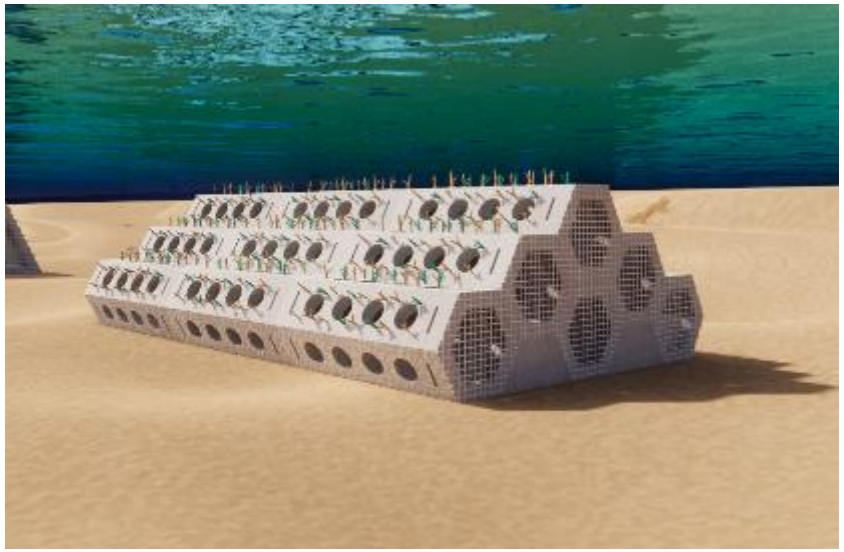
Substrate Design and Structure: Design a submerged breakwater using innovative structures, materials, hydrodynamic models, and wave tank testing
Goal: *reduce wave energy by >90% after 5 years*

Ecological Engineering: Engineer ecological communities that enhance the capacity of the structure to self-build and self-repair to enhance wave attenuation benefits
Goal: *increase coral cover by >35% and reduce seaweed cover by >50% after 5 years*

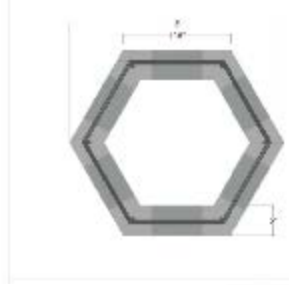
Adaptive Biology: Identify, test, and deploy novel technologies to improve the adaptive capacity of corals and increase the long-term resilience of the structure
Goal: *increase heat tolerance of corals by +3.0^{o}C and their growth by >30% after 5 years*

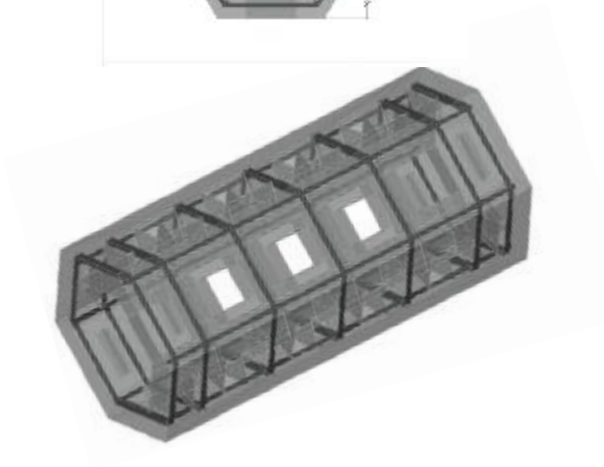
Structure design and materials: Base structure design

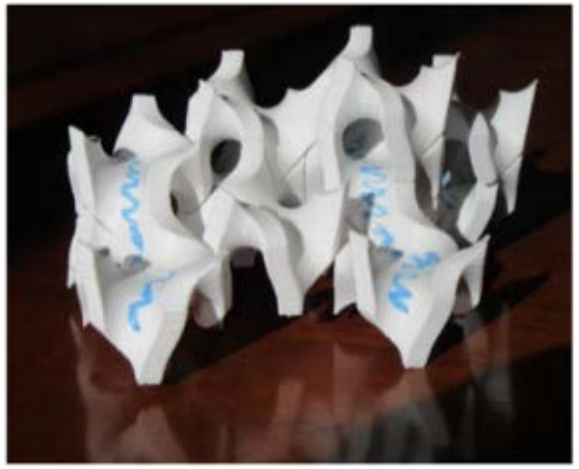




SEAHIVE base structure configuration







Gyroid lattice superstructure

Concrete mixture design

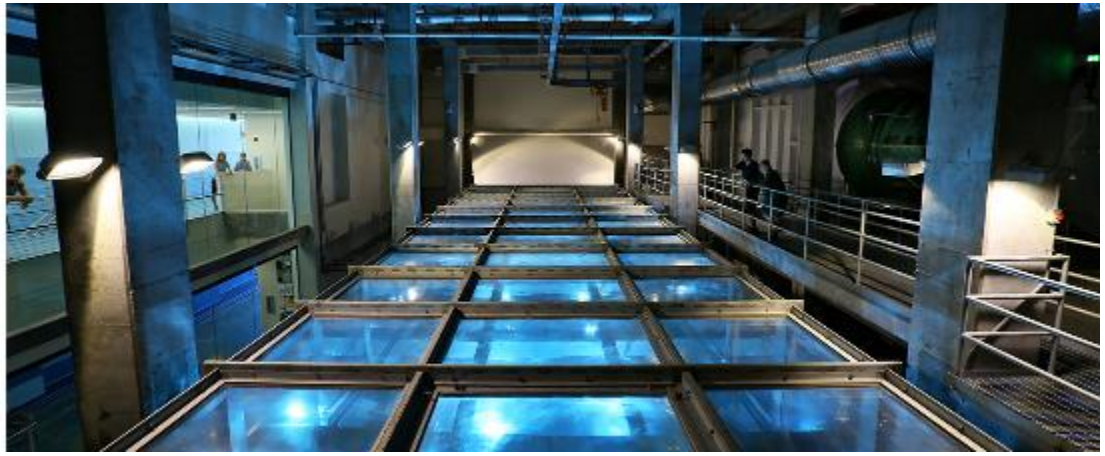
High-performance

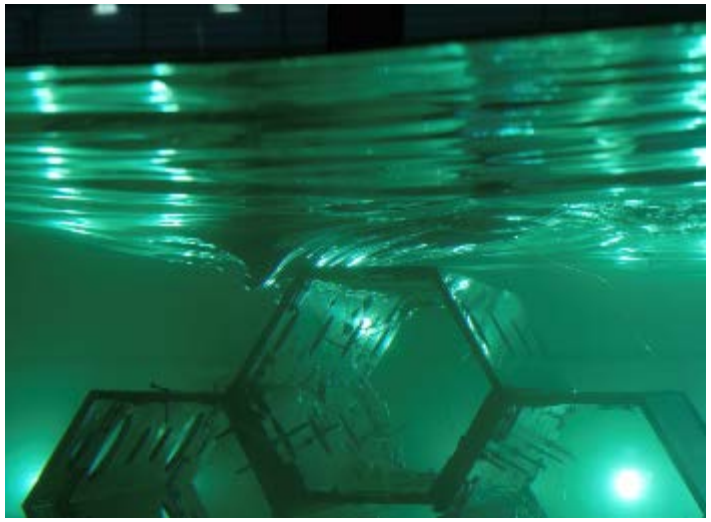
Sustainable, low carbon footprint

Durable when exposed to seawater

Create chemical microenvironment that increases growth of young corals

Testing in SUSTAIN wave tank





Capable of simultaneously generating Category 5 wind and waves at scale
(23-m x 6-m x 2-m, test section is 18-m long)

Pilot / Test Bed Deployment

Test Bed deployed off Miami Beach (Surfside) on March 1, 2023

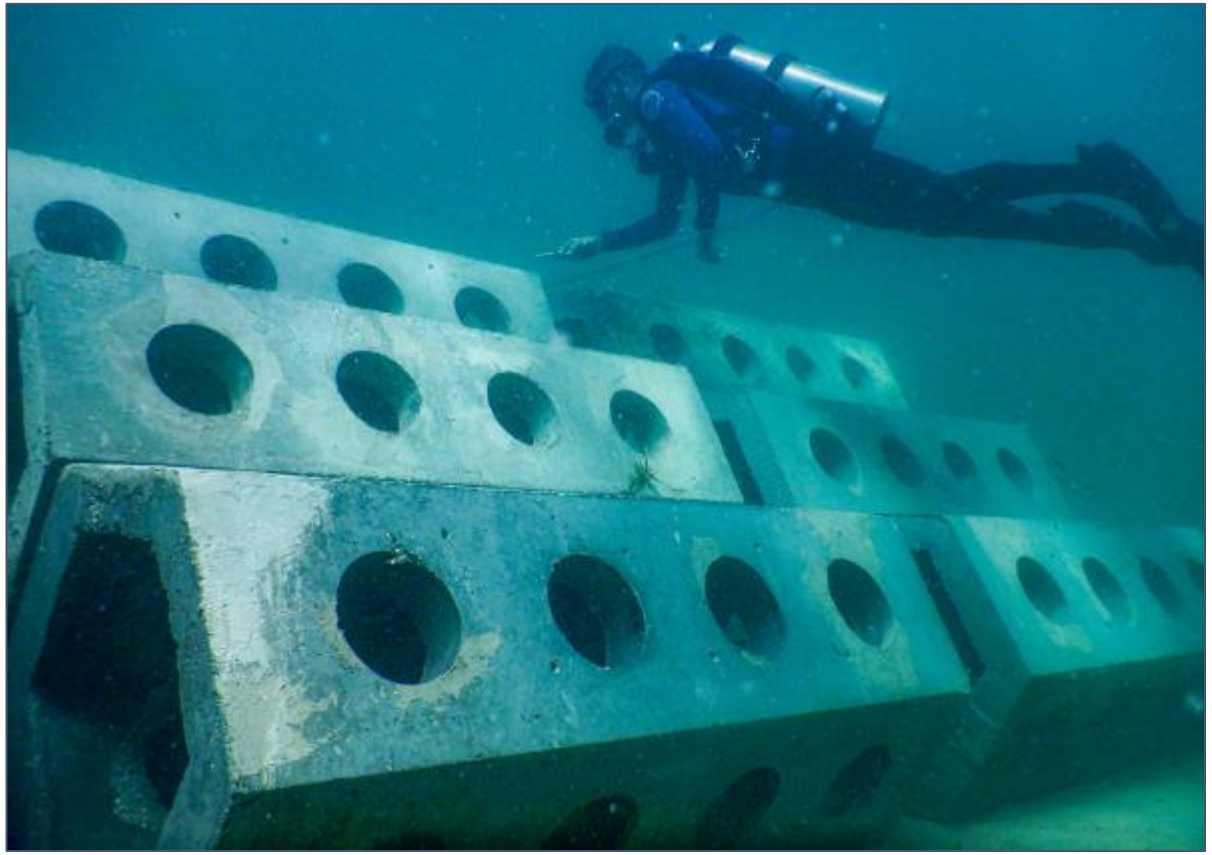
Hybrid reef structures on barge prior to deployment

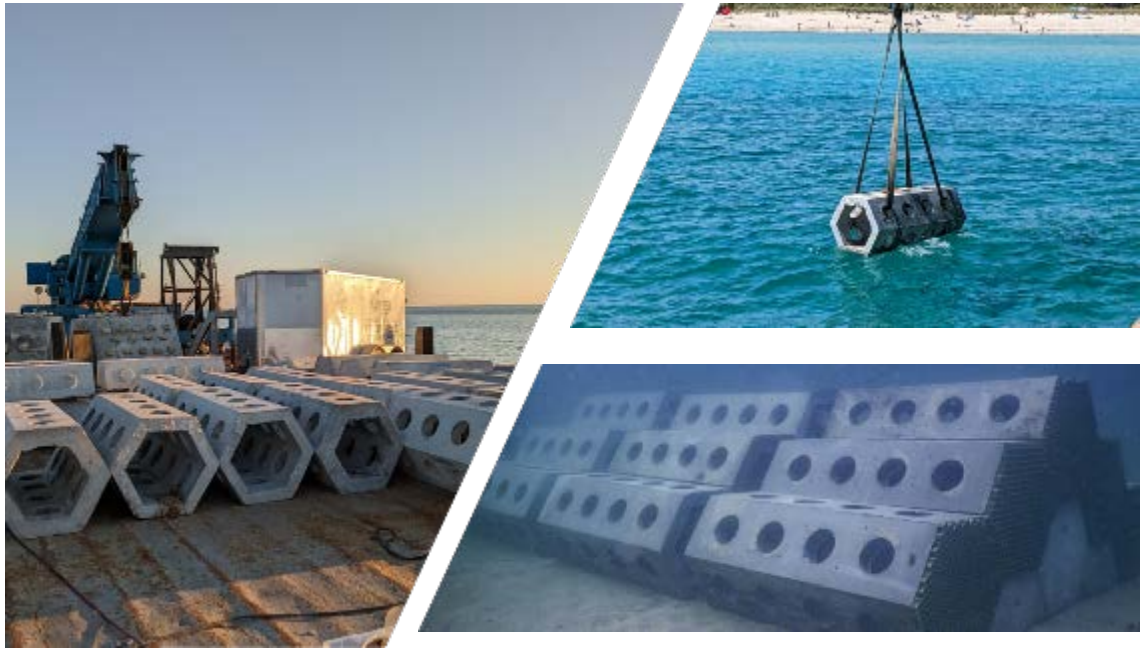
SEAHIVE unit being lowered into the ocean off Surfside, Miami Beach

Post Deployment Surveys

Post-deployment surveys and monitoring

- Installation of buoys and rebar
- Baseline photography of structure
- Monitoring of stability on sand bed



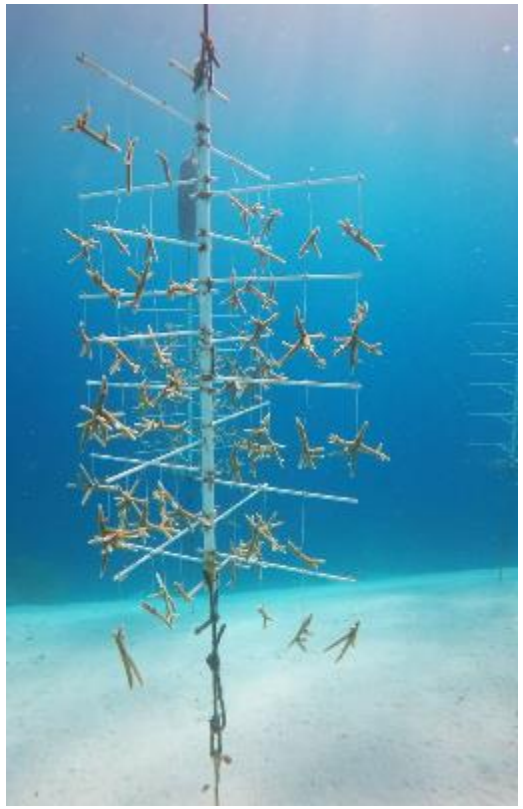


Ecological Engineering: Coral nursery propagation

Clonal coral propagation in offshore nurseries to scale up biomass production

Screening of coral stocks for thermal tolerance

Construction of new nurseries in ‘condition’ corals to the appropriate environment



Ecological Engineering: Managed coral breeding

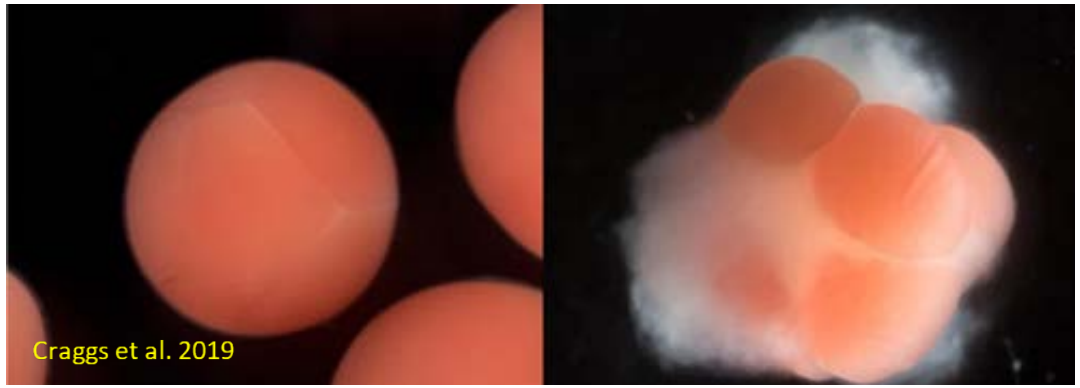
Assisted coral recruitment

Coral spawning and larval production

Microbial and/or chemical settlement cues

Field attraction of recruits

Larval encapsulation and bioprinting using hydrogels



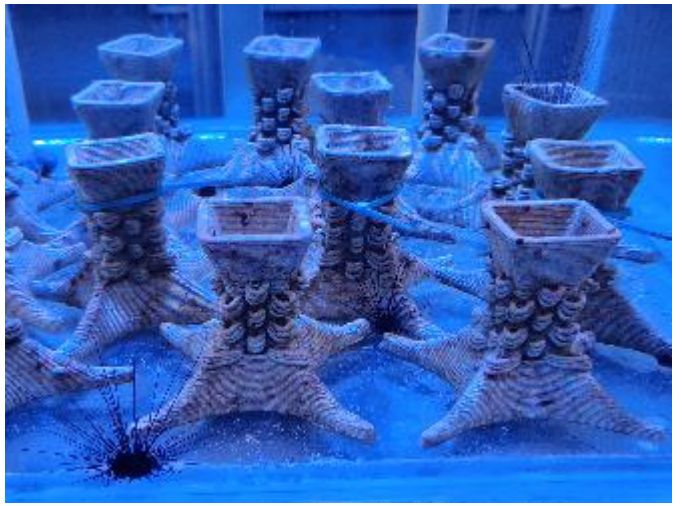
Ecological Engineering: Community enhancement

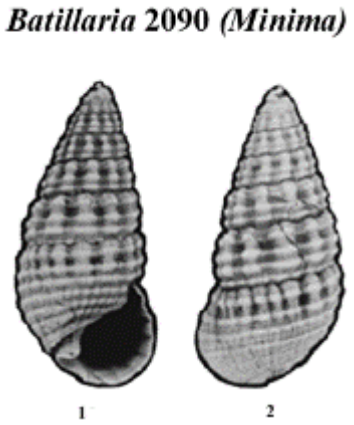
Reduce algal cover and attract/promote growth of coral recruits

Rearing of grazing herbivores and crustose coralline algae

Anti-algal coatings (Quaternary ammonium salts - QAS)

Enhanced alkalinity in boundary layer via additives and/or altered concrete characteristics



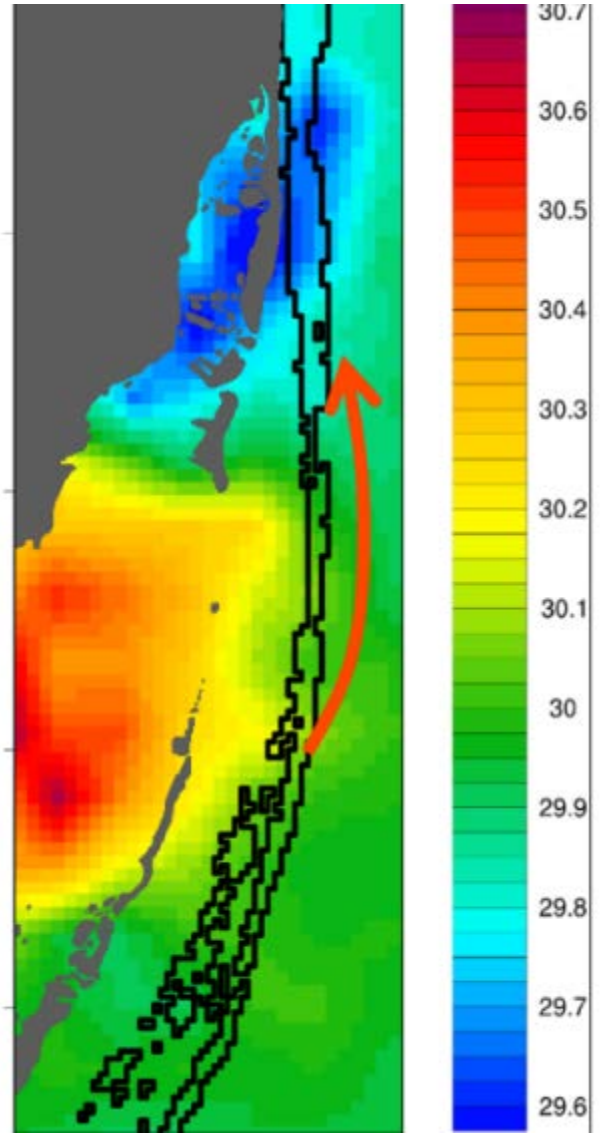


Adaptive Biology: Selective breeding

Identify and collect thermally tolerant parents (including from outside Florida)

Spawn corals in lab and in the wild (+ cryopreservation)

Production of resilient hybrid and chimeric corals

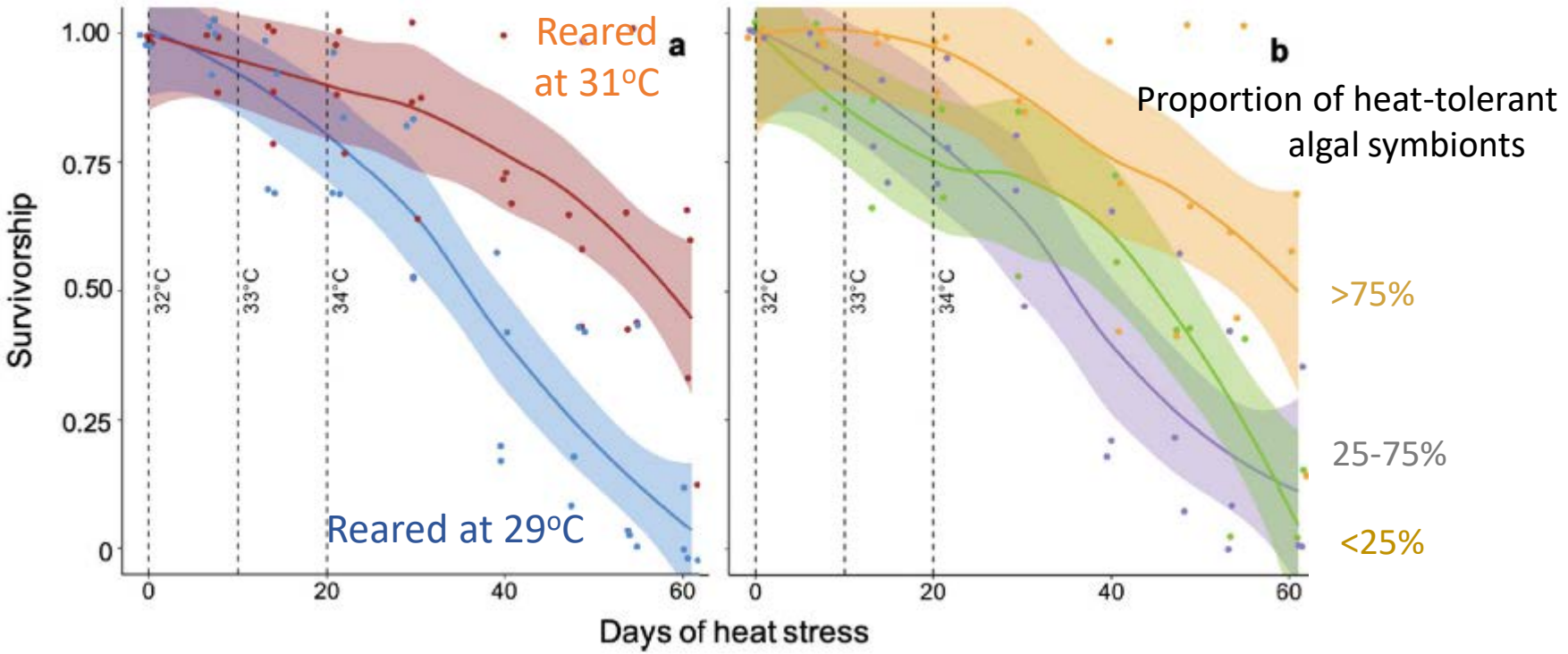


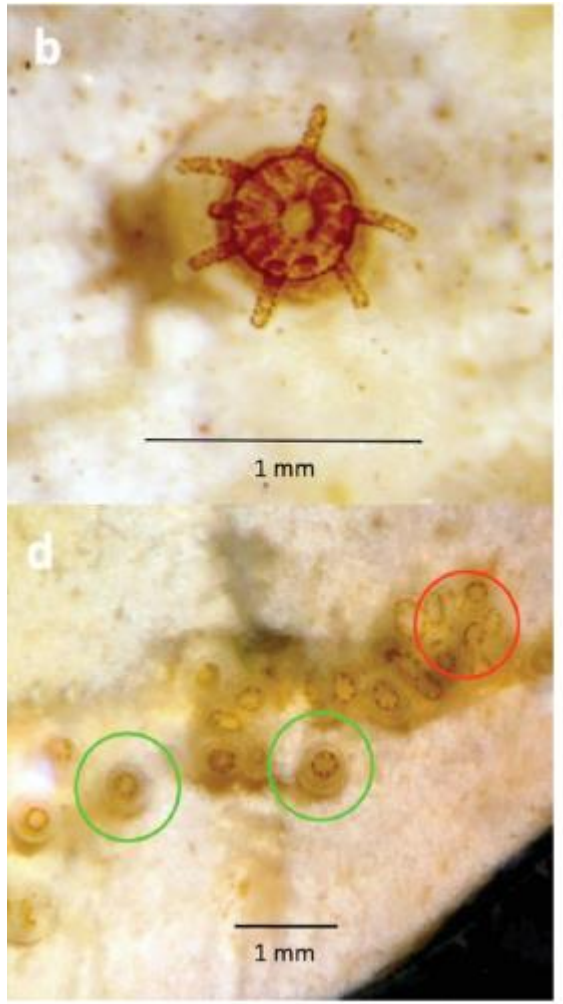
Adaptive Biology: Boosting resilience of baby corals

Inoculate corals with heat-tolerant algal symbionts to resist “bleaching”

Conditioning and stress-hardening

Treatment with probiotics (beneficial bacteria)





Williamson et al. (2021)

HYBRID REEF DESIGN

TA1

SEAHIVE BASE STRUCTURE
Hexagonal perforated base structure

LATTICE SUPERSTRUCTURE
Strong and lightweight concrete lattice forms optimized for wave attenuation and ecosystem services

ADVANCED CORAL MIMICS
Generatively designed meter-scale structures optimized to maximize wave attenuation, strength and habitat complexity

NOVEL CONCRETE MATERIALS
Optimized for strength, durability, coral growth, and reduced carbon footprint

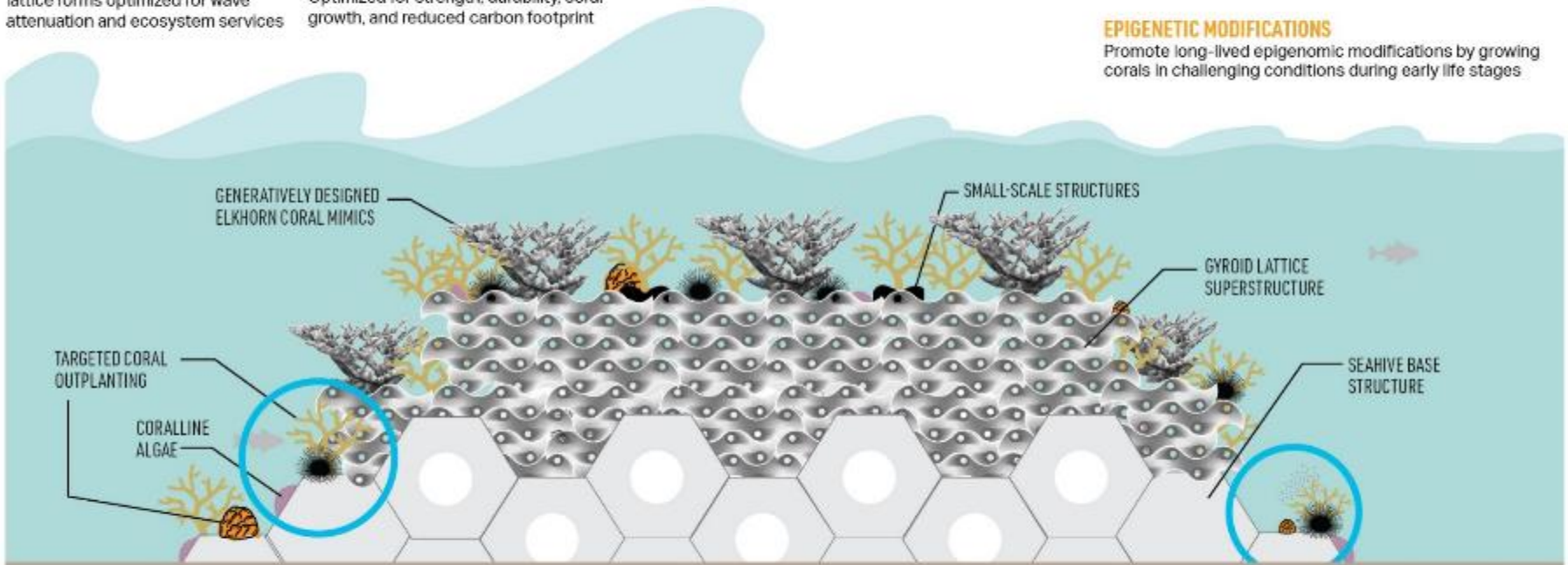
MANAGED BREEDING
Selectively breed more resilient corals using advanced phenotyping and genomic approaches

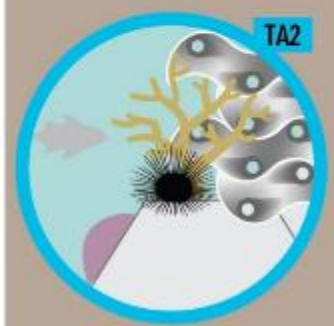
ALGAL SYMBIONT MANIPULATION
Seed early life stage of corals with resilient algal symbionts to increase thermotolerance and disease resistance

PROBIOTICS
Increase coral resilience through probiotic treatments applied during early life stages

HYBRID & CHIMERIC CORALS
Increase coral resilience using hybrid species and mergers of multiple genotypes

EPIGENETIC MODIFICATIONS
Promote long-lived epigenomic modifications by growing corals in challenging conditions during early life stages





ANTI-ALGAL COATINGS & HYDROGELS
Novel coatings to reduce macroalgal growth and deliver targeted chemicals or bacteria

SMALL-SCALE STRUCTURES
Modular interchangeable experimental platforms also enhance habitat complexity

LARVAL ENCAPSULATION & BIOPRINTING
Encapsulate coral larvae and print to fieldable substrates to target settlement and increase survivorship

ALKALINITY ENHANCEMENT
Incorporate slow-dissolving compounds to enhance coral growth

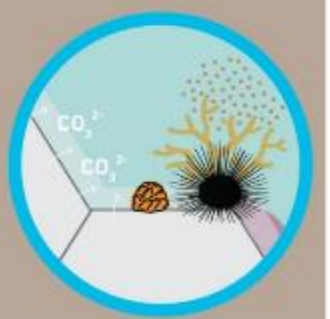
TARGETED CORAL OUTPLANTING
Restoration of adult corals using highest performing species/genotypes from nurseries

ASSISTED RECRUITMENT
Propagate corals from larvae and facilitate settlement

MICRO-DESIGN
Concrete shapes and textures to enhance local coral recruitment and survivorship

CRUSTOSE CORALLINE ALGAE
Promote CCA growth to enhance coral recruitment and block competitors

REEF HERBIVORY
Propagate invertebrate herbivores to control macroalgae



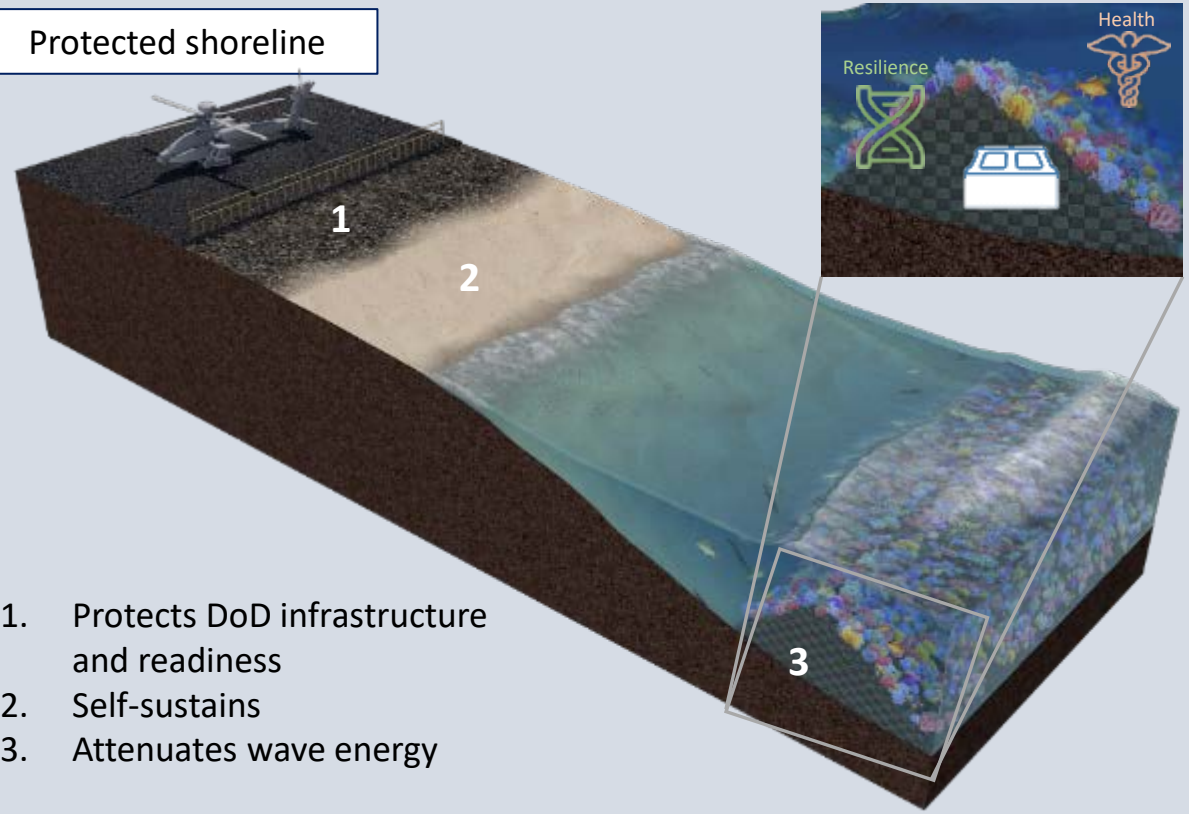
Conceptual diagram for representative purposes only

Expanding Infrastructure for Coral Restoration and Adaptation

Vulnerable shoreline

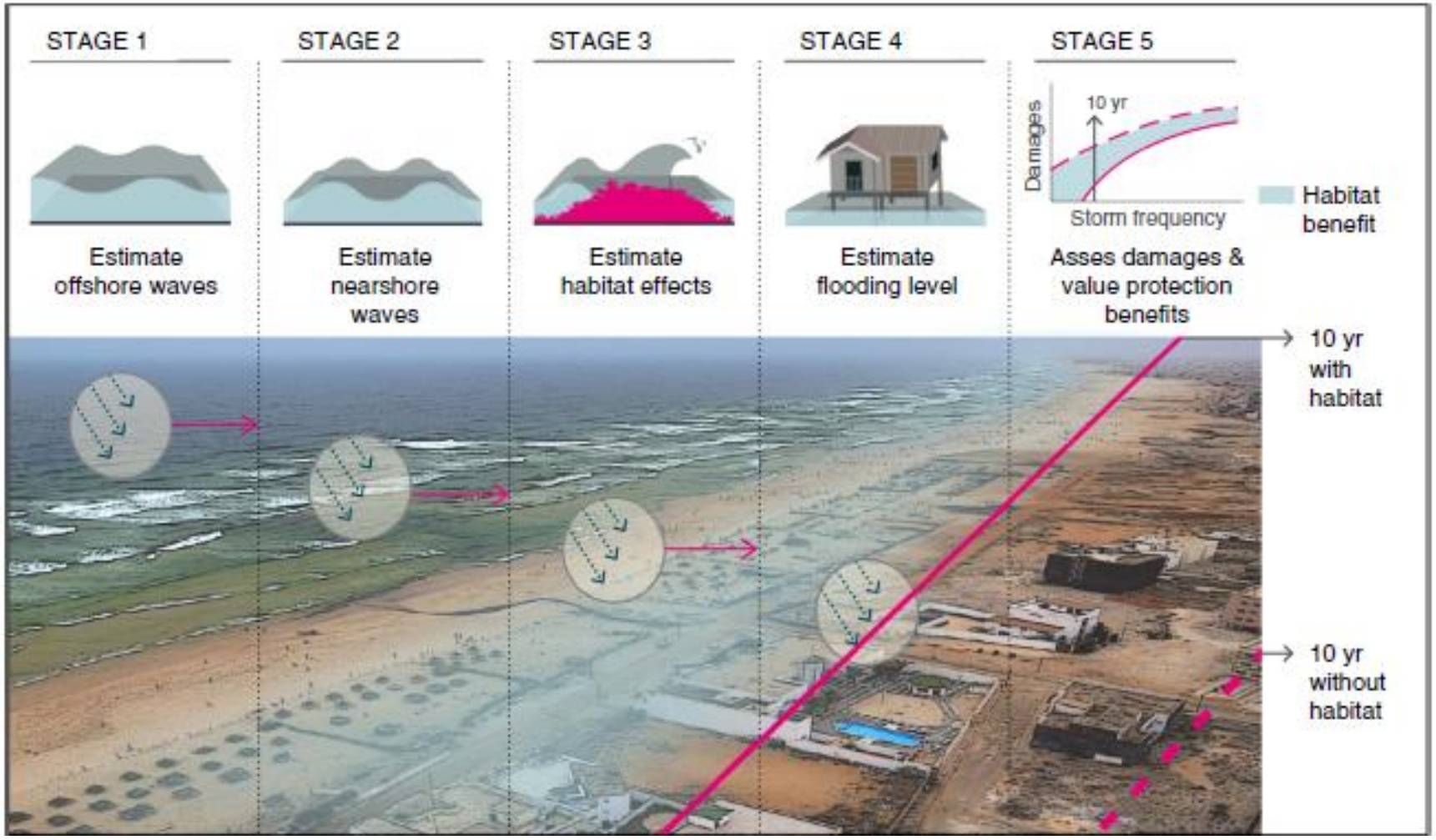
1. Threatens DoD infrastructure and readiness
2. Requires maintenance
3. Reflects wave energy

Protected shoreline



1. Protects DoD infrastructure and readiness
2. Self-sustains
3. Attenuates wave energy

Coral reefs Florida alone provide ~$675M/year in benefits



Can corals still be “agents of transformation”?

Thank you!

Prof. Andrew Baker
abaker@miami.edu
@coralprof

The Coral Reef Futures Lab

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