NOAA Coral Reef Conservation Program Ecosystem Science Evaluation: *In Situ* Ocean Acidification and Climate Change Monitoring in the Atlantic

Derek P. Manzello, I. Enochs, R. Carlton, G. Kolodziej, L. Valentino, M. Jankulak, P. Jones, B. Gintert, A. Gleason, J. Morgan, A. Sutton, S. Musielewicz, J. Kimball, D. Gledhill, J. Morrel, M. Melendez, R. van Hooidonk

Acidification, Climate, and Coral Reef Ecosystems TEam (ACCRETE)

http://www.coral.noaa.gov/research/accrete.html

Atlantic Oceanographic and Meteorological Laboratory, NOAA
Miami, FL 33149 USA

CRCP Ocean Acidification and Climate Change Monitoring

- Major Science Question
  - *What is the impact of climate change and ocean acidification on US coral reefs?*
    - What are the spatiotemporal trends in climate change and ocean acidification on US coral reefs?
    - What are the ecosystem impacts of ocean acidification on US coral reefs?

Funding Support

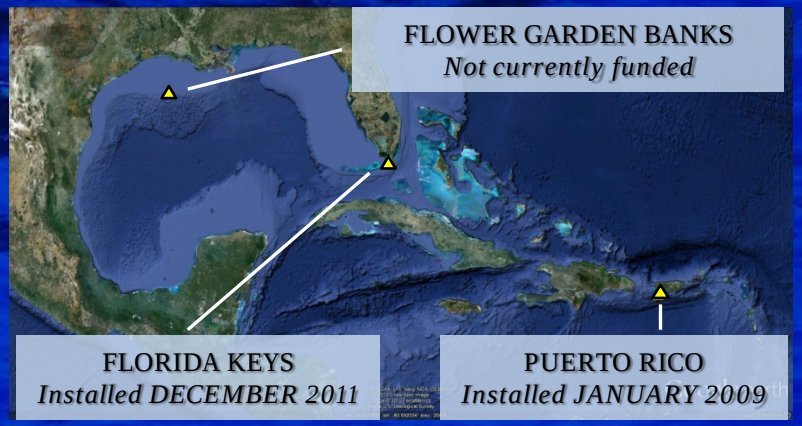
- NCRMP funding
  - Co-funded by **CRCP** and **Ocean Acidification Program (OAP)**
- Ocean Acidification Project Suite
  - Developed with CRCP funds
  - Maintained via OAP support
- Ancillary Project's funding by CRCP is variable both by year and project
  - e.g., Maug high-CO_2 seep study: CRCP award with OAP-funded ship time
- OAP also invests in data management, advancing technology development, and lab inter-comparisons

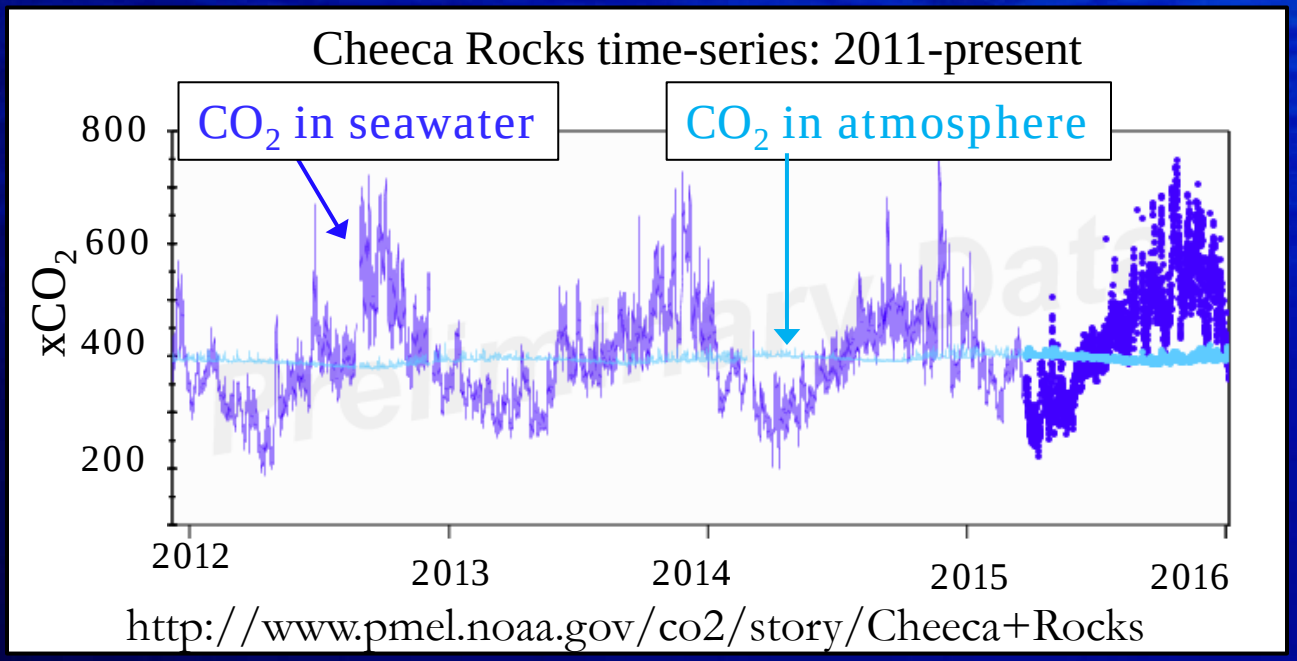
I. What are the spatial and temporal trends in temperature and ocean acidification on US coral reefs?

NCRMP Climate Site Classes

- Class III or 'Sentinel' Climate Monitoring Sites
  - 2 of 3 planned sites fully instrumented: Cheeca Rocks, Florida Keys and La Parguera, Puerto Rico
    - CO_2 time-series
    - Ecosystem response to OA

Class III sites in Atlantic



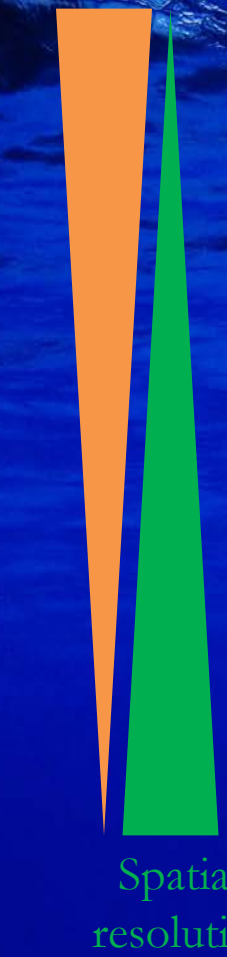


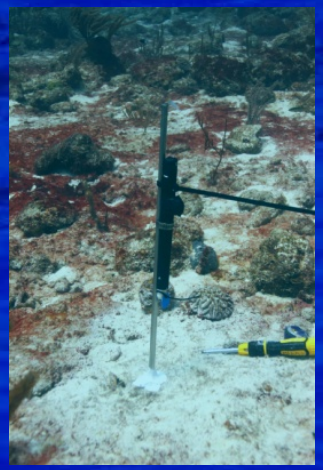
Cheeca Rocks $MApCO_2$

I. What are the spatial and temporal trends in temperature and ocean acidification on US coral reefs?

NCRMP Climate Site Classes

- **Class II** (n = 3 sites in Atlantic: St. Croix, St. Thomas, Dry Tortugas – expanding to 27 total sites over next 3 yrs)
  - 72 hr diurnal sampling of TCO_2 and total alkalinity (TA)
  - Ecological Response (Calcification, Bioerosion etc.)
- **Class I** (n = 27 transects, 108 sites in Atlantic)
  - Each transect is an array of four thermistors across a depth gradient
  - Temperature measurements obtained every 5 minutes
- **Class O** (n = 150/year in Atlantic)
  - Randomized bottle sampling for TCO_2 and TA
  - Highest spatial resolution, least temporal resolution
  - US coral reef sites in Virgin Islands, Puerto Rico, Florida, Flower Garden Banks
  - Each region sampled once every 2 years



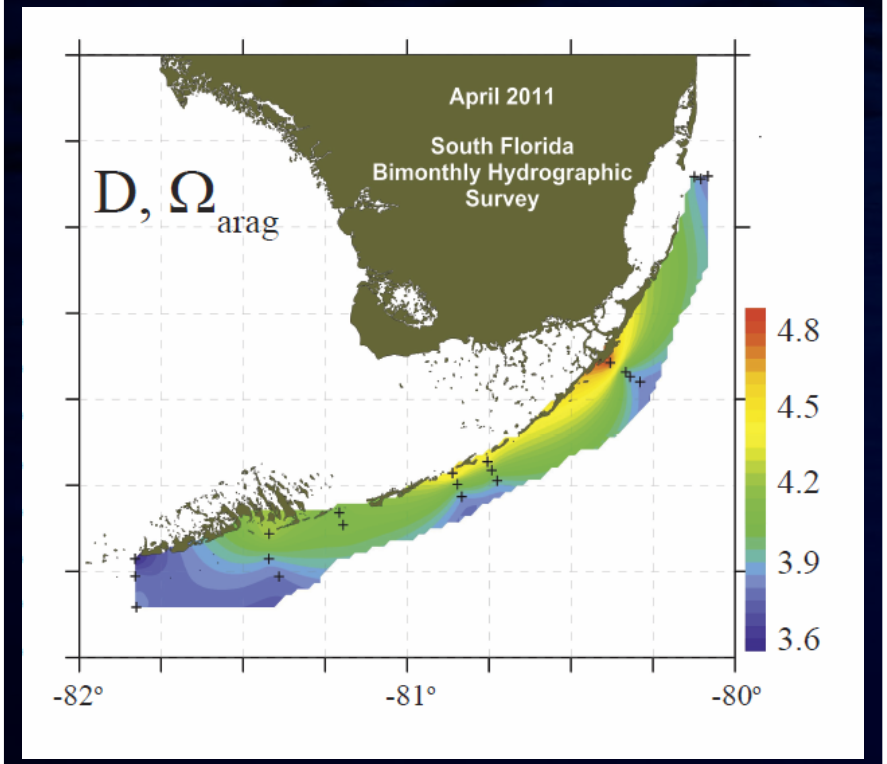


Class I
Lang Bank,
St Croix

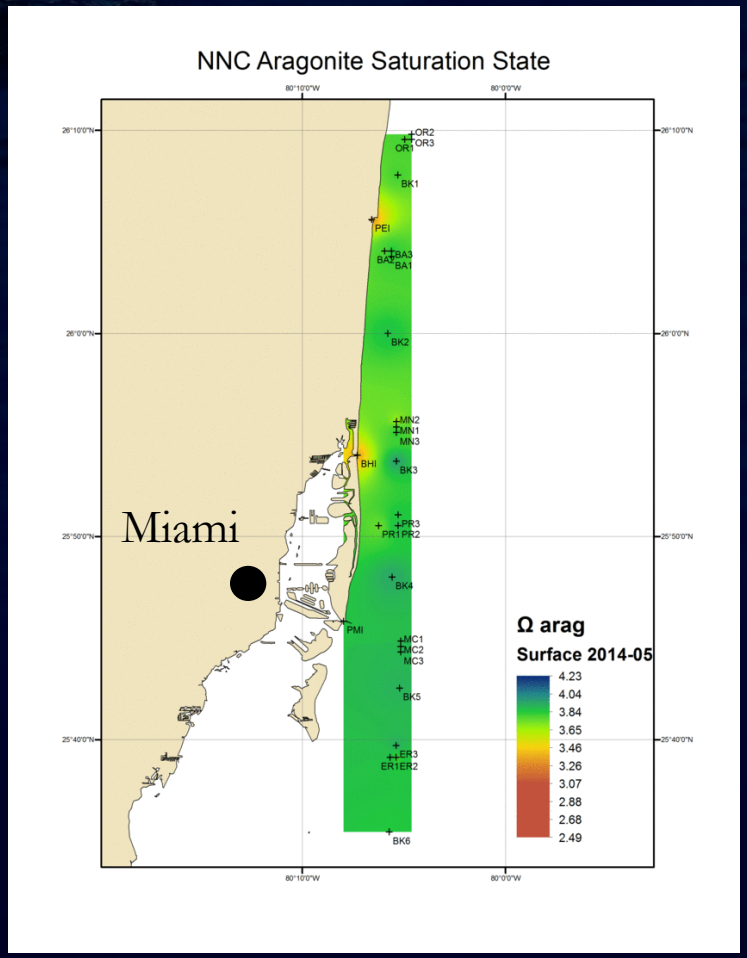
Class I sites on Florida Reef Tract

I. What are the spatial and temporal trends in ocean acidification on US coral reefs?

Class O data snapshot from Florida Keys

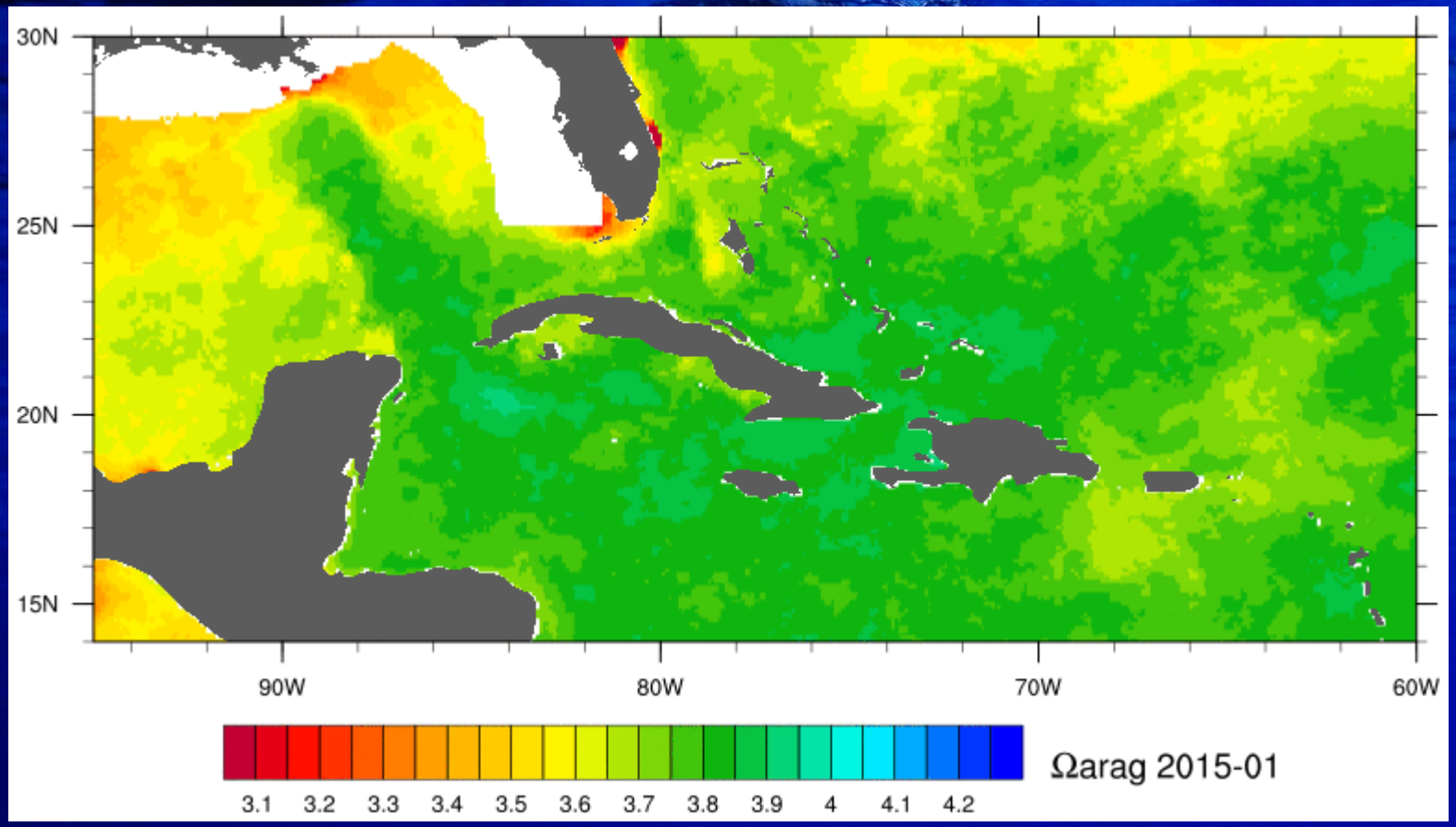


Ancillary project providing information on seasonal variability



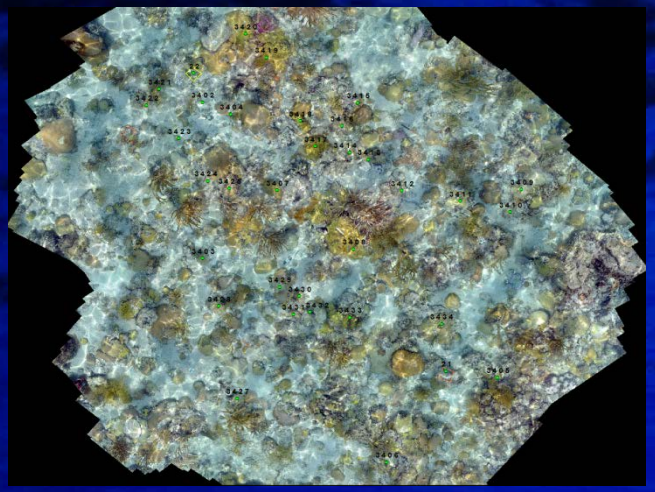
I. What are the spatial and temporal trends in ocean acidification on US coral reefs?

Ocean Acidification Product Suite
Developed by D. Gledhill, updated by R. van Hooidonk
Greatest spatial resolution

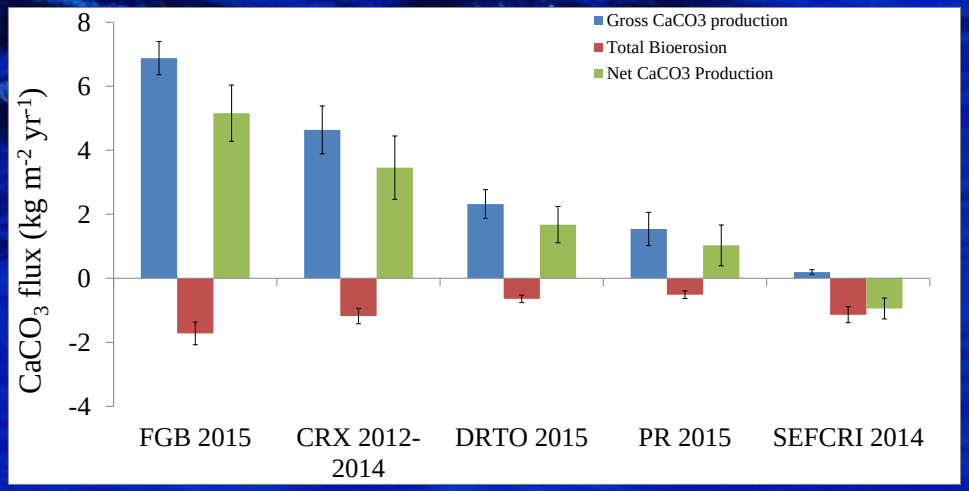


http://www.coral.noaa.gov/accrete/oaps.html

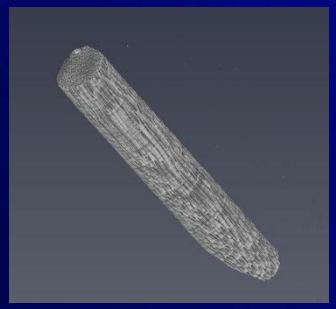
II. What are the ecosystem impacts of ocean acidification on US coral reefs?



Landscape Mosaic



$CaCO_3$ flux



Coral Calcification

CAU (Calcification Accretion Unit) + BMU

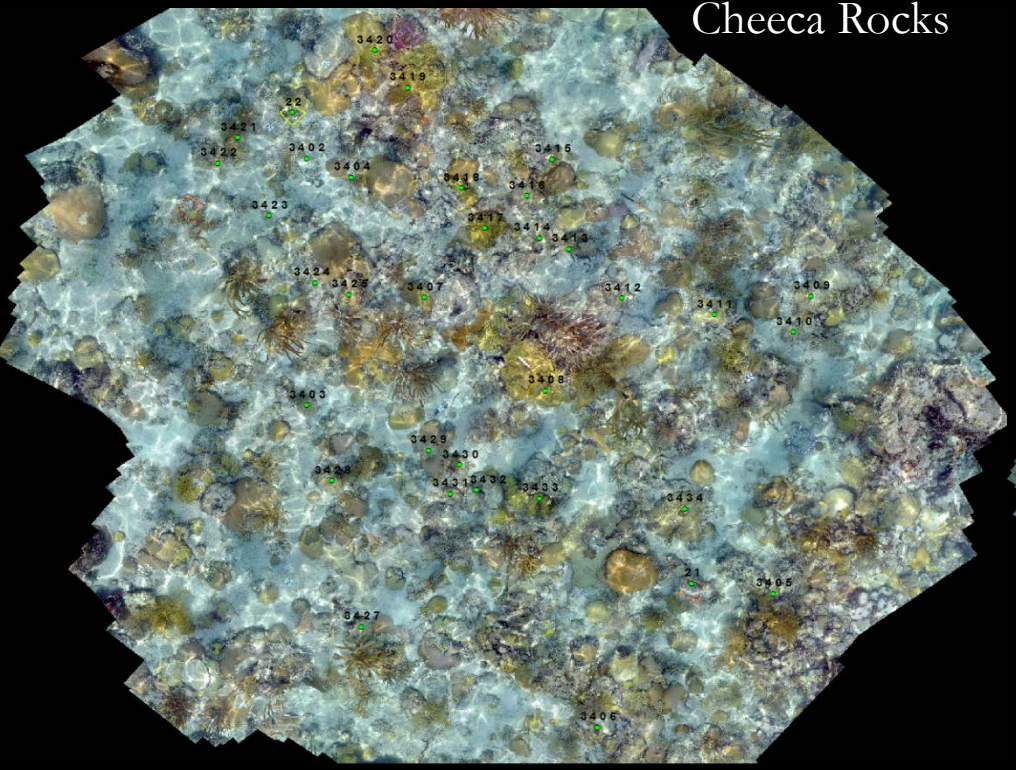
BMU (Bioerosion monitoring unit)

ARMs (Artificial Reef Monitoring Structure)

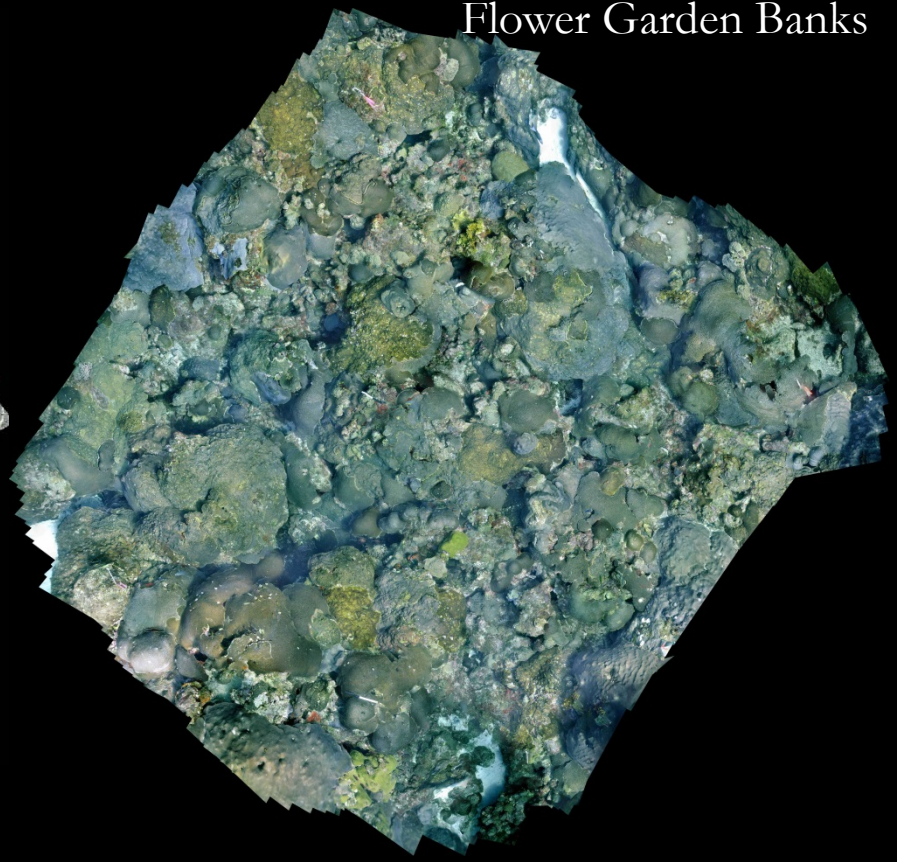
II. What are the ecosystem impacts of ocean acidification?

Landscape mosaics

Cheeca Rocks



Flower Garden Banks



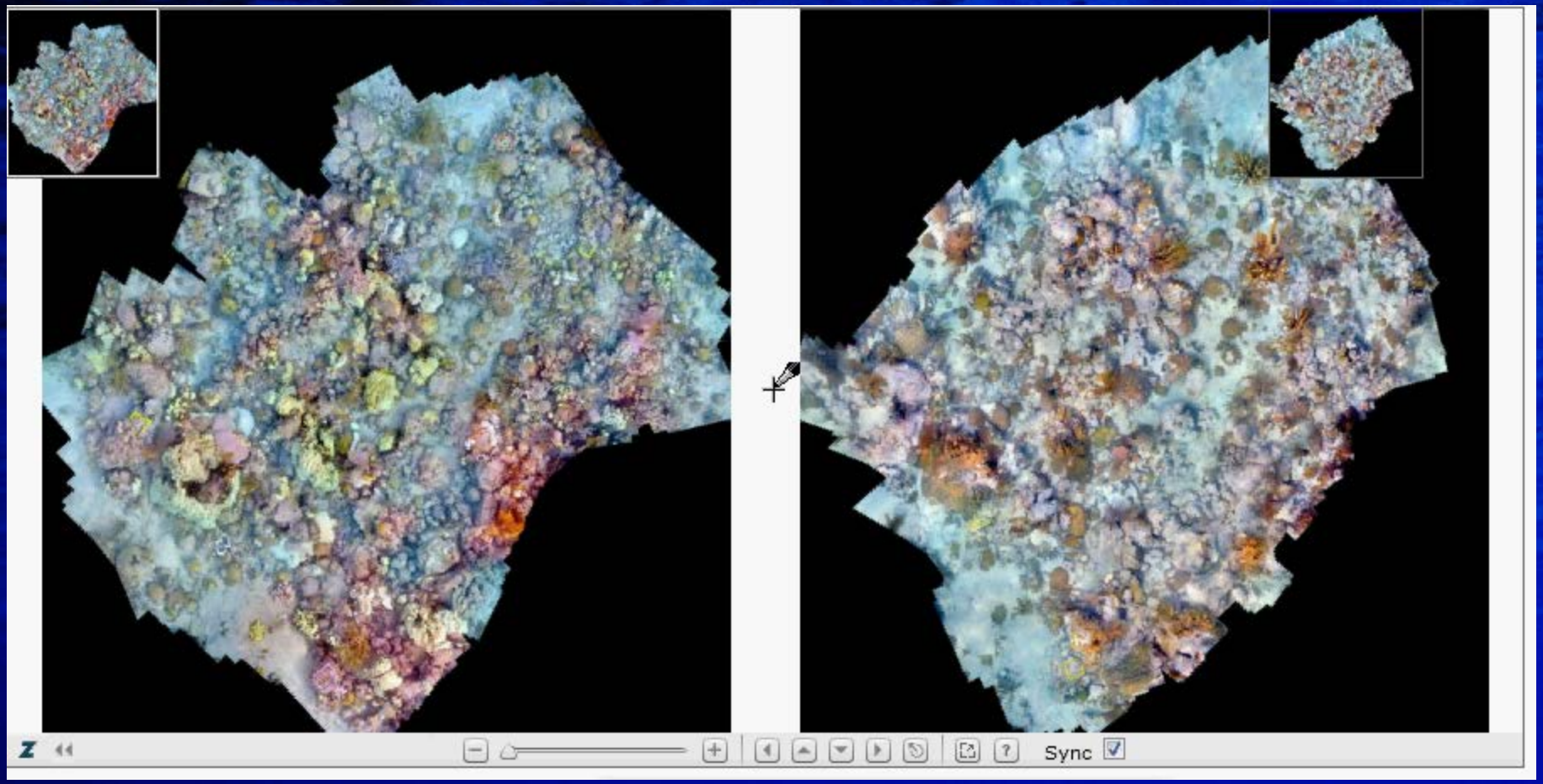
- High-resolution benthic characterization
  - *Visual archive posted on web*
  - *Measure any metric of interest (coral cover, H', etc)*
  - *Rotate annually between class III sites – ONCE EVERY 3 YRS PER SITE*

UM collaborator Art Gleason conducts landscape mosaic survey at Cheeca Rocks, Sept 2015

Cheeca Rocks Coral Bleaching Patterns: 2014-2015

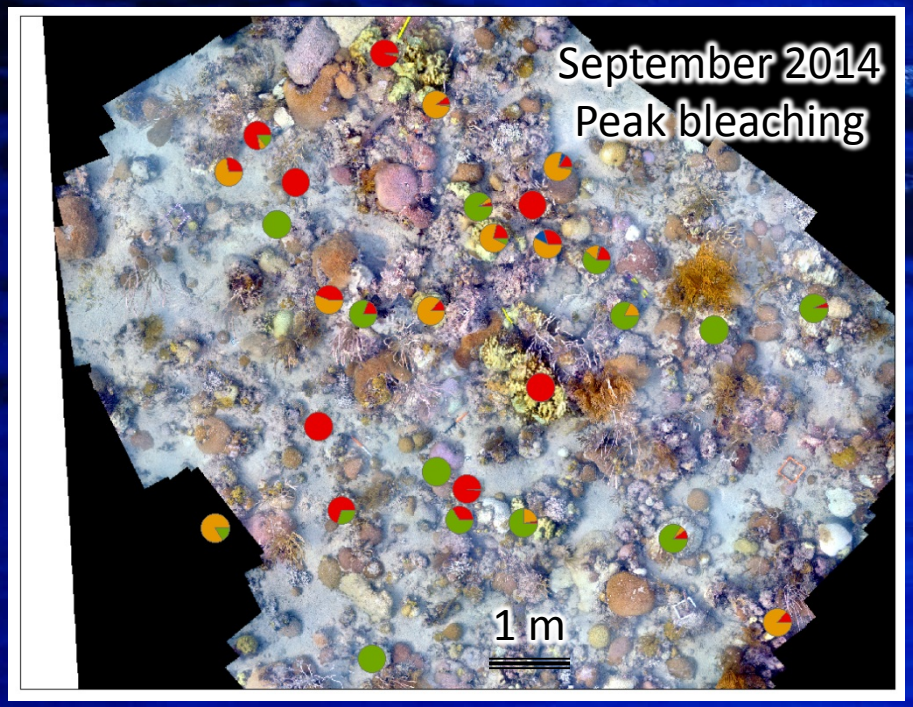
September 2014

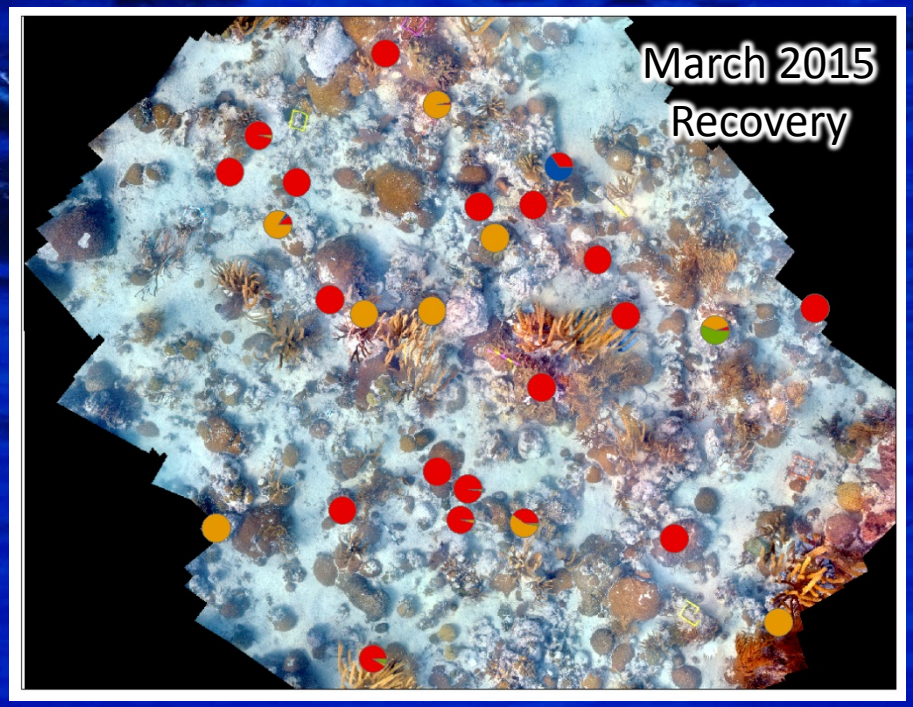
March 2015



1.3-3.7% coral mortality despite 2014 and 2015 being two hottest summers on record; 99% colony survival

Relative abundance of algal symbiont types during bleaching/recovery





Pie charts show relative abundance of symbionts from clades A B C D

Preliminary results

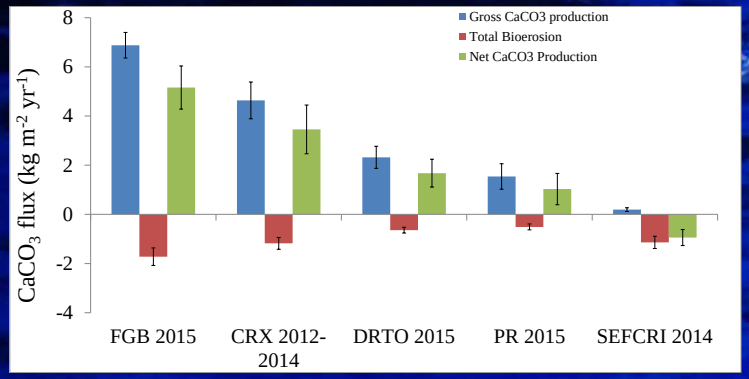
- Clades B and D increased, whereas A decreased
- Clade D known to be heat tolerant

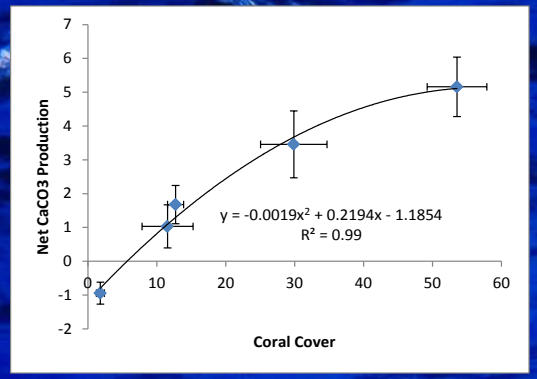
Next steps

- Determine if clade type and flexibility correlates with mortality

II. What are the ecosystem impacts of ocean acidification on US coral reefs?

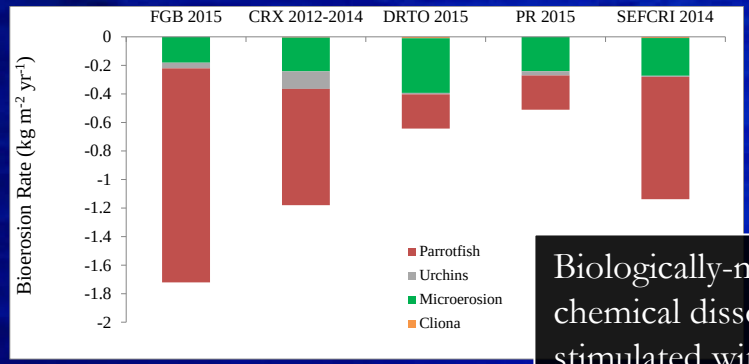
$CaCO_3$ Budget Monitoring

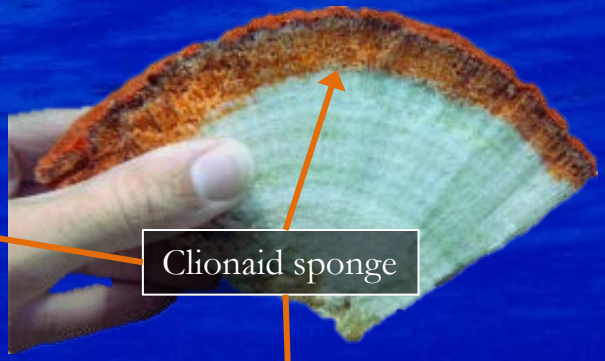




Census-based $CaCO_3$ flux

- Net $CaCO_3$ Production = Gross $CaCO_3$ Production – Bioerosion
- Parrotfish and microborers dominant agents of bioerosion in Atlantic
- Shift from net accretion to net erosion around 5% coral cover
- Once every 3 years at each class III site

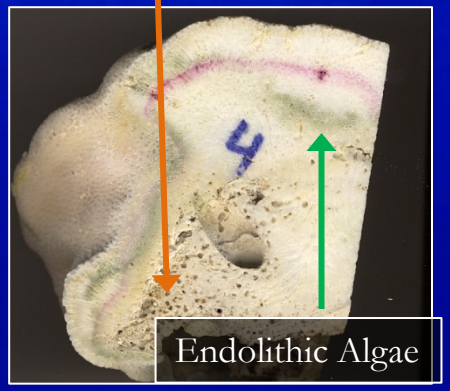




Biologically-mediated chemical dissolution stimulated with OA

Clionaid sponge

Lithophagine bivalves



Endolithic Algae

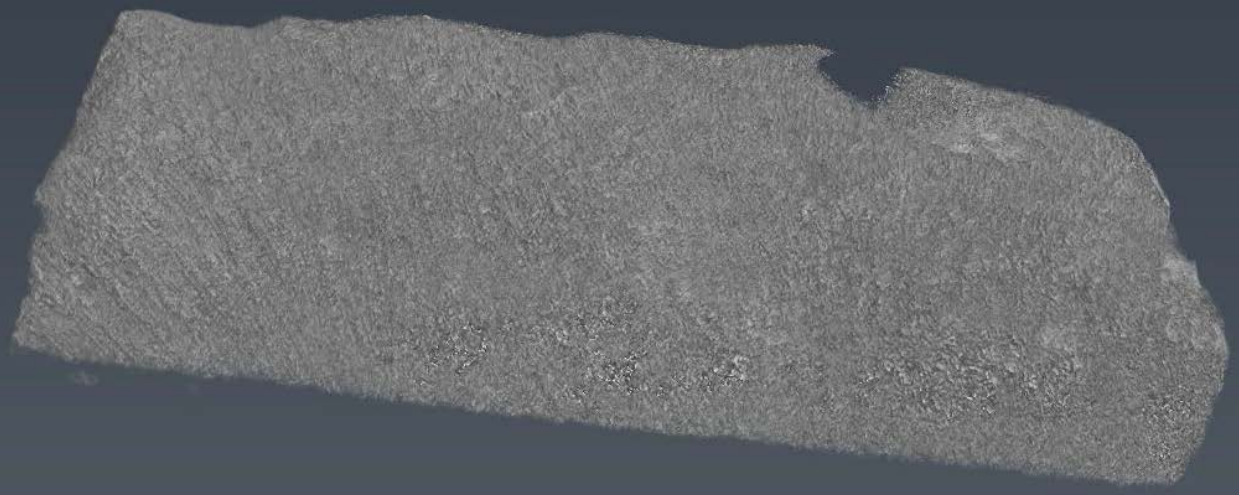
II. What are the ecosystem impacts of ocean acidification on US coral reefs?

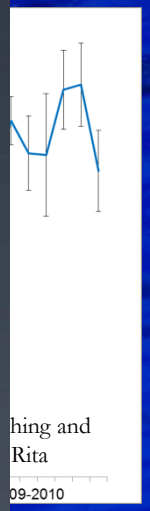
Coral

Calcifi

27 sites

CAU
BMU





Volumetric determination of net accretion, grazing, macroboring, and microboring

Key Contributions and Strengths

<u>Key Outcomes</u>

Providing high-quality data on the rate and magnitude of OA and its ecosystem impacts

Unprecedented in scale and scope, no one else is doing this at this scale

Basic information on relative risk of regions/reefs to OA (e.g., hotspots vs. refugia)

Advancing science of climate change and OA impacts to coral reefs

How is the information being disseminated?

28 peer-reviewed journal publications since 2010 for ACCRETE lab

- Peer reviewed publications

1. Enochs IC, Manzello DP, Tribollet A, Valentino L, Kolodziej G, Donham EM, Fitchett M, Carlton RD, Price NN (2016) Elevated colonization of microborers at a volcanically acidified coral reef. PLoS ONE 11(7): e0159818.
2. Humphreys A, Halfar J, Rivera F, Manzello DP, Reymond C, Westphal H, Riegl B (2016) Variable El Niño Southern Oscillation influence on biofacies dynamics of Eastern Pacific shallow water carbonate systems. Geology 44(7):571-574
3. Camp E, Smith D, Evenhuis C, Enochs IC, Manzello DP, Woodcock S, Suggett D (2016) Acclimatisation to high variance habitats does not enhance physiological tolerance of two key Caribbean corals to future temperature and pH. Proceedings of the Royal Society B 283(1831)
4. Enochs IC, Manzello DP, Wishing HH, Carlton R, Serafy J (2016) Micro-CT analysis of the Caribbean octocoral Eunicea flexuosa subjected to elevated pCO2. ICES Journal of Marine Science 73 (3): 910-919,
5. Manzello DP (2015) Rapid recent warming of coral reefs in the Florida Keys. Scientific Reports 5, 16762; doi: 10.1038/srep16762
6. Towle E, Carlton R, Langdon C, Manzello DP (2015) In-situ measurement of metabolic status in three coral species from the Florida Reef Tract. Regional Studies in Marine Science 2:145-153.
7. E.K. Towle, Enochs, I.C., Langdon, C. (2015) Threatened Caribbean coral is able to mitigate the adverse effects of ocean acidification on calcification by increasing feeding rate. PLoS ONE 10(4): e0123394.
8. Enochs IC, Manzello DP, Donham E, Kolodziej G, Okano R, Johnston L, Young C, Iguel J , Edwards C, Fox M, Valentino L, Johnson S, Benavente D, Clark S, Carlton RD, Burton T, Eynaud Y, Price N (2015) Shift from Coral to Macroalgae Dominance on a Volcanically Acidified Reef. Nature Climate Change doi:10.1038/nclimate2758
9. Manzello DP, Enochs IC, Kolodziej G, Carlton R (2015) Coral growth patterns of Montastraea cavernosa and Porites astreoides in the Florida Keys: the importance of thermal stress and inimical waters. Journal of Experimental Marine Biology and Ecology 471:198-207 doi: 10.1016/j.jembe.2015.06.010
10. Sutton A, Manzello DP, Gintert B (2015) Coupled chemical and biological monitoring to understand the impact of ocean acidification on coral reef ecosystems. Oceanography 28(2):12-13
11. Enochs IC, Manzello DP, Carlton R, Graham D, Ruzicka R, Collela M (2015) Ocean acidification enhances the bioerosion of a common coral reef sponge: implications for the persistence of the Florida Reef Tract. Bulletin of Marine Science 91, 271-290 doi: 10.5343/bms.2014.1045
12. Manzello DP, Enochs IC, Kolodziej G, Carlton R (2015) Recent Decade of Growth and Calcification of Orbicella faveolata in the Florida Keys: An Inshore-Offshore Comparison. Marine Ecology Progress Series 521:81-89, doi: 10.3354/meps11085.
13. Manzello DP, Enochs IC, Bruckner A, Renaud P, Kolodziej G, Budd D, Carlton R, Glynn PW (2014) Galápagos Coral Reef Persistence after ENSO Warming Across an Acidification Gradient. Geophysical Research Letters 41 (24), 9001-9008
14. P.W. Glynn, Enochs, I.C., Afflerbach, J.A., Brandtneris, V.W., Serafy, J.E. (2014) Eastern Pacific reef fish responses to coral recovery following El Nino disturbances. Marine Ecology Progress Series 495: 233-247.
15. Enochs IC, Manzello DP, Carlton R, Schopmeyer S, van Hooidonk R, Lirman D (2014) Effects of light and elevated pCO2 on the growth and photochemical efficiency of Acropora cervicornis. Coral Reefs 33(2):477-485,
16. van Hooidonk R, Maynard J, Manzello DP, Planes S (2014) Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. Global Change Biology 20(1):103-112,
17. Manzello DP, Enochs IC, Musielewicz S, Carlton R, Gledhill DK (2013) Tropical Cyclones Cause CaCO3 Undersaturation of Coral Reef Seawater in a High-CO2 World. Journal of Geophysical Research: Oceans, 118(10): 5312-5321,
18. Bignami S, Enochs IC, Manzello DP, Sponaugle S, Cowen RK (2013) Ocean acidification alters the otoliths of a pan-tropical fish species with implications for sensory function. *Proceedings of the National Academy of Sciences, U.S.A.* 110 (19):7366-7370
19. Manzello DP, Enochs IC, Melo N, Gledhill DK, Johns EM (2012) Ocean Acidification Refugia of the Florida Reef Tract. *PLoS ONE* 7(7): e41715. doi:10.1371/journal.pone.0041715.
20. Enochs IC, Manzello DP (2012) Species richness of motile cryptofauna across a gradient of framework erosion. *Coral Reefs* 31:653-661.
21. Enochs IC, Manzello DP (2012) Responses of Cryptofaunal Species Richness and Trophic Potential to Coral Reef Habitat Degradation. *Diversity* 4:94-104.
22. L.T. Toth, Aronson, R.B., Vollmer, S.V., Hobbs, J.W., Urrengo, D.H., Cheng, H., Enochs, I.C., Combosch, D.J., van Woesik, R., Macintyre, I.G. (2012) ENSO drove 2500-year collapse of eastern Pacific coral reefs. Science 337(6090): 81-84.
23. van Hooidonk R, Manzello DP, Moye J, Brandt M, Hendee J, McCoy C, Manfrino C (2012) Coral bleaching in Little Cayman, Cayman Islands 2009. *Estuarine Coastal and Shelf Science* 106:80-84
24. Mcleod E, Anthony KRN, Andersson A, Beeden R, Kleypas J, Kroeker K, Manzello DP, Salm R, Schuttenberg H, Smith JE (2012) Preparing to manage coral reefs for ocean acidification: Lessons from coral bleaching. *Frontiers in Ecology and the Environment* 11:20-27, doi:10.1890/110240
25. Enochs IC, Toth LT, Brandtneris VW, Afflerbach JC, Manzello DP (2011) Environmental determinants of motile cryptofauna on an eastern Pacific coral reef. Marine Ecology Progress Series 438:105-118.
26. Lirman D, Schopmeyer S, Manzello DP, et al. (2011) Severe 2010 cold-water event caused unprecedented mortality to corals of the Florida Reef Tract and reversed previous survivorship patterns. PLoS ONE 6(8): e23047.
27. Manzello DP (2010) Coral growth with thermal stress and ocean acidification: Lessons from the eastern Pacific. Coral Reefs 29 (3): 749-758.
28. Manzello DP (2010) Ocean acidification hotspots: Spatiotemporal dynamics of the seawater CO2 system from eastern Pacific coral reefs. Limnology and Oceanography 55 (1): 239-248.

How is the information being disseminated?

- Peer reviewed publications
- International Scientific Conferences (ICRS, Oceans in a High-CO_2 World etc.)
  - Since 2007, 41 oral presentations, 12 poster presentations
- Data freely available at:
  - Ecological Data
    - CoRIS (Coral Reef Information System)
  - CO_2 data
    - NCEI (National Centers for Environmental Information)
    - CDIAC (Carbon Dioxide Information Analysis Center)
- ACCRETE website
  http://www.coral.noaa.gov/research/accrete.html
- PMEL website
  http://www.pmel.noaa.gov/co2/story/Cheeca+Rocks
- NCRMP report card
- Monitoring reports (e.g., Flower Garden Banks monitoring reports)
- Presentations to local managers (e.g., FL Keys National Marine Sanctuary)

How is the information intended to be used?

REVIEWS REVIEWS REVIEWS

Preparing to manage coral reefs for ocean acidification: lessons from coral bleaching

Elizabeth Mcleod[1*], Kenneth RN Anthony[2], Andreas Andersson[3], Roger Beeden[4], Yimnang Golbuu[5], Joanie Kleypas[6], Kristy Kroeker[7], Derek Manzello[8,9], Rod V Salm[10], Heidi Schuttenberg[11], and Jennifer E Smith[3]

Frontiers in Ecology and Evolution, 2012

Five research priorities:

1. Establishing an ocean carbonate chemistry baseline
2. Establishing ecological baselines
3. Determining species/habitat/community sensitivity to ocean acidification
4. Projecting changes in seawater carbonate chemistry
5. Identifying potentially synergistic effects of multiple stressors

How is the information intended to be used?

- **Who are the intended users of the information?**
  - Resource managers, policy makers, scientists
- **How will they/could they use this information to make management decisions?**
  - Focusing restoration/mitigation activities to those places or species least likely to be impacted or buffered
    - e.g., Current CRCP project directly measuring how seagrasses may stimulate growth for restoration activities of ESA-listed *Acropora cervicornis*
  - MPA design
    - Priority focus of neighboring seagrass habitats in coral reef management plans
    - Protecting areas with naturally high or low CO_2, or high/low variability: research evolution will work to inform which areas are most important to building resilience
    - Most at risk places may warrant increased protection of herbivores to control macroalgae and favor coral and crustose corraline algae despite depressed growth

What are your challenges?

- NCRMP plan called for 3 sentinel sites in Atlantic and Pacific, but currently there are only 2 fully functional in the Atlantic and 1 in the Pacific (though funding in place for procurement of 2nd Pacific buoy)

- Requires sustained, long-term funding given subtle, yet progressive nature of OA. This will be a challenge given personnel turnover within funding agencies/programs that operate on 3-5 year project cycles and expect immediate results

- Requires measurement of 1) physical environment, 2) the biological variables expected to be impacted by OA, **as well as 3) those variables that could interfere with detection of an OA signal**
  - e.g., coral bleaching mortality will cause large depression in calcification regardless of OA
  - Fluctuations in parrotfish populations swamping subtle increases in bioerosion by endolithic algae, clionaid sponges etc.
  - *In essence, we must know what is happening to those variables that are* ***expected to be directly impacted by OA*** *as well as those things that could* ***interfere with detection of an OA signal***

- Need to have personnel in place that are proficient with analysis/interpretation of seawater chemistry **AND** knowledge/experience with field-based coral reef ecology
  - Most are one or the other! Rare to find people with combined skill set

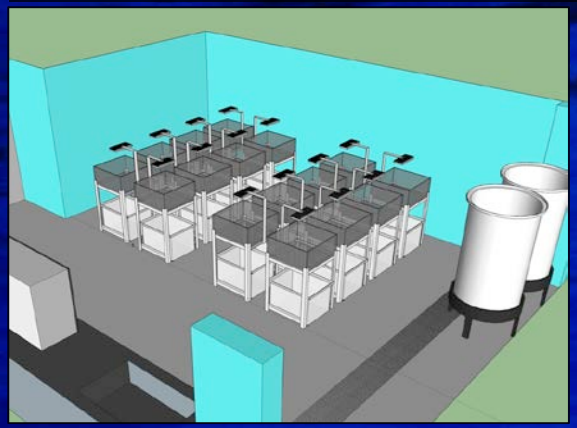
- No funding in place for hydrochemical determination of reef calcification; reef metabolism tier 3 NCRMP metric

What are the potential future directions for this work?

- Incorporation of results into management plans
- Utilize this information to more accurately project future CO_2 conditions and how that will actually impact coral reefs
  - Right now we take (generally) poor characterizations of seawater CO_2 conditions and then forecast into the future assuming arbitrary thresholds; $\Omega < 3$ is 'bad' and this ocean hits that value in 2072!
- We are currently addressing 3 of the 5 of McCleod et al.'s priority needs for managers very well, thus should incorporate more projects to better address other two:
  - Determining species/habitat/community sensitivity to ocean acidification
  - Identifying potentially synergistic effects of multiple stressors

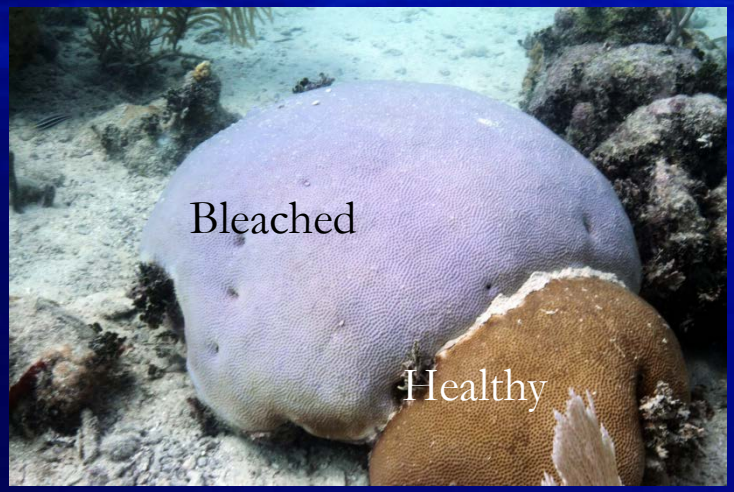
What are the potential future directions for this work?

- Link with new Coral Reef Omics initiative to understand genetic basis to better understand why certain corals are more resistant and/or resistant to climate and OA stress



Schematic of new aquaria facility for CO_2, temperature, and nutrient experiments

Same coral species



Different coral species

Bibliography: Summary statistics, 2007-2016

- 4.5 core personnel
  - Currently 2 Ph.D.s, 1.5 M.S., 1 B.S.
  - Less personnel before 2013 (2 in 2011; 3 in 2012)
- 33 peer-reviewed journal publications; 28 since 2010
  - 22 with ACCRETE 1st author
- 1 book, 6 book chapters, 4 conference proceeding articles
- Four television documentaries (1 more currently in production)
- Multiple articles
  - e.g., New York Times (2x), Scientific American (2x), Discovery News, National Geographic Online News, Miami Herald etc.
- 41 oral presentations at scientific conferences
  - 27 by ACCRETE presenter
- 12 poster presentations at scientific conferences
  - 7 by ACCRETE presenter
- 3 sessions chaired at scientific conferences
- Other
  - Google hangout, Nerd Nite Miami, Skype with scientists etc.

Bibliography: Peer-reviewed publications I

1. Enochs IC, Manzello DP, et al. (2016) Elevated colonization of microborers at a volcanically acidified coral reef. *PLoS ONE* 11(7): e0159818.
2. Humphreys A, Halfar J, Rivera F, Manzello DP, Reymond C, Westphal H, Riegl B (2016) Variable El Niño Southern Oscillation influence on biofacies dynamics of Eastern Pacific shallow water carbonate systems. *Geology* 44(7):571-574
3. Camp E, Smith D, Evenhuis C, Enochs IC, Manzello DP, Woodcock S, Suggett D (2016) Acclimatisation to high variance habitats does not enhance physiological tolerance of two key Caribbean corals to future temperature and pH. *Proceedings of the Royal Society B* 283(1831)
4. Enochs IC, Manzello DP, Wishing HH, Carlton R, Serafy J (2016) Micro-CT analysis of the Caribbean octocoral *Eunicea flexuosa* subjected to elevated pCO_2. *ICES Journal of Marine Science* 73(3):910-919
5. Manzello DP (2015) Rapid recent warming of coral reefs in the Florida Keys. *Scientific Reports* 5:16762; doi: 10.1038/srep16762
6. Towle E, Carlton R, Langdon C, Manzello DP (2015) In-situ measurement of metabolic status in three coral species from the Florida Reef Tract. *Regional Studies in Marine Science* 2:145-153
7. Towle E, Enochs, I, Langdon C (2015) Threatened Caribbean coral is able to mitigate the adverse effects of ocean acidification on calcification by increasing feeding rate. *PLoS ONE* 10(4): e0123394
8. Enochs IC, Manzello DP, et al. (2015) Shift from Coral to Macroalgae Dominance on a Volcanically Acidified Reef. *Nature Climate Change* doi:10.1038/nclimate2758
9. Manzello DP, Enochs IC, Kolodziej G, Carlton R (2015) Coral growth patterns of *Montastraea cavernosa* and *Porites astreoides* in the Florida Keys: the importance of thermal stress and inimical waters. *Journal of Experimental Marine Biology and Ecology* 471:198-207 doi: 10.1016/j.jembe.2015.06.010
10. Sutton A, Manzello DP, Gintert B (2015) Coupled chemical and biological monitoring to understand the impact of ocean acidification on coral reef ecosystems. *Oceanography* 28(2):12-13
11. Enochs IC, Manzello DP, et al. (2015) Ocean acidification enhances the bioerosion of a common coral reef sponge: implications for the persistence of the Florida Reef Tract. *Bulletin of Marine Science* 91:271-290 doi: 10.5343/bms.2014.1045
12. Manzello DP, Enochs IC, Kolodziej G, Carlton R (2015) Recent Decade of Growth and Calcification of *Orbicella faveolata* in the Florida Keys: An Inshore-Offshore Comparison. *Marine Ecology Progress Series* 521:81-89, doi: 10.3354/meps11085.
13. Manzello DP, Enochs IC, et al. (2014) Galápagos Coral Reef Persistence after ENSO Warming Across an Acidification Gradient. *Geophysical Research Letters* 41 (24):9001-9008
14. Glynn PW, Enochs I, Afflerbach J, Brandtneris V, Serafy,J (2014) Eastern Pacific reef fish responses to coral recovery following El Nino disturbances. *Marine Ecology Progress Series* 495: 233-247
15. Enochs IC, Manzello DP, et al. (2014) Effects of light and elevated pCO_2 on the growth and photochemical efficiency of *Acropora cervicornis*. *Coral Reefs* 33(2):477-485.
16. van Hooidonk R, Maynard J, Manzello DP, Planes S (2014) Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. *Global Change Biology* 20(1):103-112
17. Manzello DP, Enochs IC, Musielewicz S, Carlton R, Gledhill DK (2013) Tropical Cyclones Cause $CaCO_3$ Undersaturation of Coral Reef Seawater in a High-CO_2 World. *Journal of Geophysical Research: Oceans* 118(10): 5312-5321

Bibliography: Peer-reviewed publications II

18. Bignami S, Enochs IC, Manzello DP, Sponaugle S, Cowen RK (2013) Ocean acidification alters the otoliths of a pan-tropical fish species with implications for sensory function. *Proceedings of the National Academy of Sciences USA* 110 (19):7366-7370
19. Manzello DP, Enochs IC, Melo N, Gledhill DK, Johns EM (2012) Ocean Acidification Refugia of the Florida Reef Tract. *PLoS ONE* 7(7): e41715. doi:10.1371/journal.pone.0041715.
20. Enochs IC, Manzello DP (2012) Species richness of motile cryptofauna across a gradient of framework erosion. *Coral Reefs* 31:653-661.
21. Enochs IC, Manzello DP (2012) Responses of Cryptofaunal Species Richness and Trophic Potential to Coral Reef Habitat Degradation. *Diversity* 4:94-104.
22. Toth L, Aronson R, Vollmer S, Hobbs J, Urrengo D, Cheng H, Enochs I, Combosch D, van Woesik R, Macintyre I (2012) ENSO drove 2500-year collapse of eastern Pacific coral reefs. *Science* 337(6090):81-84.
23. van Hooidonk R, Manzello DP, Moye J, Brandt M, Hendee J, McCoy C, Manfrino C (2012) Coral bleaching in Little Cayman, Cayman Islands 2009. *Estuarine Coastal and Shelf Science* 106:80-84
24. Mcleod E, Anthony KRN, Andersson A, Beeden R, Kleypas J, Kroeker K, Manzello DP, Salm R, Schuttenberg H, Smith JE (2012) Preparing to manage coral reefs for ocean acidification: Lessons from coral bleaching. *Frontiers in Ecology and the Environment* 11:20-27, doi:10.1890/110240
25. Enochs IC, Toth LT, Brandtneris VW, Afflerbach JC, Manzello DP (2011) Environmental determinants of motile cryptofauna on an eastern Pacific coral reef. *Marine Ecology Progress Series* 438:105-118.
26. Lirman D, Schopmeyer S, Manzello DP, et al. (2011) Severe 2010 cold-water event caused unprecedented mortality to corals of the Florida Reef Tract and reversed previous survivorship patterns. *PLoS ONE* 6(8): e23047.
27. Manzello DP (2010) Coral growth with thermal stress and ocean acidification: Lessons from the eastern Pacific. *Coral Reefs* 29 (3):749-758.
28. Manzello DP (2010) Ocean acidification hotspots: Spatiotemporal dynamics of the seawater CO2 system from eastern Pacific coral reefs. *Limnology and Oceanography* 55 (1):239-248.
29. Manzello DP, Warner ME, Stabenau E, Hendee JC, Lesser MP, Jankulak M (2009) Remote monitoring of chlorophyll fluorescence in two reef corals during the 2005 bleaching event at Lee Stocking Island, Bahamas. *Coral Reefs* 28: 209-214.
30. Lirman D, Manzello DP (2009) Patterns of resistance and resilience of the stress-tolerant coral Siderastrea radians (Pallas) to sub-optimal salinity and sediment burial. *Journal of Experimental Marine Biology and Ecology* 369: 72-77.
31. Manzello DP, Kleypas JA, Budd DA, Eakin CM, Glynn PW, Langdon C (2008) Poorly cemented coral reefs of the eastern tropical Pacific: possible insights into reef development in a high-CO2 world. *Proceedings of the National Academy of Sciences USA* 105 (30):10450-10455.
32. Manzello DP, Brandt M, Smith TB, Lirman D, Hendee JC, Nemeth R (2007) Hurricanes benefit bleached corals. *Proceedings of the National Academy of Sciences USA* 104 (29): 12,035-12,039.
33. Manzello DP, Berkelmans RW, Hendee JC (2007) Coral bleaching indices and thresholds for the Florida Reef Tract, Bahamas, and St. Croix, U.S. Virgin Islands. *Marine Pollution Bulletin* 54:1923-1931.

Peer-reviewed Book chapters, Conference Proceedings, Newletters

1. Glynn PW, Manzello DP, Enochs IC [eds] (2016) *Coral Reefs of the Eastern Tropical Pacific: Persistence and Loss in a Dynamic Environment*. Springer. 655 p.
2. Manzello DP, Eakin CM, Glynn PW (2016) Effects of Global Warming and Ocean Acidification on Carbonate Budgets of Eastern Pacific Coral Reefs. In: Glynn PW, Manzello DP, Enochs IC (eds), *Coral Reefs of the Eastern Tropical Pacific: Persistence and Loss in a Dynamic Environment*. Springer, p 517-533, Enochs I, Glynn PW (2016) Corallivory in the eastern Pacific. In: P.W. Glynn, Manzello, D.P., Enochs, I.C. (eds.) *Coral reefs of the eastern tropical Pacific: Persistence and loss in a dynamic environment*. Springer
3. Enochs I, Glynn PW (2016) Trophodynamics of eastern Pacific coral reefs. In: P.W. Glynn, Manzello, D.P., Enochs, I.C. (eds.) *Coral reefs of the eastern tropical Pacific: Persistence and loss in a dynamic environment*. Springer
4. J Cortés, Enochs I, et al. (2016) Marine biodiversity of eastern tropical Pacific coral reefs. In: P.W. Glynn, Manzello, D.P., Enochs, I.C. (eds.) *Coral reefs of the eastern tropical Pacific: Persistence and loss in a dynamic environmen*t. Springer
5. Glynn PW, Manzello DP (2015) Bioerosion and Coral Reef Growth: A Dynamic Balance. In: Birkeland C (ed) *Coral Reefs in the Anthropocene*. Springer, Dordrecht. pp. 67-97.
6. Manzello DP, Shamberger KEF (2015) Is there a CO2 tipping point for coral reefs? Ocean Carbon and Biogeochemistry News 8 (1):1-2
7. NCRMP Working Group (In alphabetical order): Brainard R, Caldow C, Eakin M, Gittings S, Gledhill D, Hill R, Jeffrey C, Karazsia J, Kosaki R, Loper C, Manzello DP, Miller M, Piniak G, Schroeder B, Schull J, Vargas-Angel B, Williams I (2014). National Coral Reef Monitoring Plan (NCRMP). Silver Spring, MD, NOAA Coral Reef Conservation Program. 40 p.
8. Glynn PW, Enochs I (2010) Invertebrates and their roles in coral reef ecosystems. In: Z. Dubinsky, Stambler, N. (eds.) *Coral reefs: an ecosystem in transition*. Springer. pp 273-326.
9. Gledhill DK, Goedeke T, Helmle K, Hendee J, Hilting A, Jewett E, Keller B, Manzello DP, Miller M, Rule E, Sunda B, Van Dolah F, Wanninkhof R (2010) Southeast Atlantic and Gulf of Mexico Region Ocean Acidification Research Plan. In: NOAA Ocean Acidification Steering Committee (eds.), NOAA Ocean and Great Lakes Acidification research plan. NOAA Spec. Rpt. pp. 77-94
10. Brainard RE, Bainbridge S, Brinkman R, Eakin CM, Field M, Gattuso J-P, Gledhill D, Gramer L, Hendee J, Hoeke R, Holbrook S, Hoegh-Guldberg O, Lammers M, Manzello DP, McManus M, Moffitt R, Monaco M, Morgan J, Obura D, Planes S, Schmitt R, Steinberg C, Sweatman H, Vetter O, Wong K (2009) An International Network of Coral Reef Ecosystem Observing Systems (I-CREOS). *Proceedings of OceanObs09, Venice, Italy*, 21-25 Sept. 2009. 25 p.
11. Manzello DP, Kleypas JA (2009) Reef development in a high-CO2 world: Coral reefs of the eastern tropical Pacific. *Global Change Newsletter* 73: 24.
12. Manzello DP (2009) Reef development and resilience to acute (El Niño warming) and chronic (high-CO2) disturbances in the eastern tropical Pacific: a real-world climate change model. *Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, USA*, 1299-1304.
13. Hendee JC, Gramer L, Manzello DP, Jankulak M (2009) Ecological forecasting for coral reef ecosystems. *Proceedings of the 11th Intl Coral Reef Symposium, Ft. Lauderdale, USA*, 534-539.
14. Hendee JC, Gramer L, Manzello DP, Jankulak M (2008) Integrating near real-time data for coral reef ecological forecasting. *Proceedings of the Gulf and Caribbean Fisheries Institute* 59:525-528.
15. Hendee JC, Gramer L, Kleypas JA, Manzello DP, Jankulak M, Langdon C (2007) The Integrated Coral Observing Network: Sensor solutions for sensitive sites. *3rd Intl Conf on Intelligent Sensors, Sensor Networks and Information*, 669-673.

Bibliography: Select Media Coverage

- TV documentaries
  - Waterways, Ocean Acidification and Tortugas Tide Gauge: https://www.youtube.com/watch?v=rAvhOrp81dg
  - PBS Television, Changing Seas, Galápagos: Windows into the future: http://www.changingseas.tv/episode603.html
  - PBS Television, Changing Seas, Maug's Caldera: A Natural Laboratory: http://www.changingseas.tv/episode803.html

- Articles
  - Discovery News, Fla. Coral Bleaching Could Soon Occur Yearly: http://news.discovery.com/earth/oceans/fla-coral-bleaching-could-soon-occur-yearly-151125.htm
  - Science News, Galápagos waters preview future for corals: https://www.sciencenews.org/article/gal%C3%A1pagos-waters-preview-future-corals
  - The New York Times, Near Miss by Hurricane Can Bring a Big Chill to Overheated Coral Reefs: http://www.nytimes.com/2007/07/17/science/17obse2.html?ref=science
  - The New York Times, Pacific Region May Show The Future of Coral Reefs In More Acidic Oceans: http://www.nytimes.com/2008/07/29/science/earth/29obreef.html?ref=science
  - Scientific American, Water too hot? Hope for a hurricane: http://www.scientificamerican.com/article.cfm?id=water-too-hot-hope-for-hurricane
  - Scientific American, As Ocean Warms, Coral Loses Anchor in Acidic Waters: http://www.scientificamerican.com/article.cfm?id=coral-reefs-lose-grip-under-global-warming
  - National Geographic News, Hurricanes Heal Reefs in Surprising Cases: http://news.nationalgeographic.com/news/2007/07/070702-hurricane-coral.html