NOAA CORAL REEF CONSERVATION PROGRAM

NOAA Coral Reef Conservation Program
Ecosystem Science Evaluation

Physiological Response to Stressors & Restoration Genomics

Topical Area
Organism Responses and Biodiversity Metrics

Presenter
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NOS NCCOS

Team
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Overview

Ecosystem

Community

Species

Population

Individual

Organ

Tissue

Cell

Early and direct effects of stressors

Overview

Current Methods of Coral Reef Health Assessment

- ✓ Can document quality and quantities of stressors
- ✓ Can detect gross responses
  - Dead vs alive
  - Presence vs absent
  - Rare vs common
- ➢ CANNOT directly link a stressor to its effect on the organism or health of their ecosystem
- ➢ CANNOT provide prognosis
- ➢ CANNOT provide remedies

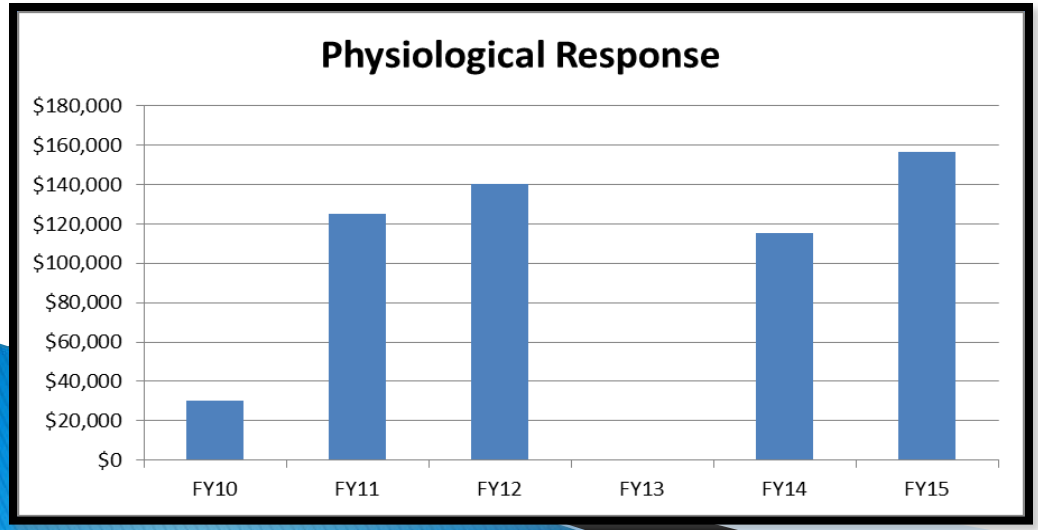
Objectives

- **Effects of single stressors on larvae and adult Caribbean ESA coral spp.**
  - Water quality
  - Ammonia
- **Effects of combined stressors on larvae of Caribbean ESA coral spp.**
  - Temperature & Eutrophication (nitrate)
  - Temperature & pH (Ocean Acidification)
- **Effect of genetics on coral restoration**
  - Effect of depth

NOAA CORAL REEF CONSERVATION PROGRAM

Funding support 2010-2015

Project Title	Project Manager	LO	Funding Year(s)	Total Years	Total Funding
Climate Change Impacts: Potential for Recovery/Resilience of Corals and Algal Interference	Miller	NMFS	2011–2012	2	$265,000
Synergistic effects of eutrophication and elevated SST in the early life stages of two Caribbean reef corals	Hendee	AOML	2014-2015	2	$76,700
Use of Restoration Genomics in Recovering ESA Species: *Orbicella faveolata*	Woodley	NOS	2015	1	$101,850
Determination of larval survivorship and competency period for ESA broadcasting corals	Miller	NMFS	2015	1	$16,000



Total $459,550

Funding Support Needed

Amount needed to conduct this work

$300-400K/yr per lab

Ex. Contract labor costs $70K-110K/person

Other leveraged resources

- National Research Council (2013-2014)
- Ford Foundation (2013-2015)
- Mote Marine Lab (2013-2015)
- NOS NCCOS base funds for FTE salaries
- NOS NCCOS Discretionary funds for related project
- DOD – SERDP – stressor-related project (2011-2013)
- Canon Foundation to Penn State – 5 reference genome sequencing
- Canon Foundation to Penn State – postdoc salary (2015-2016)
- Penn State - genomic database
- NSF to Penn State – initial transplant experiments

Information - Products - Tools

- Peer-reviewed publications
- Technical Memoranda
- Quick-look reports to managers
- Direct communication with Managers (local, state & federal)
- Oral presentations (scientific meetings, lectures)
- CoRIS database
- Archived genomic data & metadata
  - Dryad Digital Repository (datadryad.org) for SNP genetic markers
  - Five reference genomes of *Orbicella* spp. that serve as the basis for this and other genomic-enabled work

Drivers for this work

ESA Coral Recovery Action Plans

- Objective 1. **Population Viability**
  - Action 3. Conduct Strategic Research of Elkhorn and Staghorn Coral Biology
  - Action 6. Conduct Active Population Enhancement
- Objective 2. **Eliminate or sufficiently abate, global, regional and local threats**
  - Action 11: Research and develop mechanisms to enhance adaptation/acclimation of Elkhorn and Staghorn corals to increases in climate stress
  - Action 16: Study organismal response to nutrients and contaminants and implement appropriate remedies

Objectives

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  - **Temperature & Eutrophication (nitrate)**

- **Effect of genetics on coral restoration**

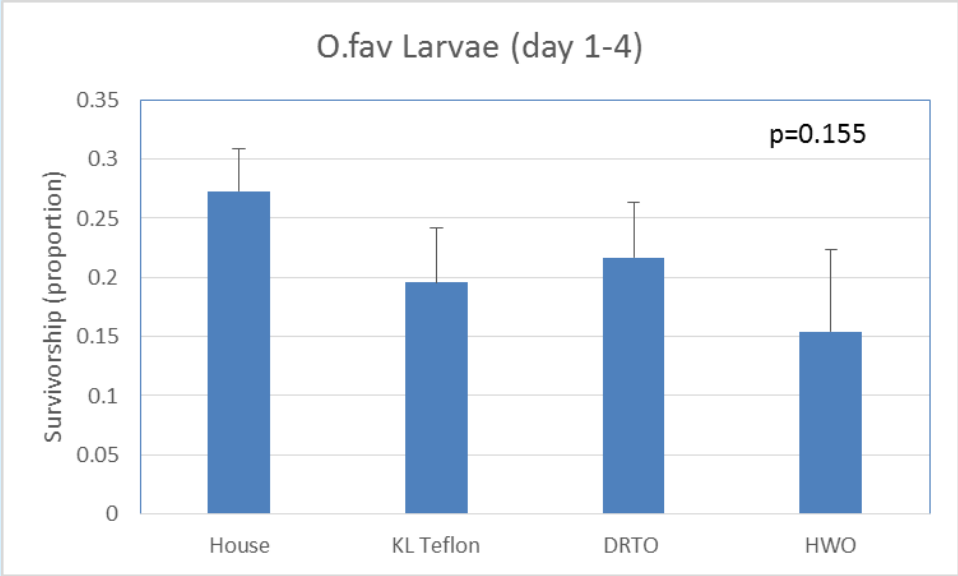
Water Quality

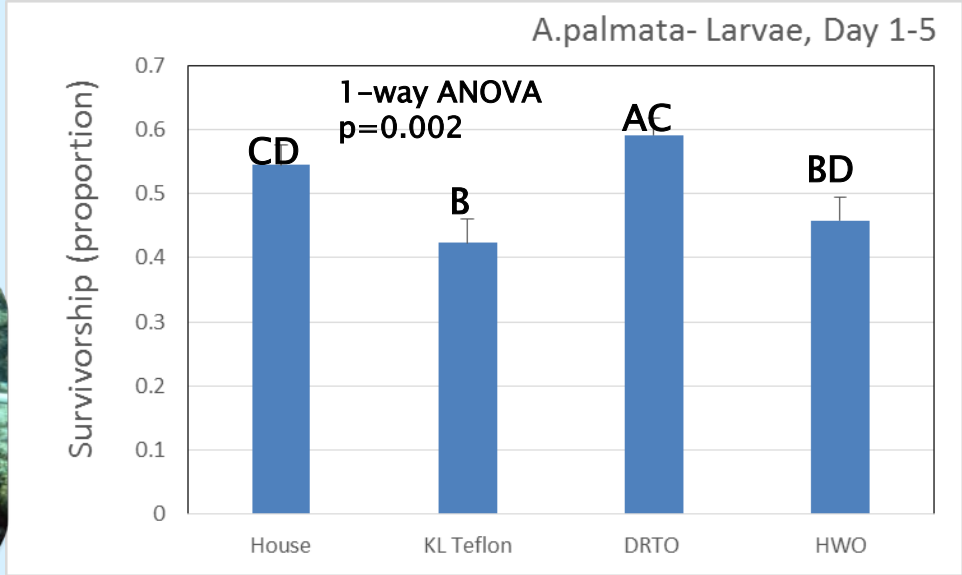
(qualitative)

Larval (swimming) Phase

(2014)

- Significant effect at swimming stage
- Key Largo reef water and Dry Tortugas performing best



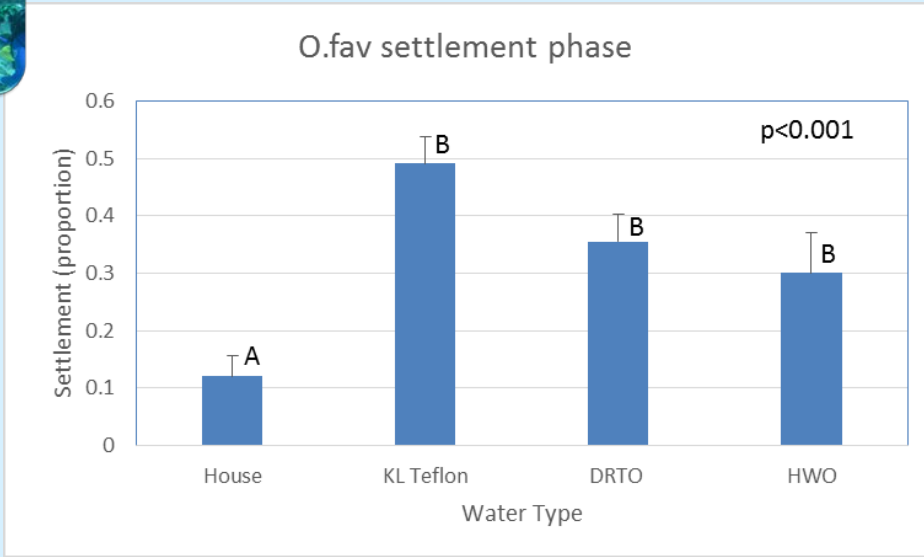


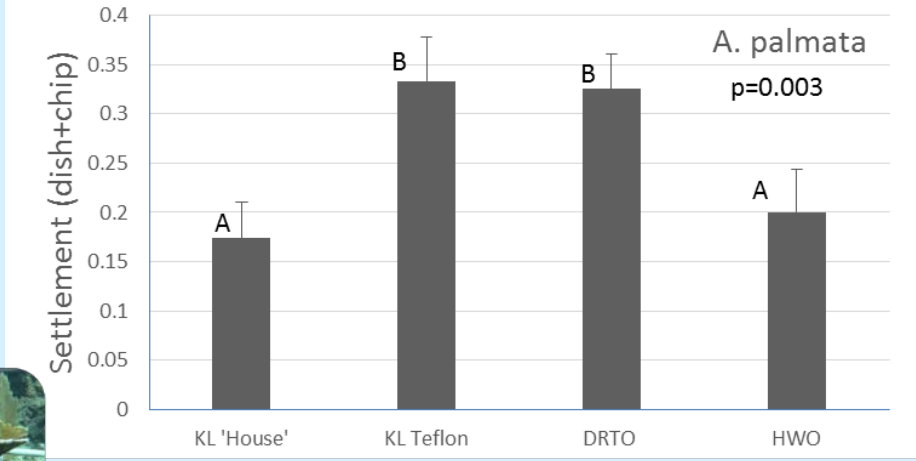
Miller et al.

Water Quality

Larval Settlement Phase (2014)

- Water type had significant effect on settlement success
- Local reef water stored in plastic showed significant inhibition of settlement (half to one-quarter) over the same water stored in Teflon; and similar to HWO water.



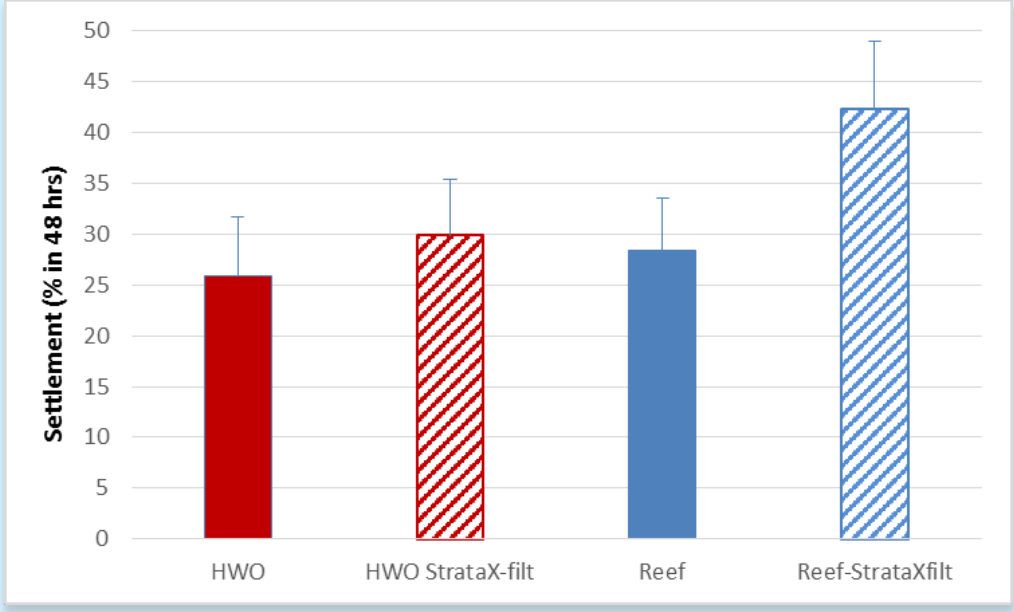


Miller et al.

Water Quality

Larval Settlement Phase (2015)

Orbicella faveolata



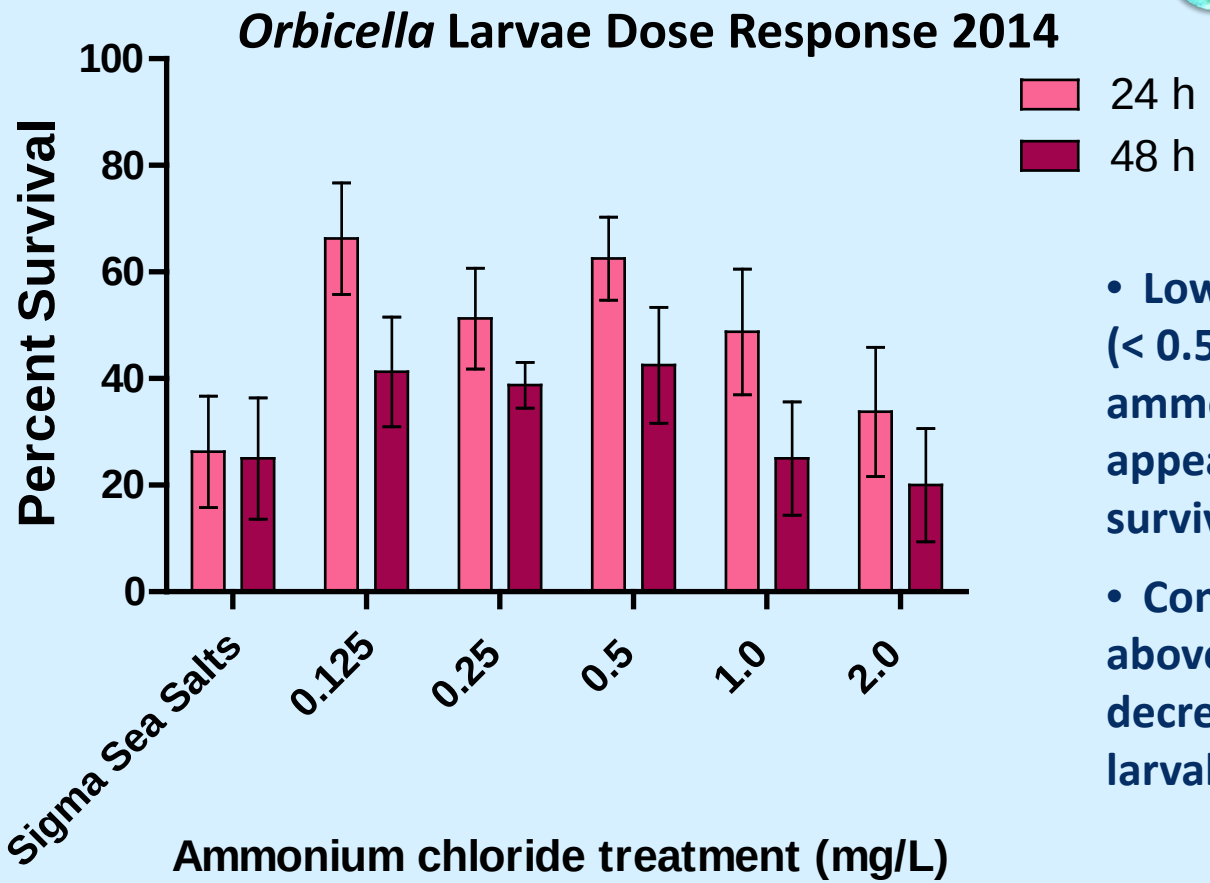
Significant and larger effect at settlement stage

- **Plastic-stored reef water performed worst with both species**
- **Chemical filtration (Strata X SPE column) of the local reef water significantly improved settlement (1-way ANOVA p=0.041)**
- **[redacted]on may improve fertilization and settlement**

Miller et al.

Nutrients

Effect of Ammonia on Larval Survival



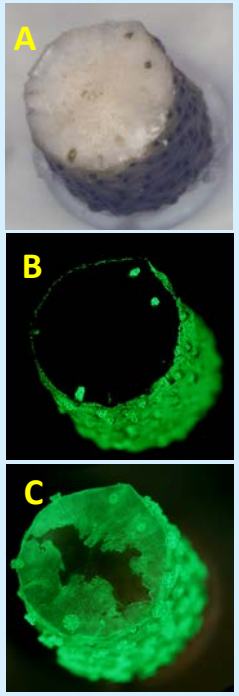
- **Low concentrations (< 0.5 mg/L) of ammonium chloride appeared to enhance survival**
- **Concentrations above 1.0 mg/L decreased *Orbicella* larval survival**

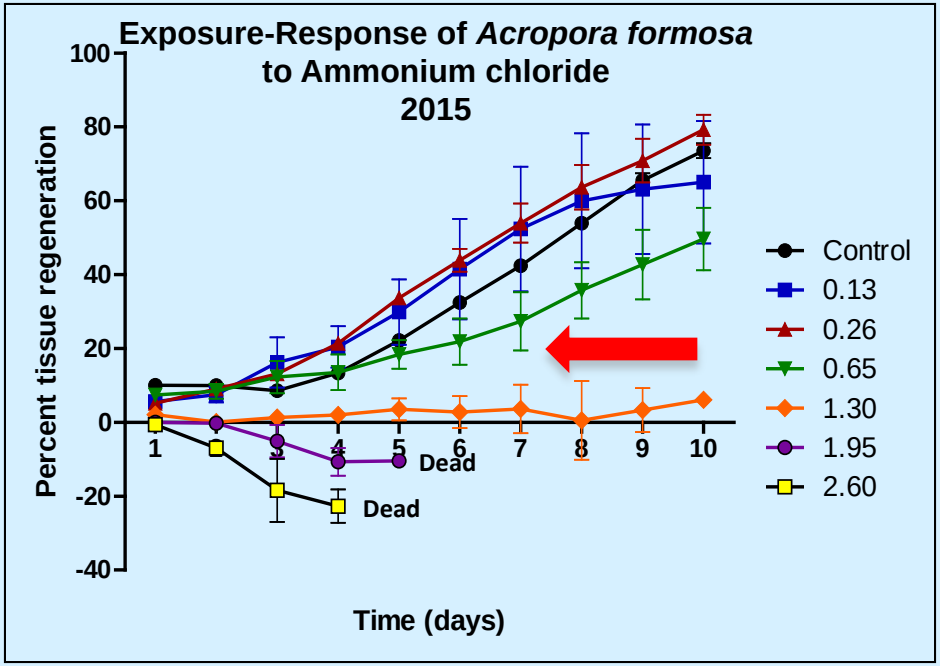
Woodley et al.

Nutrients

Effect of Ammonia on Wound Healing

Conversion factor
NH_4Cl = TAN (mg/L)
0.00 = 0.00
0.50 = 0.13
1.00 = 0.26
2.50 = 0.65
5.00 = 1.30
7.50 = 1.95
10.00 = 2.60





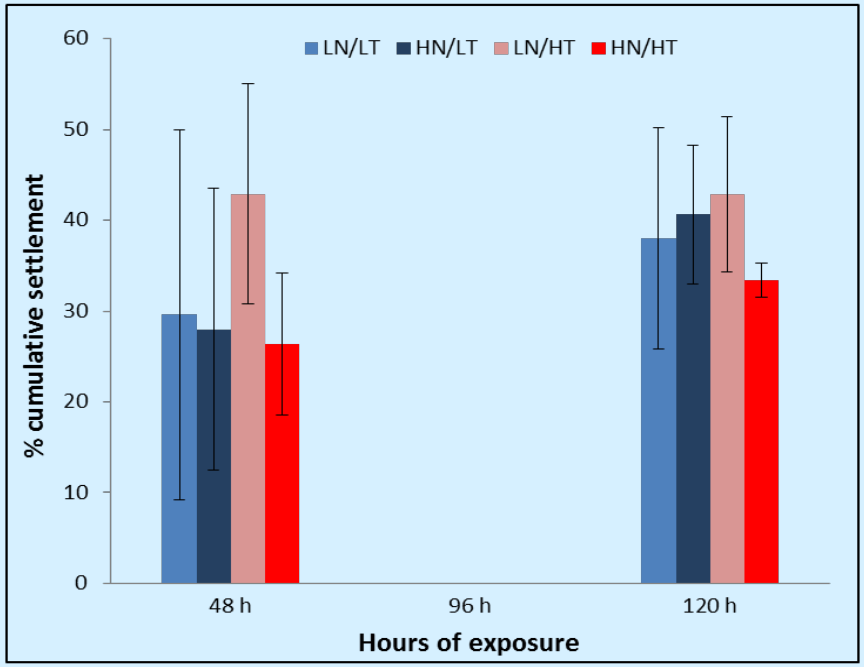
Threshold for tissue regeneration between 2.5 and 5 mg/L ammonium chloride (0.65-1.3 mg/L Total Ammonia-Nitrogen, TAN)

Woodley et al.

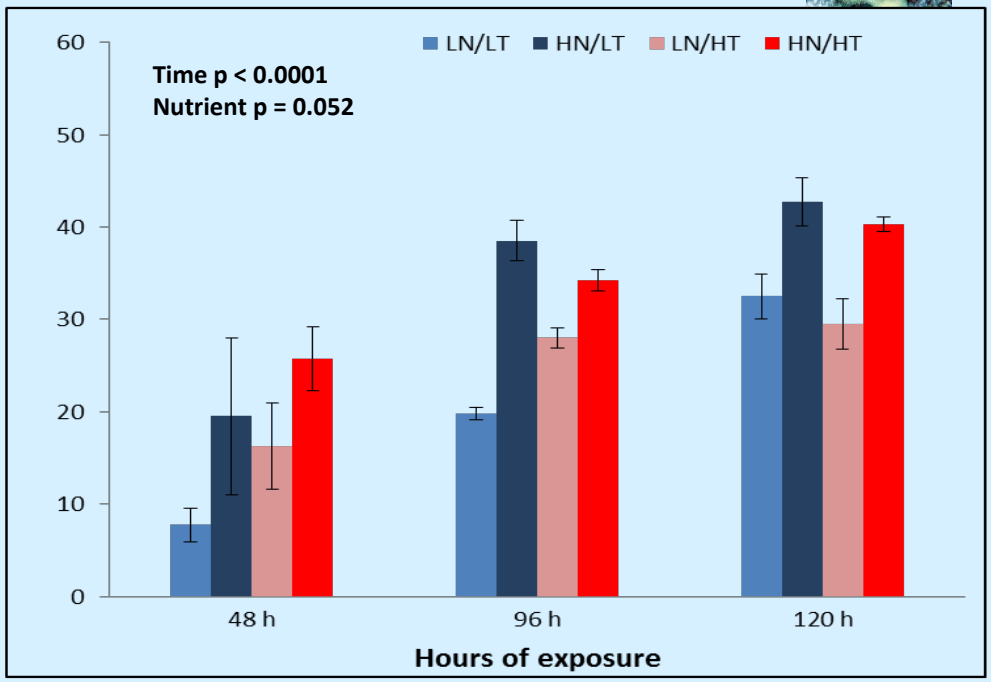
Nutrients

Effect of Nitrate and Elevated Temperature – Larval Settlement

O. faveolata (mountainous star coral)



P. astreoides (mustard hill coral)



2-way repeated measures ANOVA

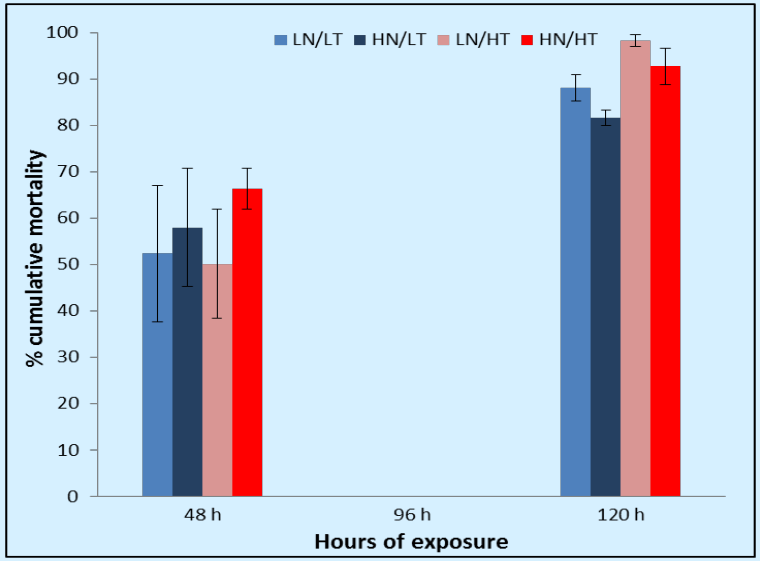
- **Faster settlement of *P. astreoides* larvae under elevated nitrate conditions**

Serrano et al. to be submitted

Nutrients

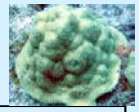
Effect of Nitrate and Elevated Temperature – Larval survival

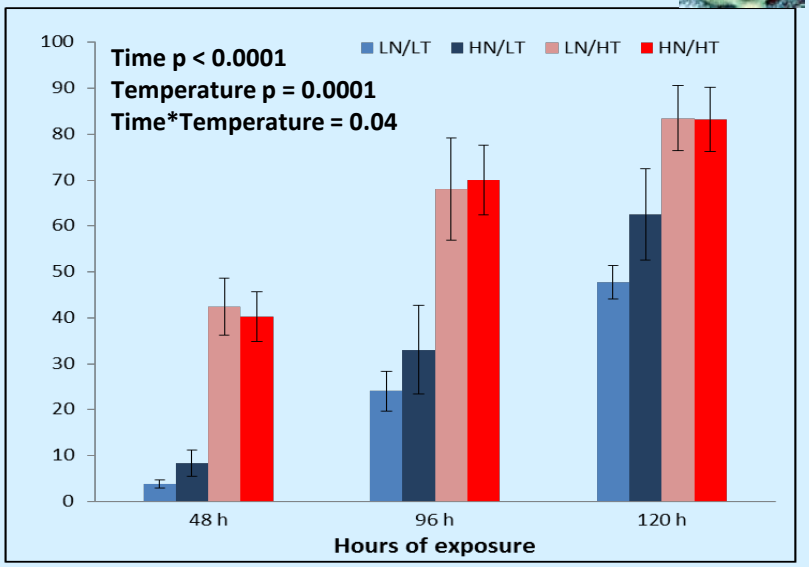
Orbicella faveolata **(mountainous star coral)**



2-way repeated measures ANOVA

Porites astreoides **(mustard hill coral)**





2-way repeated measures ANOVA

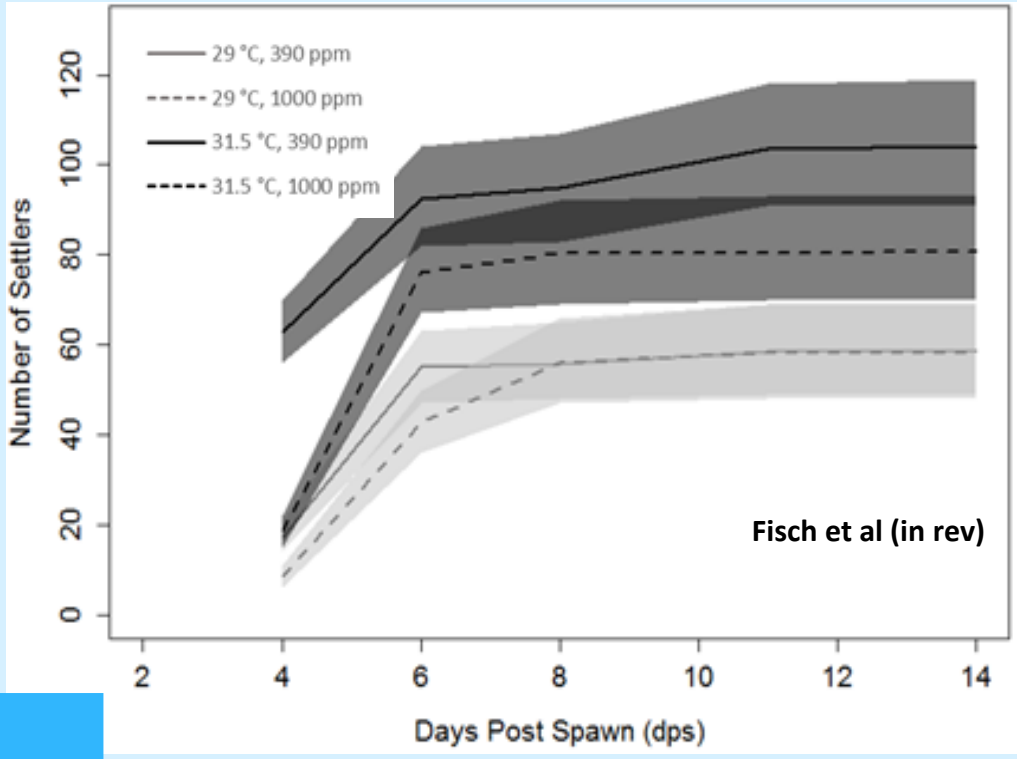
- **Significantly higher mortality with temperature for *P. astreoides* but not for *O. faveolata* larvae**
- **Early life stages of *O. faveolata* are less susceptible to elevated nitrate and thermal stress than other Caribbean coral species (e.g., *A. palmata, D. strigosa*)**

Serrano et al. to be submitted

Climate Change

Effect of Elevated Temperature and pH on Larval Mortality & Settlement

Larval survivorship and settlement under warming (31.5°C) and OA (1000ppm) for *Orbicella faveolata*



- **Higher net settlement at higher temp**
  - **earlier competency outweighs higher mortality**

- **1000 ppm CO_2 OA reduces earlier competence at warm temperatures (i.e., moderates this warming effect)**

Miller et al.

How is this information useful?

- **Identifies threshold concentrations causing adverse effects for vulnerable early-life stages.**
  - **Fertilization and settlement phases are more sensitive/vulnerable than the swimming phases**
  - **Toxicity reduction measures can be used to guide mitigation measures to improve performance of these most vulnerable developmental stages**
- **Provides thresholds for recovery of adult coral from physical damage (wounding) in a nutrient enriched environment. These data are useful in assessing damage, in siting nurseries and outplanting of fragments and provides prognosis for recovery from physical damage in reference vs impacted locations.**
- **Overall results show *O. faveolata* larvae generally are more robust to warmer temperatures (31-31.5° C) when faced with either elevated nitrates or pH than expected, with possibly higher settlement. This is better news than expected in considering climate change scenarios and increases in eutrification.**

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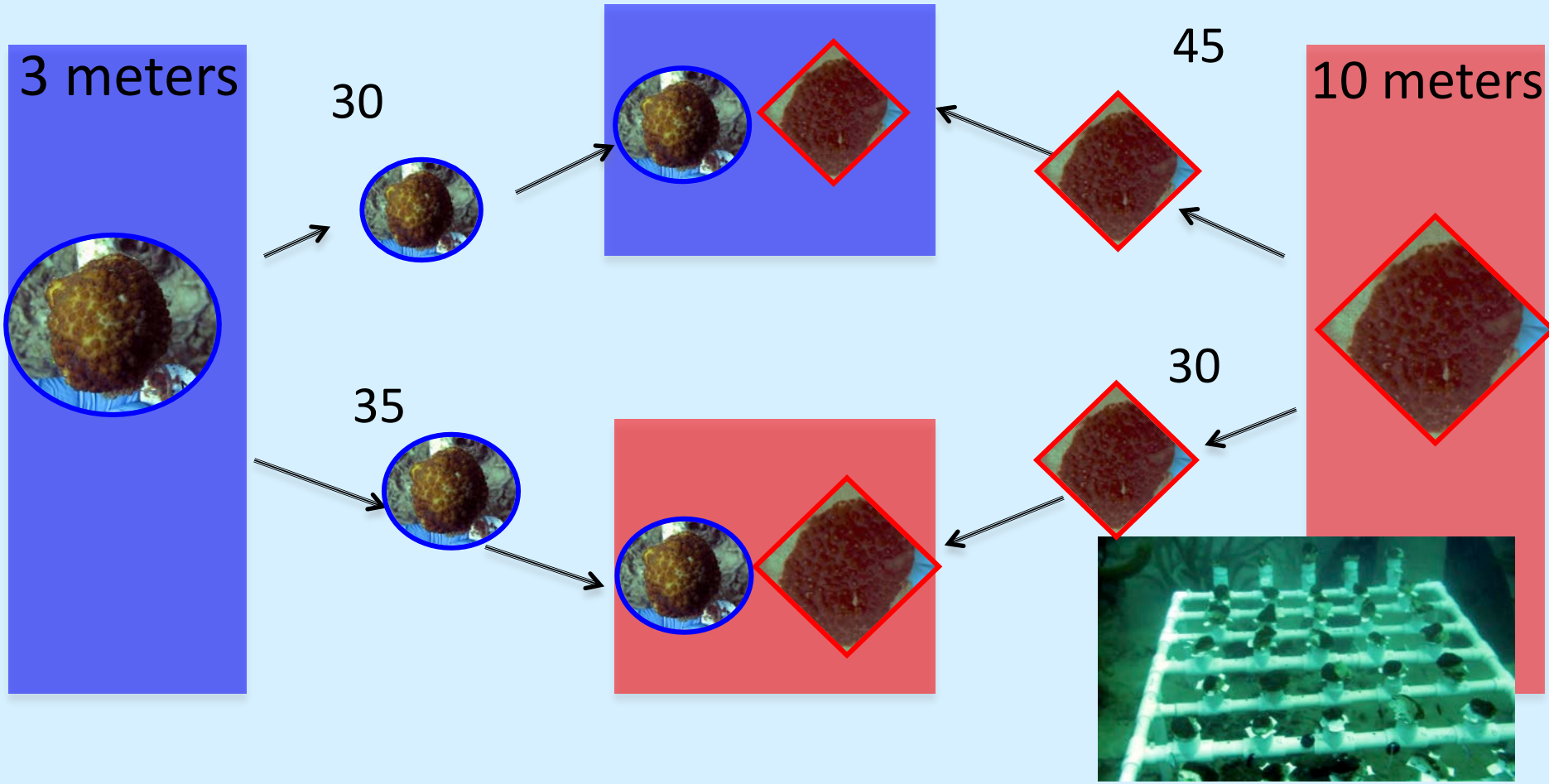
- Effect of genetics on coral restoration

Restoration Genomics

To test for adaptation in *Orbicella*, colonies were reciprocally transplanted from 3 and 10 meters



Woodley et al.

Restoration Genomics

Findings to Date

***Orbicella* spp. are adapted to different depths (habitats)**

- Data indicate a non-random depth-dependent mortality of juveniles, suggesting natural selection
- Genetic variation is non-randomly distribution across depths and reefs
- Deeper water corals have higher physiological plasticity when exposed to non-native habitats
- Mortality is increased for shallow water colonies in non-native habitats

Neutral vs adaptive genetic variation – a new paradigm

- Adaptive variation is what allows some corals to live in some habitats but not others; critical for coral conservation
- Use of genomic data and SNP markers for the first time allows us to distinguish adaptive from non-adaptive variation and to quantify adaptive variation
- This project is in collaboration with restoration nurseries to integrate this novel aspect into their efforts

Woodley et al.

How is this information useful?

- *Location Matters* – Habitat differences in nursery stocks and outplanting locations should be considered in restoration planning and implementation
- Genotype-guided restoration activities can improve restoration efforts by
  - Providing the ability to know genotype characteristics, acclimation potential, physiological responses in non-native locations
  - Identifying 'hardy' genotypes for inclusion in coral nurseries for genotype-guided restoration activities
  - Data suggest matching habitats can increase success by at least 30%.
    - Assisting in matching genetic backgrounds of out-planted progeny to locations they are best adapted, thus optimizing restoration efforts, reducing cost and increasing outplanting success.

How is this information useful?

- **Genome and SNP markers allow distinguishing adaptive from non-adaptive variation.**
  - **This can be used to better define critical habitats for the recovery of ESA species as well as conservation of others, and assist in defining boundaries of marine reserves based on preserving genetic potential of species.**
- **TNC in USVI is a collaborator on the project and the data from this project will be used to assist TNC's coral nursery effort with Orbicella species.**
- **This data is also available to NOAA Restoration Center and Dr. Sean Griffin in Puerto Rico has been involved in the study design and his nursery holdings can be genotyped based on the markers that are informative.**
- **The more nurseries use a genomic-enabled restoration approach, the more effective the efforts**

Key Contributions and Strengths

Ecosystem

Community

Species

Population

Individual

Organ

Tissue

Cell

Early and direct effects of stressors

Key Contributions and Strengths

Studying the way corals function (i.e. physiology) provides insights that:

- **CAN directly link a stressor to its effect on the organism or health of their ecosystem**
- **CAN provide prognosis**
- **CAN provide remedies**
- **Can shift paradigms**

Key Contributions and Strengths

- **Our science contributes in unique ways to define metrics for NOAA & CRCP's priorities (i.e., what does resilience look like?)**

- **Investigating underlying causes of impairments, identifying and understanding effects of single or combined physical, chemical and biological threats to coral reef ecosystems goes beyond merely documenting a problem but helps *devise solutions to ensure their recovery, protection and preservation for the future.***

Challenges

- Qualified human capital to conduct work & continuity of workforce
- Gaps in funding create a challenge to keep work going on a long-term basis
- Husbandry that is conducive for corals to spawn in captivity
- Reference populations for toxicity testing
- Permitting

Challenges

- Solutions for conserving and recovering coral reefs are complex and complicated and perceived as intractable
- Difficulty communicating to managers those applications in our portfolio which may benefit future management actions.
- Long-term banking, curating and updating genomic data and metadata and delivering the data in a user-friendly format for managers and those engaged in active coral restoration

Future Directions

- **Determine thresholds for stressors with management-potential (e.g., nutrients, contaminants, sedimentation) and support threat-reduction options**
  - **Including intraspecies comparisons and life-stage responses to assist in damage assessments and water quality guidelines.**
- **Conduct exposure-response studies to determine genotypic differences and acclimation potential in ESA coral and other species**
- **Determine gene expression in transplant experiments to better understand how colonies from different depths are using their genes.**
  - **Extend these investigations to comparisons across habitat genotypes for responses to increasing temperature and ocean acidification.**
- **Institute a clearing house for long-term continuity of this resource and utilization of these genomic and metadata resources that allows archiving, continuous curation as new information is added with the ability to delivered the information to those engaged in restoration efforts in a user-friendly format**

Publications

Miller MW, Williams DE, Fisch J. (In Press) Genet-specific spawning patterns in *Acropora palmata*. Coral Reefs. DOI: 10.1007/s00338-016-1472-6

Prada C, Woodley CM, Medina MM et al (Accepted) Empty niches after extinctions increase population sizes of modern. *Current Biology*

Serrano et al. (In prep) Effects of thermal stress and nitrate enrichment in the larval oxygen consumption, settlement and survival of two Caribbean reef corals. (submission to *Coral Reefs)*

Miller et al. (In prep) Clonal structure and fertilization incompatibility in Florida Keys broadcast spawning corals.

Prada C, Woodley CM, Medina MM et al (In prep) Location matters: genotype-guided coral restoration.