The Future of Florida's Coral Reefs

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COASTAL PROTECTION

Coral reefs **reduce wave energy by 97%** before hitting the shore.

FLOOD PROTECTION

Thanks to coral reefs, we can save up to **$272 billion** on global flood protection, without coral reefs, annual flood damage could double.

HEALTH

We are **300 times more likely** to find new drugs in the ocean than on land.

TOURISM VALUE

A potential **$36 billion** global value towards tourism.

MARINE LIFE

25% of all marine life live around coral reefs, despite corals only covering 1% of the Earth's surface.

FOOD PRODUCTION

Well managed reefs **provide food for 1.2 billion** people globally.

Source: The Nature Conservancy

Carysfort Reef in 1974

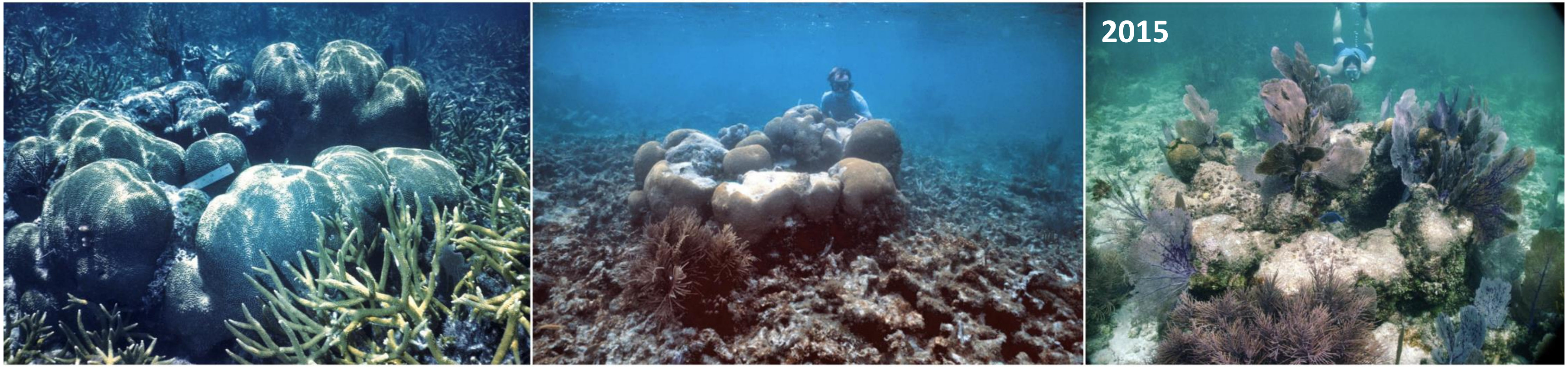
Reef Renewal USA

Caribbean reefs have lost 48% of hard coral since 1980, study finds

1971

1988

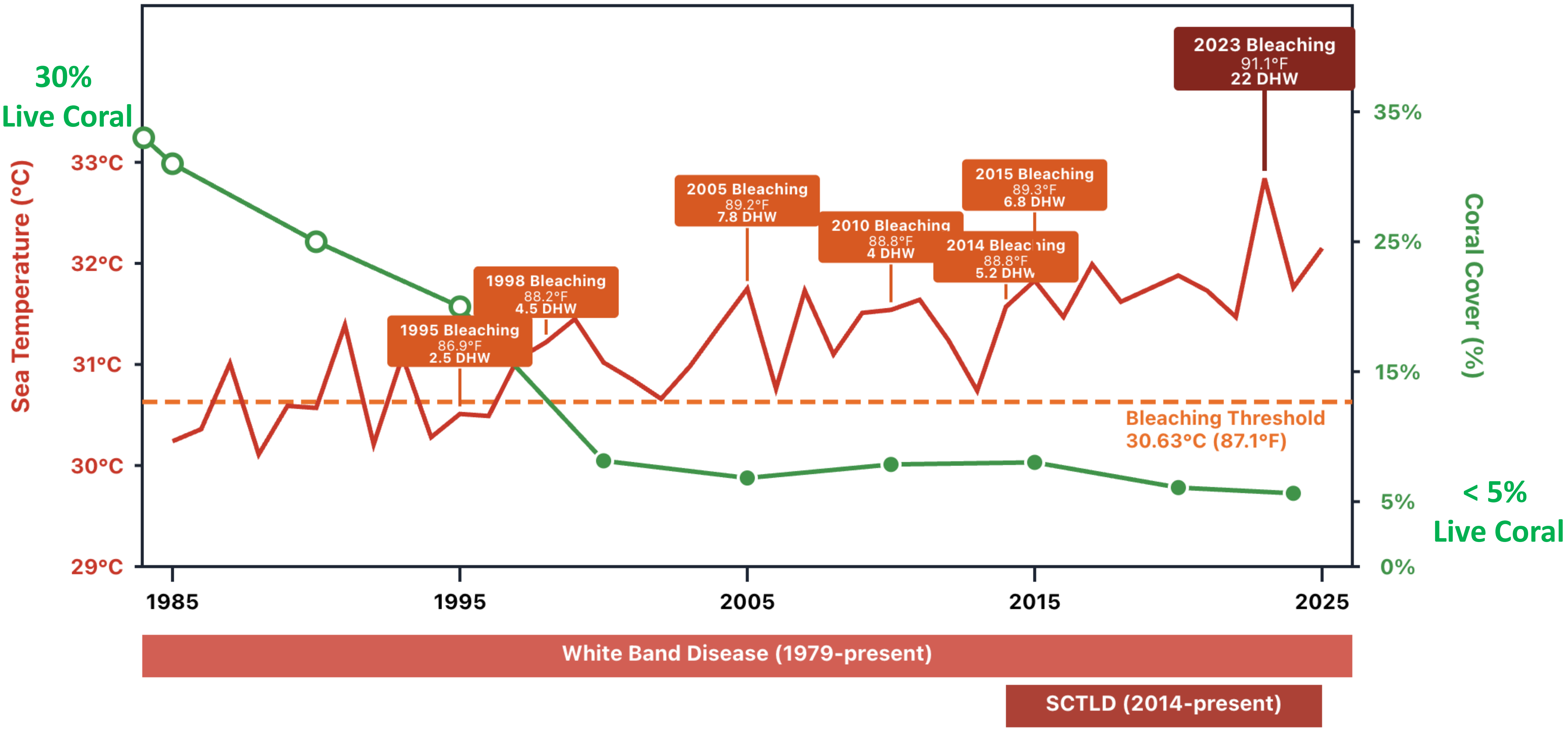
Grecian Rocks decline in the Florida Keys over the years: 1971 (left) [illegible]), and 1998 (right). (Sources: Eugene A. Shinn and Ilsa B. Kuffner)



Carysfort Reef decline in the Florida Keys over the years: 1971 (left), 1988 (center), and 2015 (right). (Sources: Eugene A. Shinn and Ilsa B. Kuffner)

Decline of Caribbean and Florida's Reefs

Key Events: 1) White Band Disease, 2) SCTLD, 3) Repeated Mass Bleaching

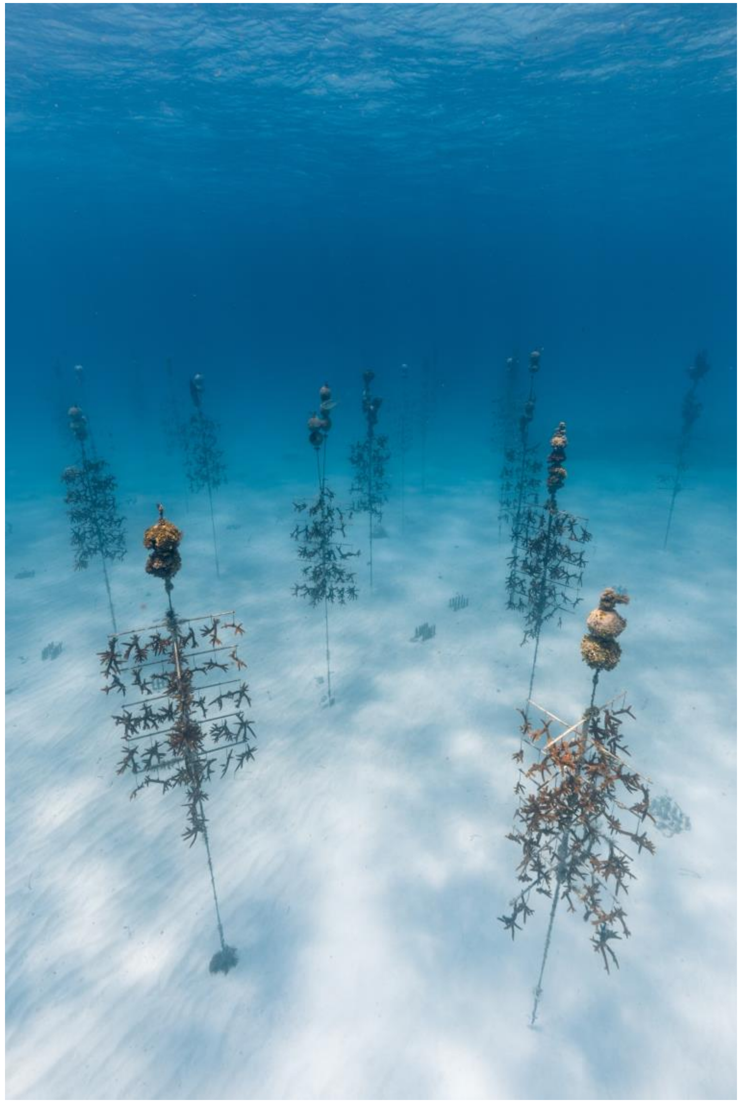


White Band Disease Outbreaks Start in 1979
Killed 95% of the Now Endangered Staghorn and Elkhorn Corals

Highly Transmissible | Bacterial Pathogen |Treated with Antibiotics

15+% Staghorn Corals Resistant to Infection

White Band Taught Us How to Restore Reefs at Scale



Stony Coral Tissue Loss Disease Emerges in Florida in 2014
Kills up to 69-100% of 25+ Key Reef-Building Corals

Transmissible, Bacterial, Treat with Antibiotics, Pathogen Still Unknown

2014	**Florida, USA**
2015	**Florida Keys, USA**
2017	**Jamaica**
2018	**Mexican Caribbean**
2019	**US Virgin Islands** **Turks & Caicos** **Dominican Republic** **Belize** **St. Eustatius**
2020	**Honduras**
2023	**Near Caribbean-wide** Reported in up to 33 countries/territories

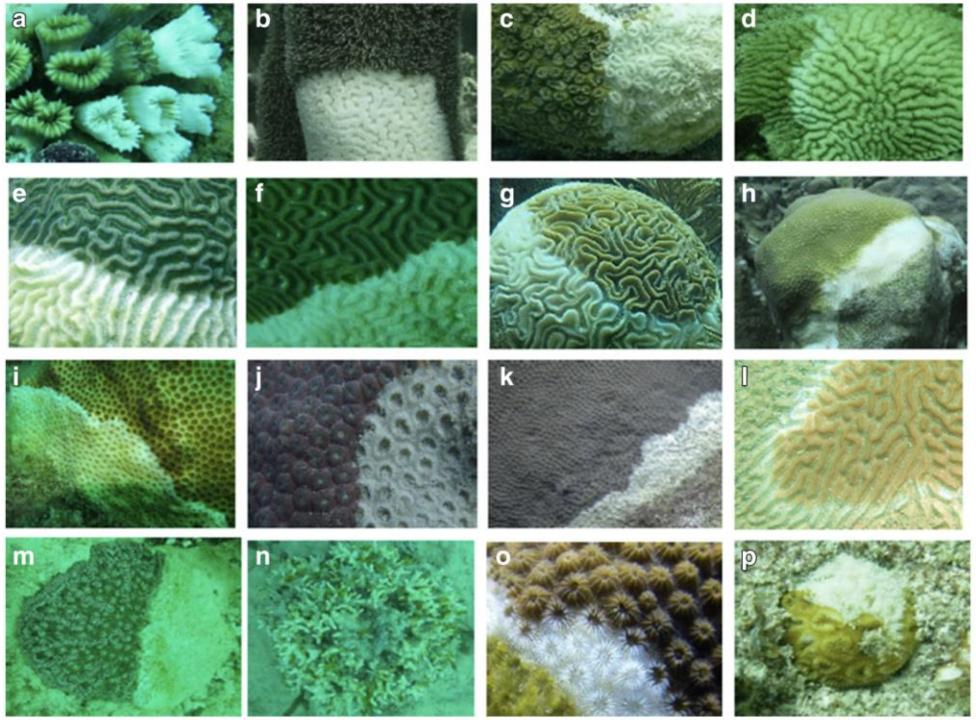


Fig. 5 Photographs of 16 coral species definitively identified with the recent WPD epizootic off Southeast Florida showing active disease signs on each species. Species are listed in decreasing order of prevalence/mortality where **a** was most heavily impacted and **o** was the least impacted. Species include **a** *Eusmilia strigosa*, **g** *Diploria labyrinthiformis*, **h** *Orbicella annularis*, **i** *Solenastrea bournoni*, **j** *Montastraea cavernosa*, **k** *Orbicella faveolata*, **l** *Pseudodiploria clivosa*, **m** *Mycetophyllia alciae*, **n** *Oculina diffusa*, **o** *Orbicella franksi*, and **p** *Favia fragum*. Photographs taken by WFP. We use species names following conven-

2023 Heatwave: A Catastrophic Bleaching Event

CORAL REEFS

Heat-driven functional extinction of Caribbean *Acropora* corals from Florida's Coral Reef

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In 2023, a record-setting marine heat wave triggered the ninth mass coral bleaching event on Florida's Coral Reef (FCR). We examined spatial patterns of heat exposure along the ~560-kilometer length of FCR and the mortality of two ecologically important, critically endangered reef-building corals. Sea surface temperatures were ≥31°C for an average of 40.7 days, leading to heat exposures 2.2- to fourfold higher than all prior years on record. In the Florida Keys and Dry Tortugas, 97.8 to 100% of the *Acropora palmata* and *Acropora cervicornis* colonies died. Mortality was lower offshore southeast Florida (37.9%), reflecting cooler temperatures in this region. Since the late 1970s, multiple stressors had already reduced the ecological relevance of *Acropora* in Florida, but the 2023 heat wave marks their functional extinction from FCR.

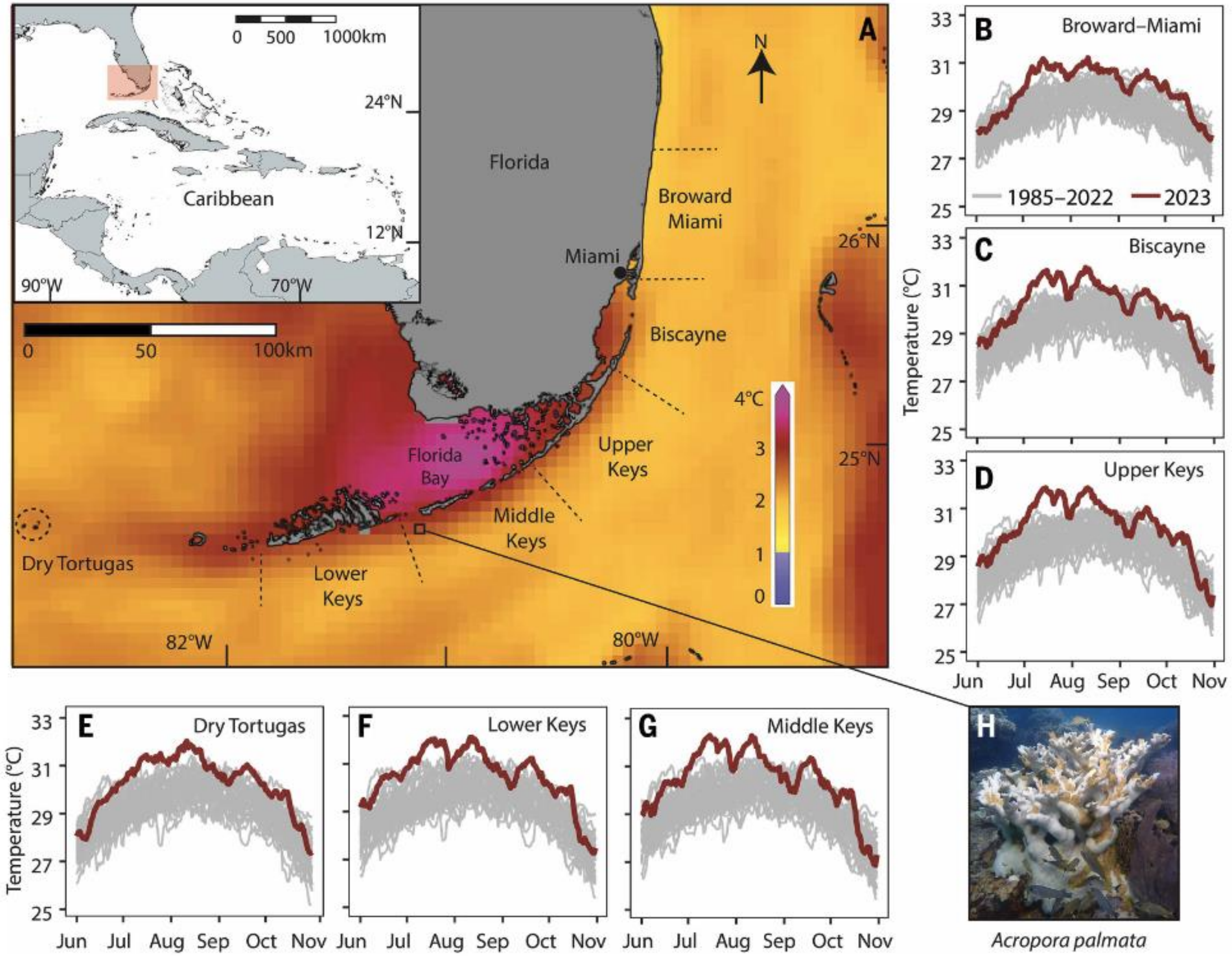


Fig. 1. Sea surface temperature patterns on Florida's Coral Reef in 2023. (**A**) Maximum hotspots (°C) in 2023. (**B** to **G**) Daily average sea surface temperature from 1985 to 2022 (gray) and 2023 (red) for six subregions of Florida's Coral Reef. (**H**) Colony of *Acropora palmata* showing rapid mortality and tissue sloughing at Sombrero Reef, 20 July 2023. Yellow-brown patches on colony are locations of tissue loss. [Photo credit, (H): Coral Restoration Foundation]

97-100% of the 52,365 wild and restored *Acropora* corals lost in the Keys and Dry Tortugas!!

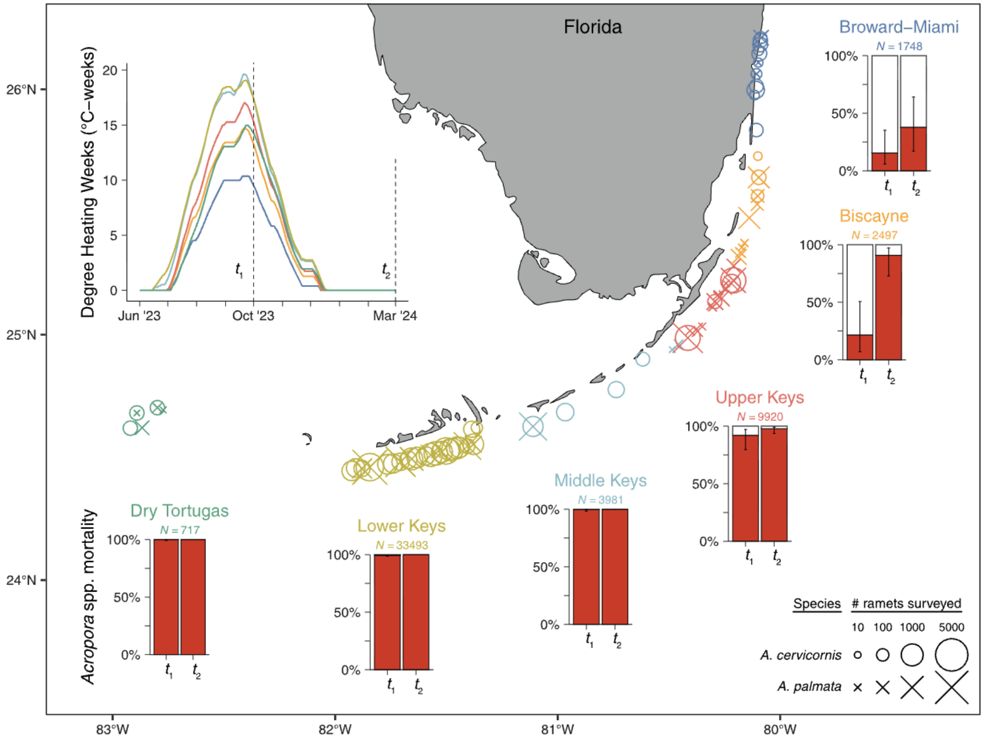


Fig. 3. Overall mortality of *Acropora* spp. on Florida's Coral Reef. Points represent site clusters where *A. palmata* (X's) and *A. cervicornis* (circles) were surveyed, with point size scaled by the number of distinct ramets observed ("ramet" refers to an individual, physically separate coral colony). Bar plots show the percent mortality (±95% confidence interval) of all *Acropora* (which did not differ between species) on 1 October 2023 (t_1) and 1 March 2024 (t_2), with the conservative estimates of the total number of ramets observed in each subregion given above the bar plots. (Inset) Mean degree heating week trajectory colored by subregion, with dashed vertical lines at the two time points of interest.

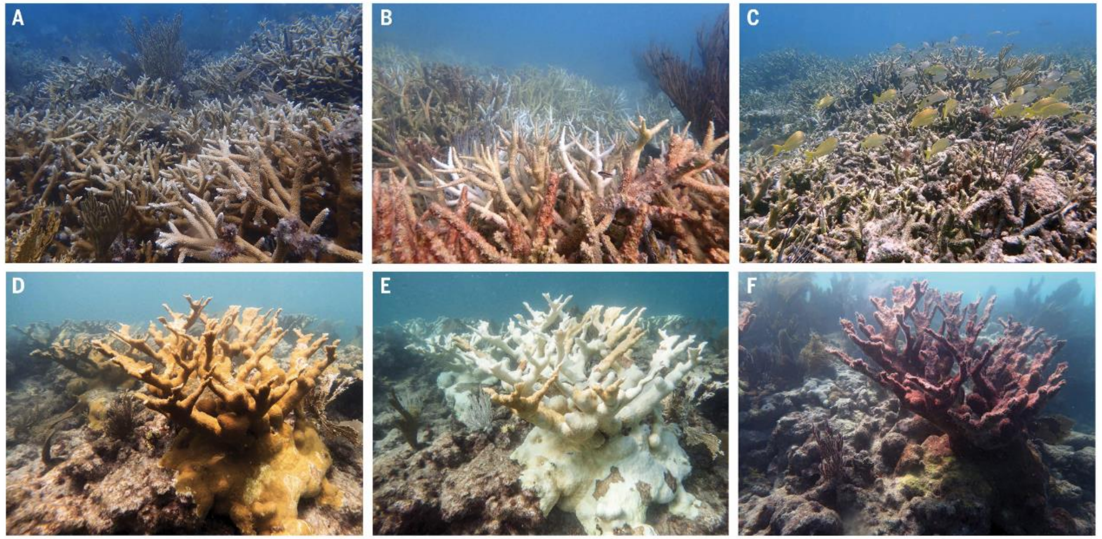


Fig. 2. Bleaching and mortality of *Acropora* on Florida's Coral Reef. Wild *Acropora cervicornis* thicket in Dry Tortugas: (**A**) non-bleached, 23 June 2023; (**B**) mostly dead, 11 September 2023; and (**C**) dead, 9 September 2023. Wild *A. palmata* colonies in Key Largo, Upper Florida Keys: (**D**) pale, 21 July 2023; (**E**) bleached, 18 August 2023; and (**F**) dead, 27 November 2023. [Photo credits: (A to C), Shedd Aquarium/S. Matsuda; (D and E), O. Williamson; (F) D. E. Williams]

The Hunt for Super Corals

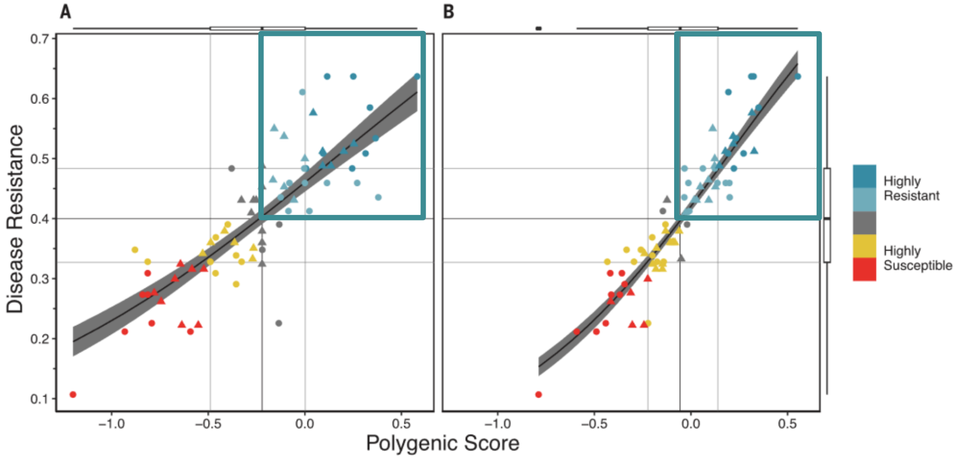
GENOMICS

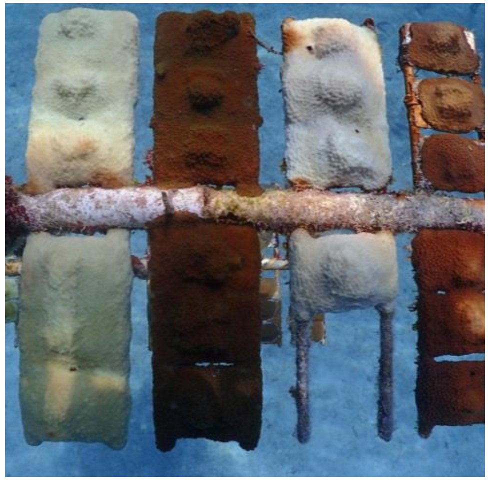
Genomic signatures of disease resistance in endangered staghorn corals

Steven V. Vollmer†*, Jason D. Selwyn†, Brecia A. Despard, Charles L. Roesel

White band disease (WBD) has caused unprecedented declines in the Caribbean *Acropora* corals, which are now listed as critically endangered species. Highly disease-resistant *Acropora cervicornis* genotypes exist, but the genetic underpinnings of disease resistance are not understood. Using transmission experiments, a newly assembled genome, and whole-genome resequencing of 76 *A. cervicornis* genotypes from Florida and Panama, we identified 10 genomic regions and 73 single-nucleotide polymorphisms that are associated with disease resistance and that include functional protein-coding changes in four genes involved in coral immunity and pathogen detection. Polygenic scores calculated from 10 genomic loci indicate that genetic screens can detect disease resistance in wild and nursery stocks of *A. cervicornis* across the Caribbean.

10 Genes Predict Disease Resistance
15-20% Staghorn Highly Resistant!



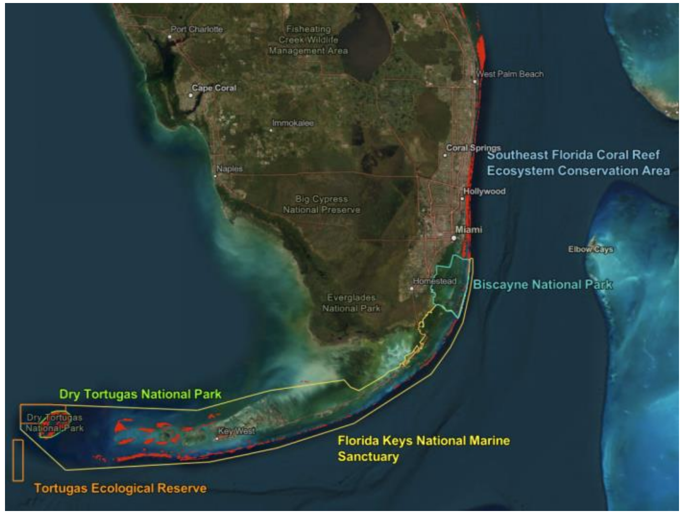


Investing in the Future of Our Reefs

US Forests $50B economy | $8.9B invested | 17.8%

FL Reefs $8.6B economy | $40M invested | 0.47%

	U.S. Forests (193M acres)	Florida Reefs (2.2M acres)	Investment Match
Economic Value	~$50B/yr	$8.5B/yr	—
Value Per Acre	~$259/acre	~$3,864/acre	—
Total Spending	$8.9B/yr	$20-40M/yr	—
Spending Per Acre	$46/acre	$9-18/acre	$101M/yr
Spending Per $1k Value	$178	$2.35-4.70	$1.5B/yr



Can corals adapt to future climate scenarios?

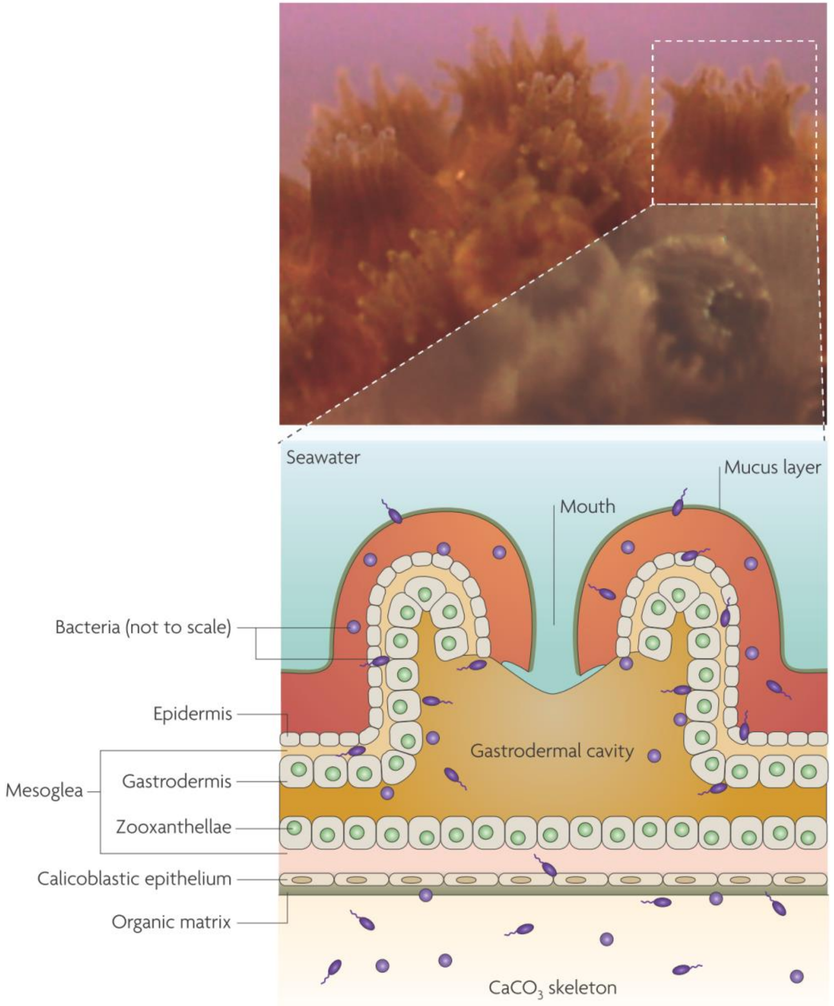
- Adapt (or acclimate) naturally or artificially
- Holobiont = coral host, algal symbionts, and bacteria

Banking Genotypes
In situ and land-based nurseries

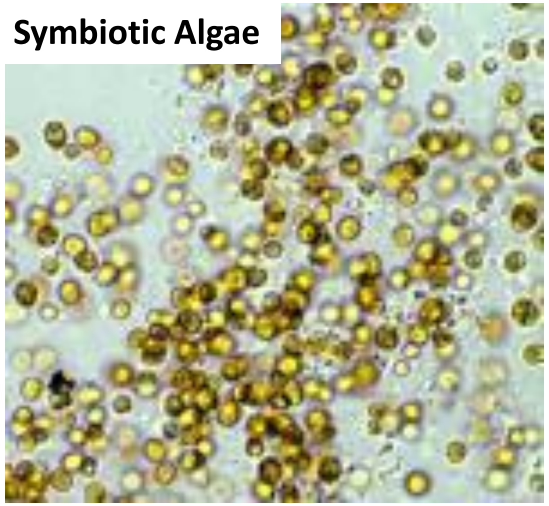
Selective Breeding
Cryopreservation
Assisted Gene Flow
GMOs

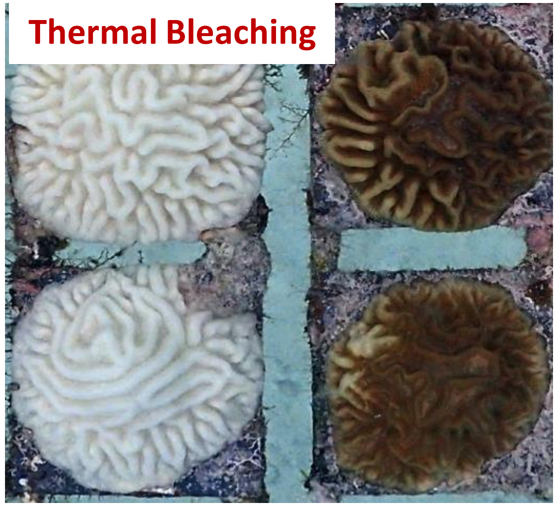
Large-Scale Outplanting

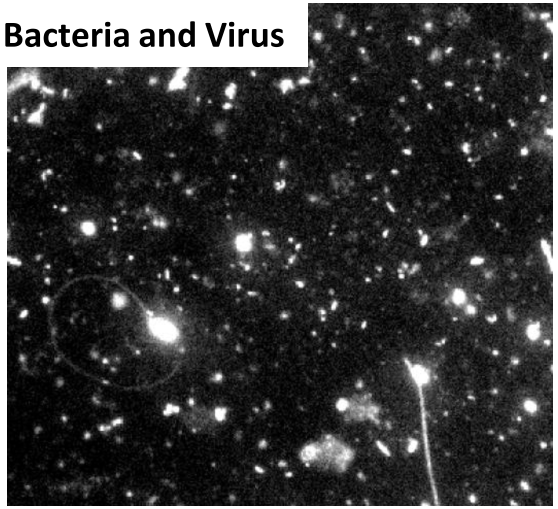
Stress breaks the bonds between the coral animal, its algae and microbes



Rosenberg et al. 2007ab







Our Efforts Must Match the Scale of the Problem

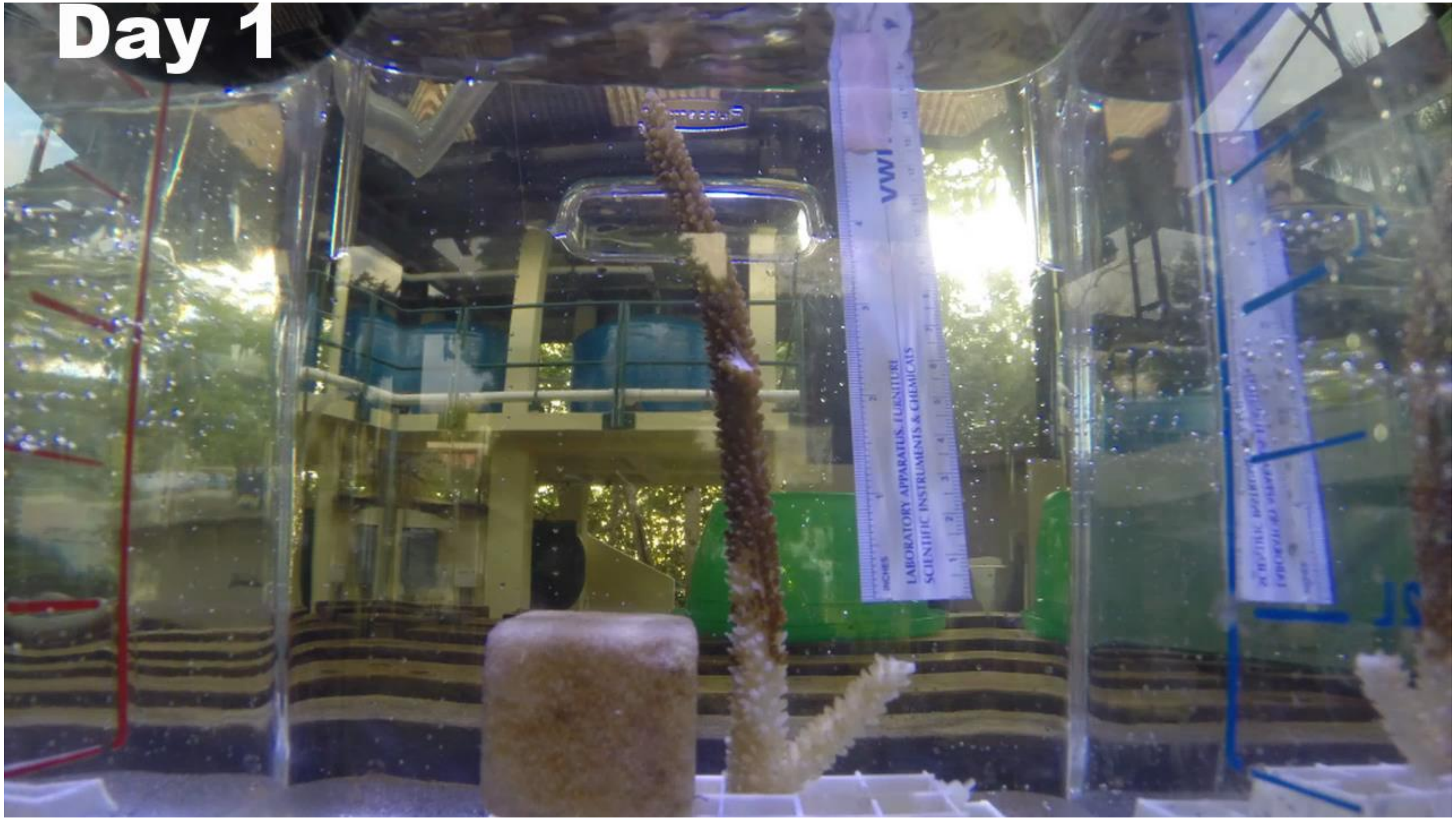
Restoration + Science + Investment







Rapid Progression of White Band on Staghorn Coral



What is the genetic basis of coral disease resistance?

RESEARCH

GENOMICS

Genomic signatures of disease resistance in endangered staghorn corals

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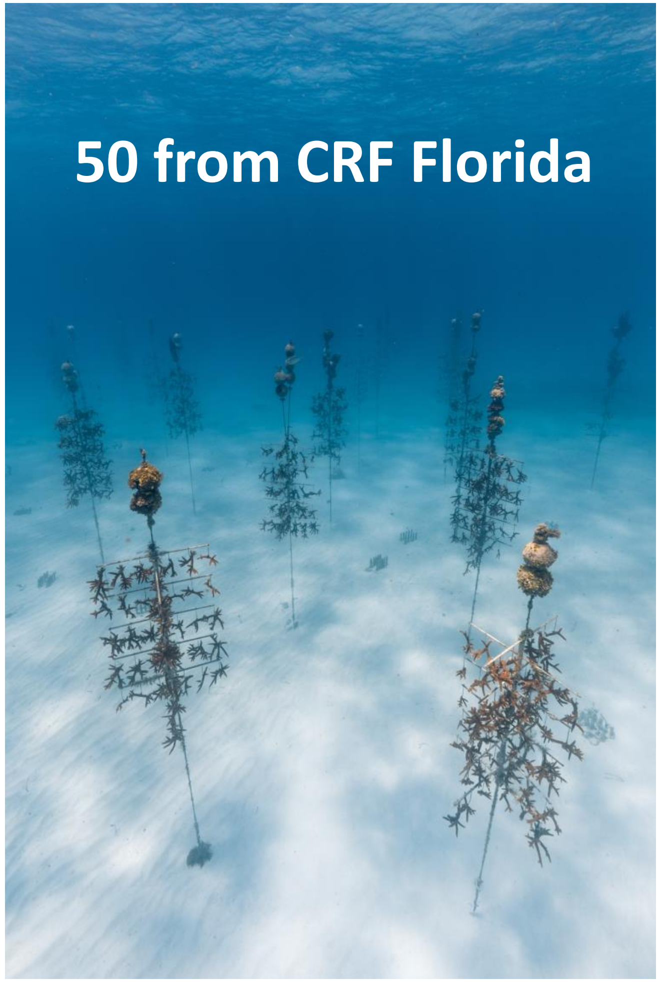
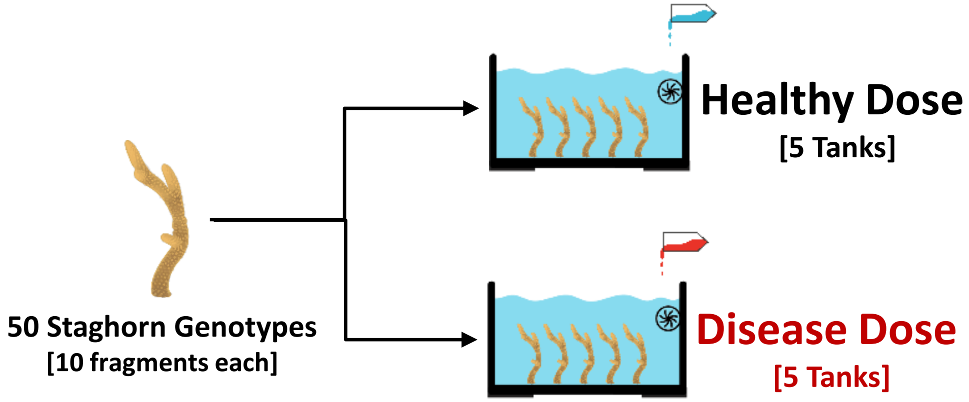
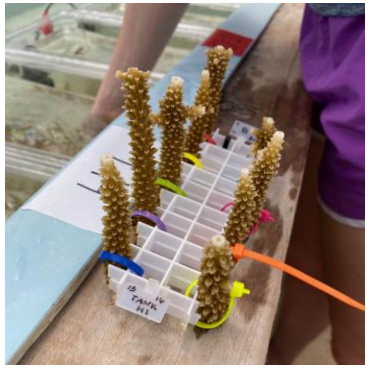


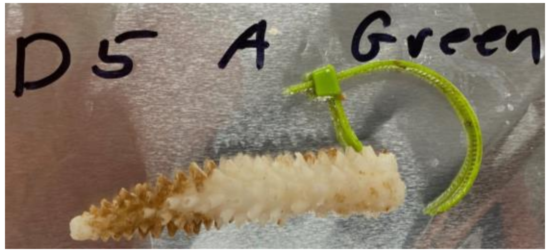
Step 1: Assay disease resistance w/ transmission experiments

Two Populations | Locations: Florida vs Panama



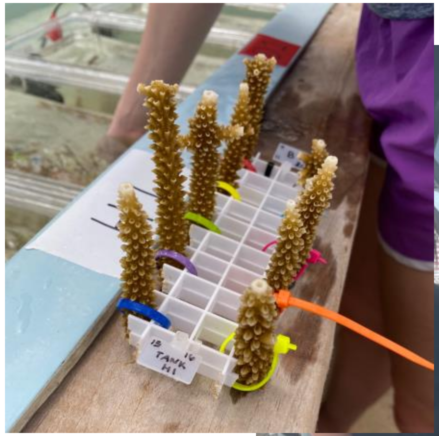
Metrics/Outcomes
- Census Disease 2x a day for 7 days
- Sample Diseased Fragments
- Disease Resistance = % Fragments Infected





How to conduct a transmission assay

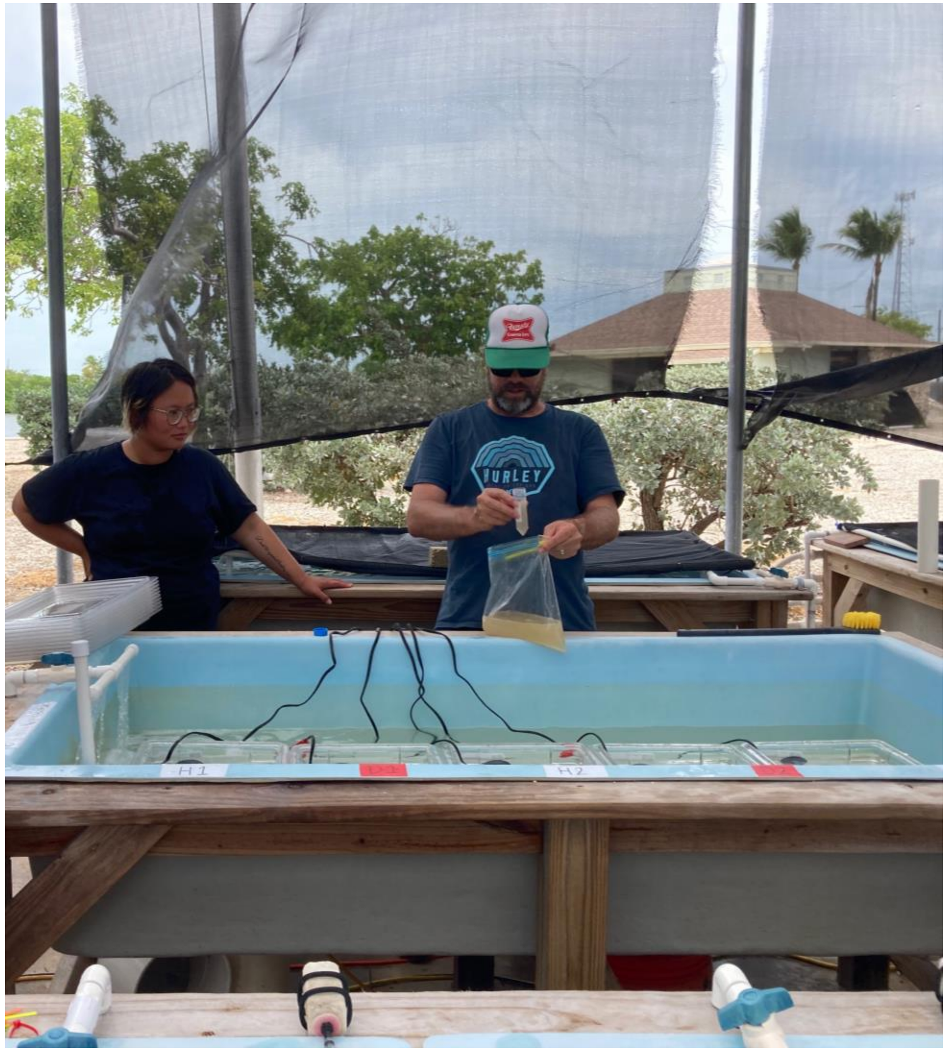
Step 1 – Rack, water-pik to lesion, place in re-circulating tanks



Replicate!

500 fragments from 50 genotypes in 10 tanks

Step 2 – Dose disease vs healthy slurries



Wait for the magic to happen!

Record, sample RNA|DNA to profile immune response and ID bacterial pathogens

Disease resistance predicted from 10 SNPs!

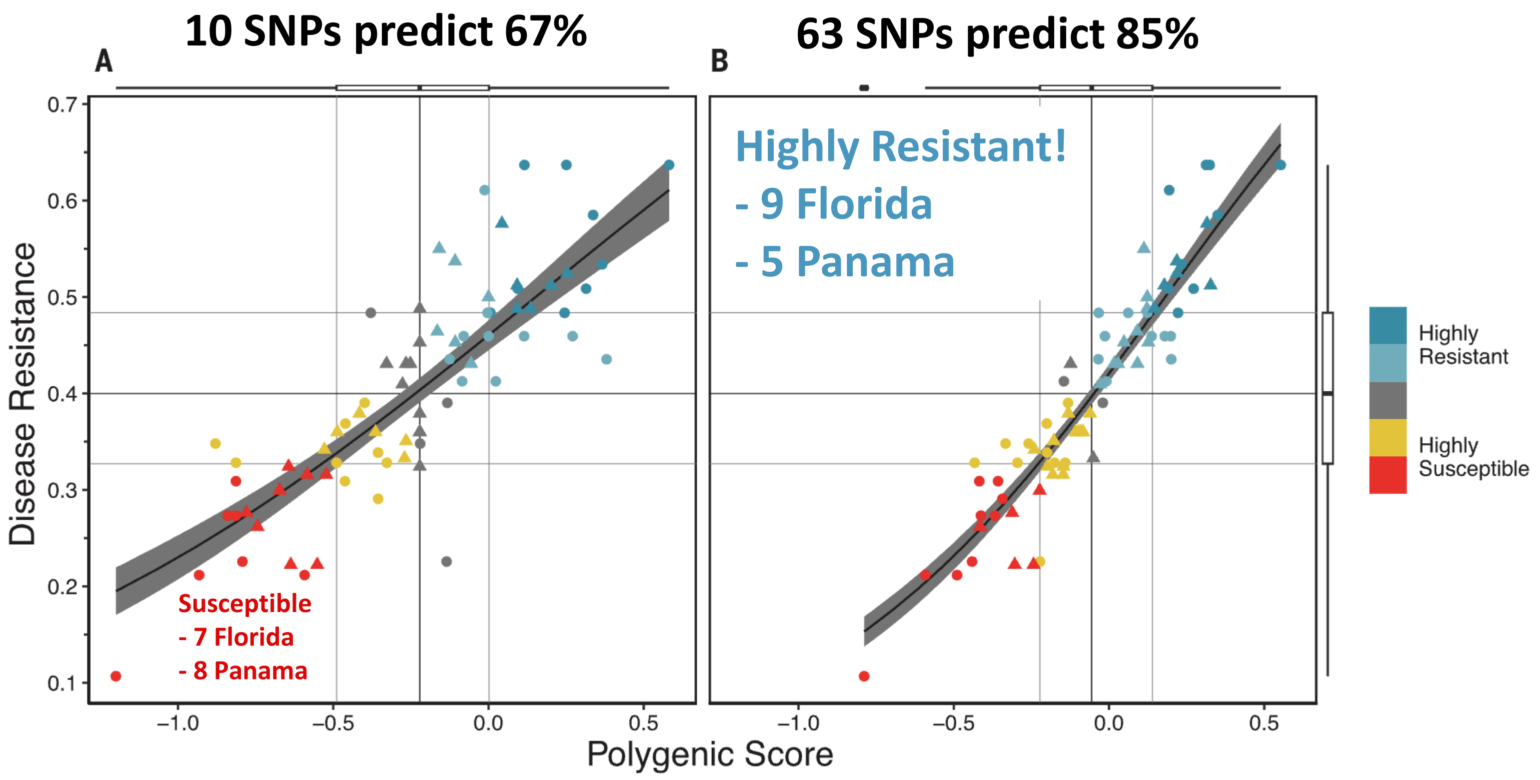


Fig. 4. Polygenic scores that predict disease resistance. (**A**) Polygenic scores for the top ten SNPs and genomic regions explain 66.9 ± 5.4% of disease resistance ($p < 0.0001$). (**B**) Polygenic scores based on the most important 63 SNPs and genomic regions ($p < 0.0001$) explain 85.3 ± 2.3% of the variation in disease resistance, showing that the inclusion of 53 additional loci improved disease-resistance predictions based on polygenic scores. Individuals represented by blue symbols have above-average polygenic scores and disease resistance; the dark blue points indicate individuals that are highly disease resistant, with polygenic scores and disease-resistance values in the top quartiles. Individuals represented by yellow and red symbols have lower-than-average polygenic scores and disease resistance, with red symbols indicating highly susceptible individuals. Coral genotypes from Florida are labeled with a circle and those from Panama are labeled with a triangle. The gray shaded area indicates ±1 standard error.

Disease resistance is genetic, heritable, & linked to immunity!

1. 10 genetic loci can ID disease resistant corals,
2. Simple genetic screens can improve disease resistance in nursery and wild stocks of these critically endangered corals by selecting the most highly resistant corals.

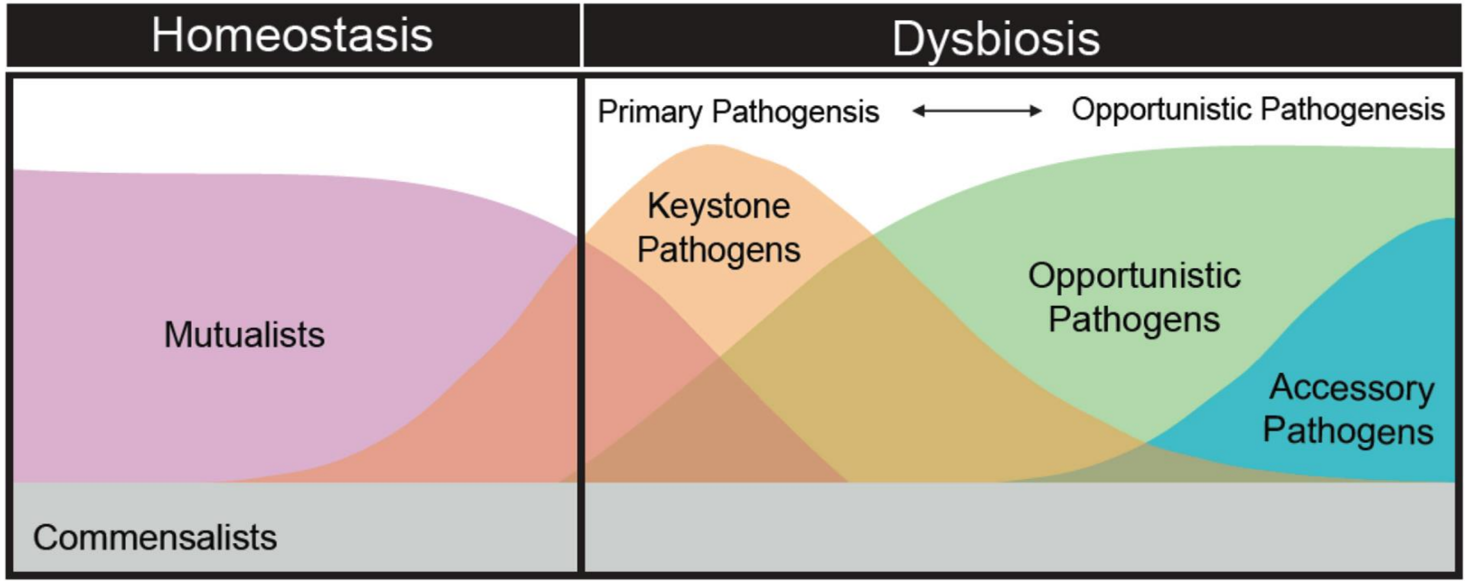
Are their fitness trade-offs?

What about thermal tolerance?

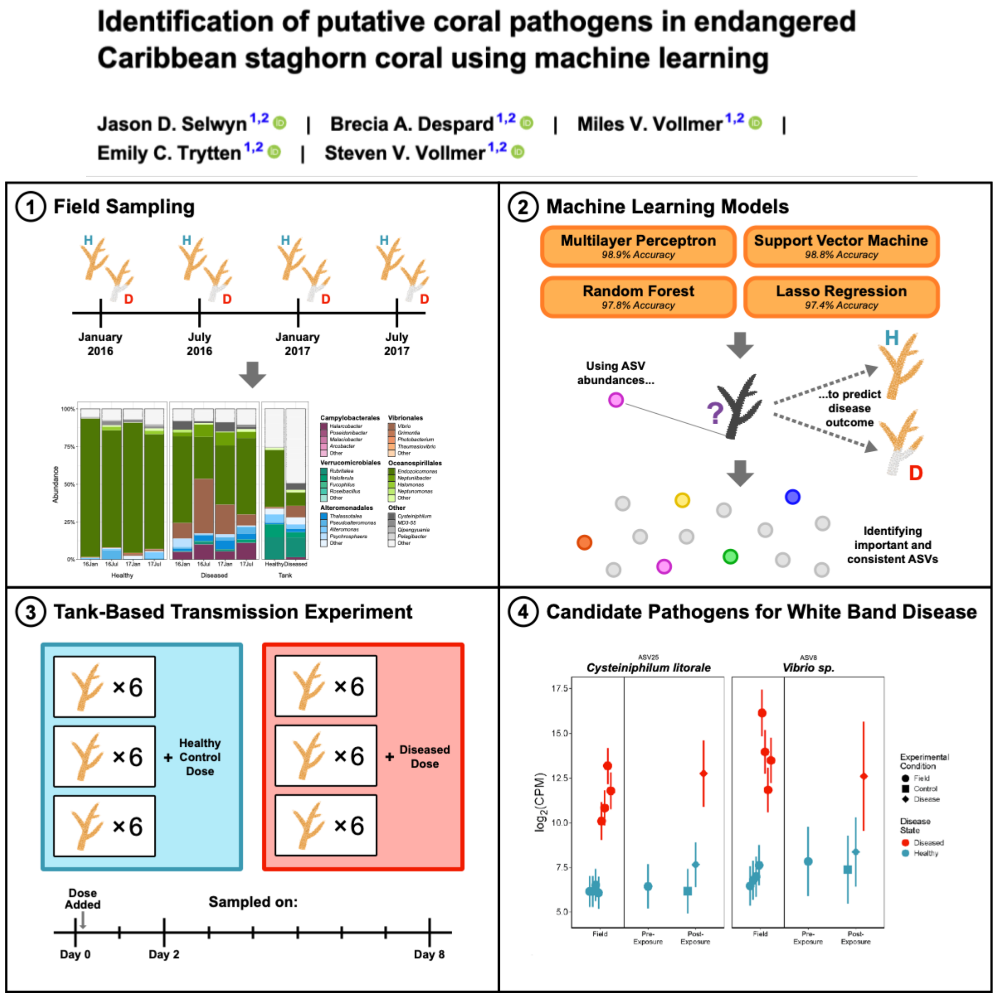
Who is the WBD pathogen?

- **Bacterial, but Henle-Koch postulate not fulfilled.**
- **Early 16S culture + transmission data suggest *Vibrio shiloi (?)***
- **16S rRNA amplicon sequencing IDs 100s of disease associations including:** Vibrionaceae, Flavobacteriaceae, Campylobacteraceae, Francisellaceae, Pasteurellaceae, Sphingomonadaceae, Rhodobacteraceae, Cryomophaceae.

How do we ID pathogens among 100s of disease associations?

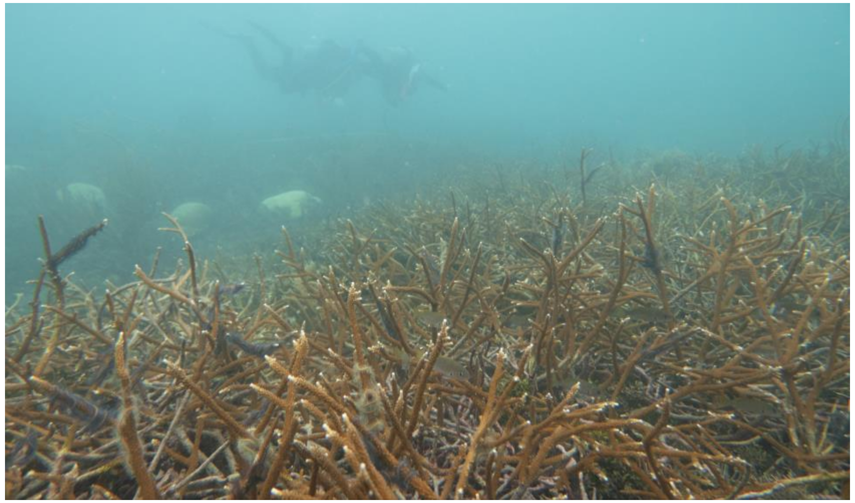


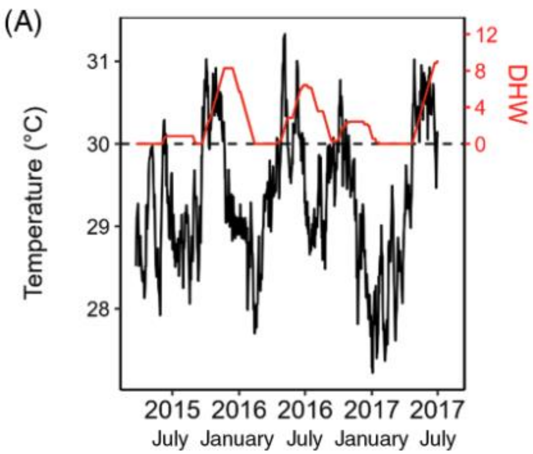
Deep Sampling, AI/ML predictions and tank validation

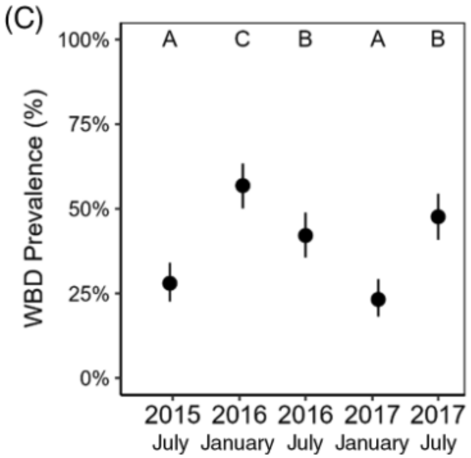


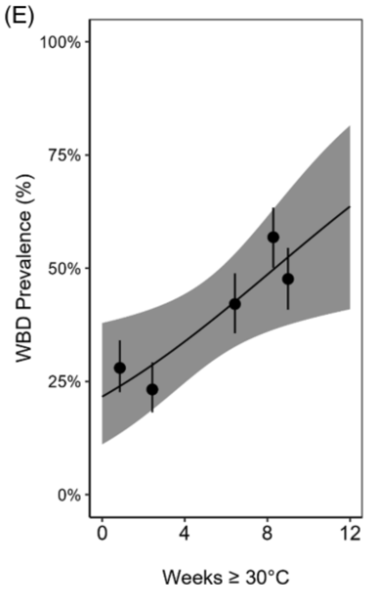
1. 16S rRNA sequencing + 143 Disease v. 269 Healthy Corals [4 times x 4 reefs]
2. Machine Learning Models + SHAP based feature ranks to ID pathogens
3. Validate top pathogens in tank transmission experiment

Disease prevalence correlated to weeks > 30°C

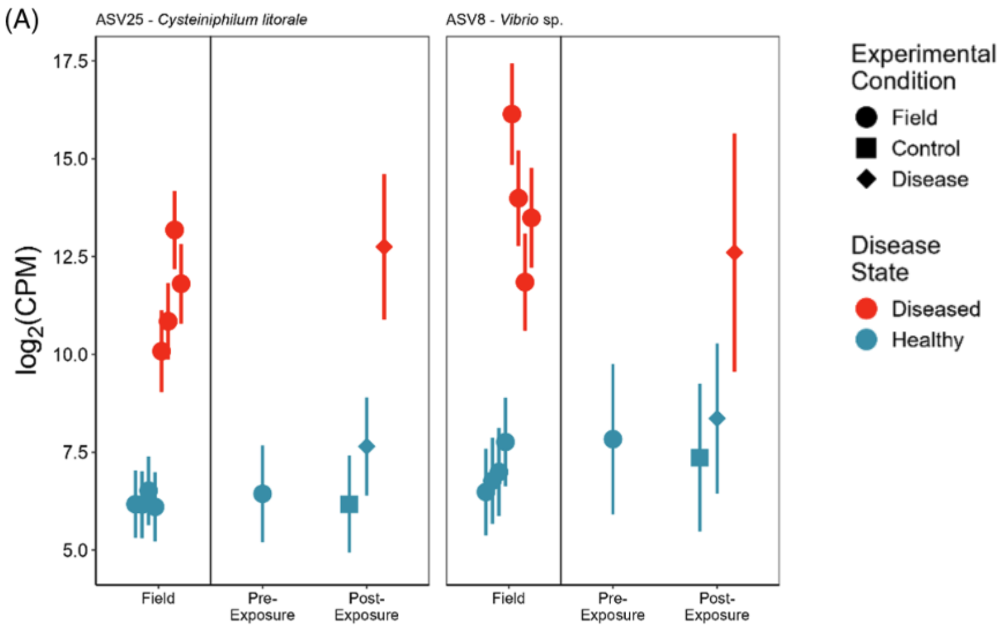








Two top putative WBD pathogens



Primary Pathogen = ASV25 *Cysteiniphilum* spp. (formerly Fransicella) new genus with pathogenic potential.

Secondary Opportunist = ASV8 Vibrio spp. = well known opportunistic coral pathogens and present at much higher prevalence on healthy corals