Long-term Monitoring of Ecological Impacts of Ocean Acidification on Coral Reefs

Rusty Brainard[1], T Oliver[2,1], C Young[2,1], M Timmers[2,1], R Feely[3], S Alin[3], A Sutton[3], D Gledhill[4], L Jewett[4], A Cohen[5], T DeCarlo[5], N Price[6], A Dickson[7], T Martz[7], A Andersson[7], N Knowlton[8], C Meyer[8], D Manzello[9], I Enochs[9], G Paulay[10], R Toonen[11], F Rohwer[12], S Khokiattiwong[13], A Chavanich[14], W Zhu[15], and many others (and hopefully many of you…)

1 NOAA Pacific Islands Fisheries Science Center, Honolulu
2 Joint Institute for Marine and Atmospheric Research, Honolulu
3 NOAA Pacific Marine Environmental Laboratory, Seattle
4 NOAA Ocean Acidification Program, Silver Spring
5 Woods Hole Oceanographic Institute, Woods Hole
6 Bigelow Lab, Univ. of Maine,
7 Scripps Institution of Oceanography, Univ. California San Diego
8 National Museum of Natural History, Smithsonian Institution, Washington
9 NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami
10 Florida Museum of Natural History, University of Florida, Gainsville
11 UH-Hawaii Institute of Marine Biology, Kaneohe
12 San Diego State University, San Diego
13 Phuket Marine Biological Lab, Phuket,Thailand
14 Chulalongkorn Univ.Thailand
15 UNESCO IOC WESTPAC, Bangkok, Thailand

Pacific Island OA Workshop, Auckland, New Zealand 7-9 Oct 2015

Why Care About Ocean Acidification?

Coral reefs provide many benefits for people: men and women, young and old, rich and poor!

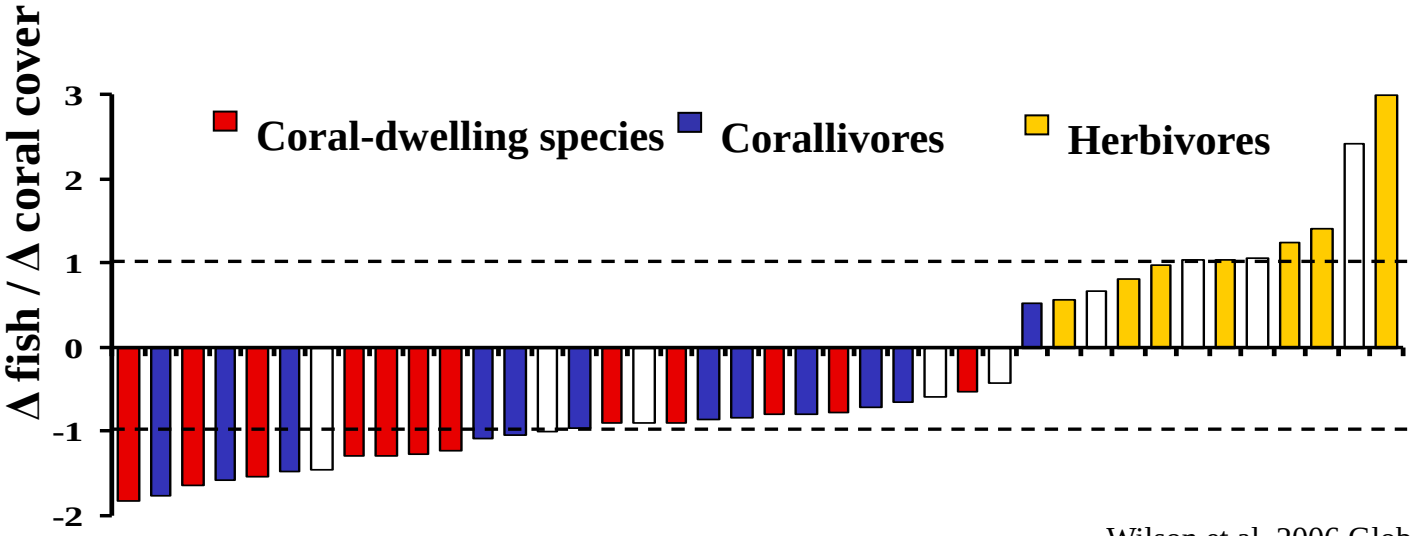
including all of the Pacific Islands countries

Coral reef ecosystems, fisheries, biodiversity, & the ecosystem goods & services they provide are now threatened by OCEAN ACIDIFICATION!

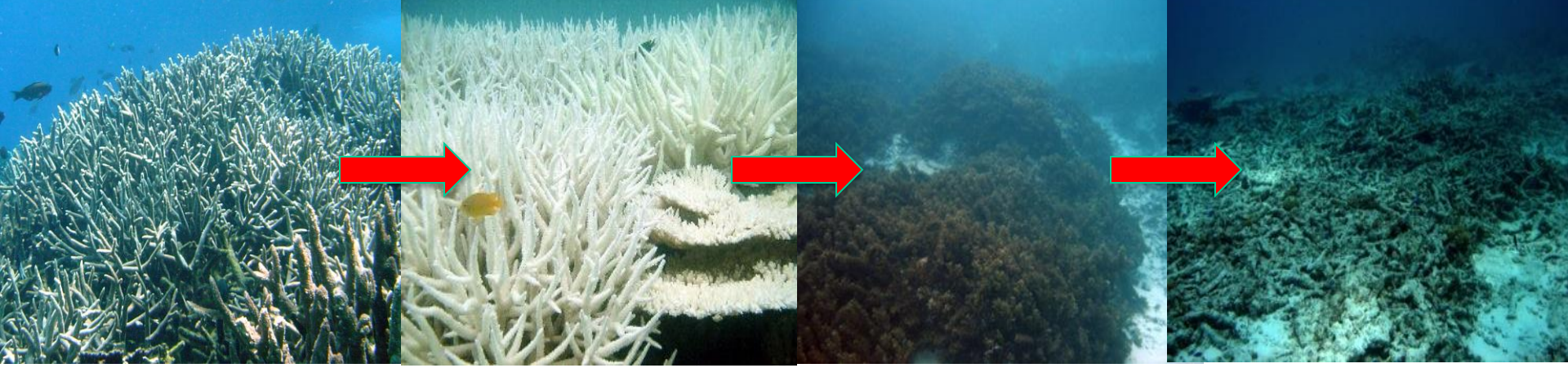
We need improved information about the current and future impacts of ocean acidification to improve management decision-making and adaptation strategies.

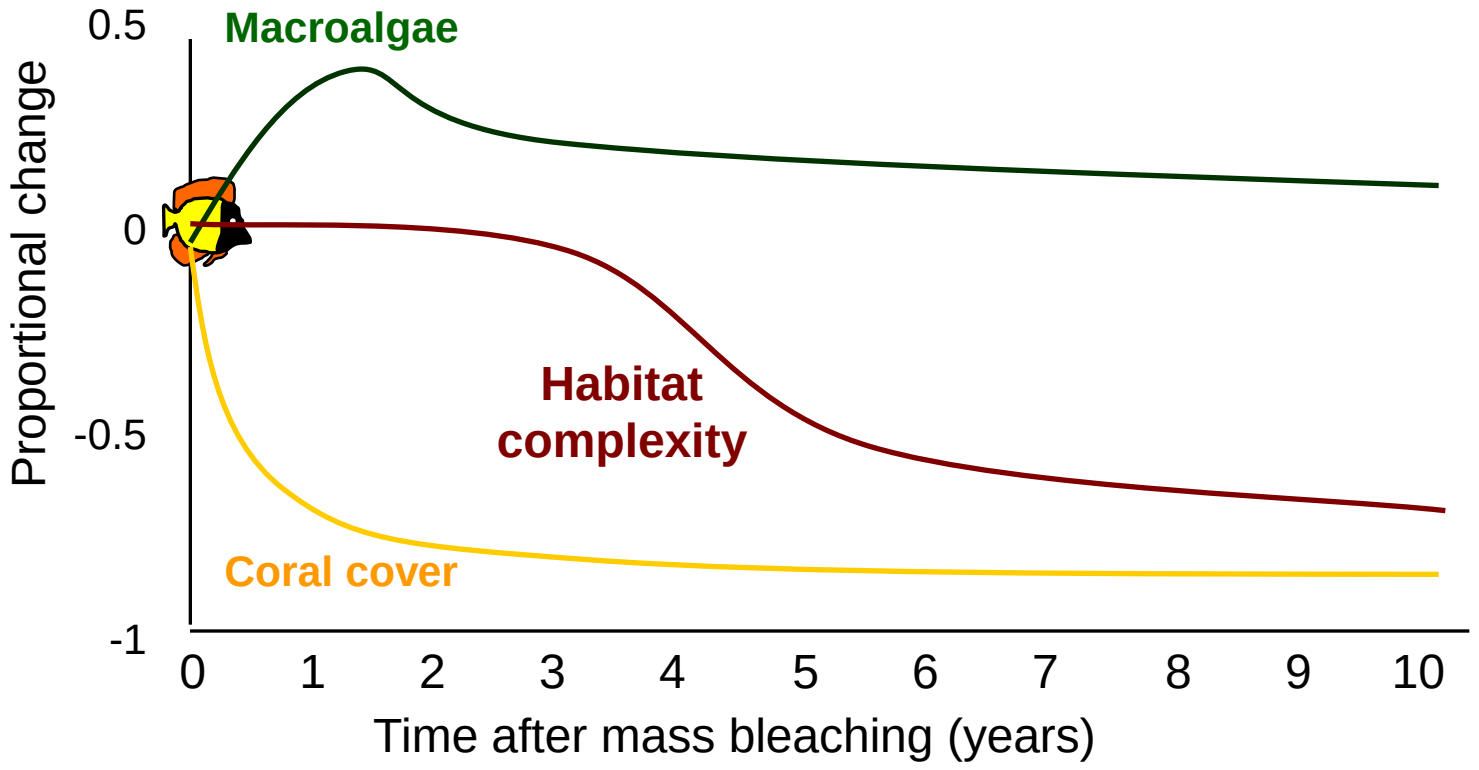
Why It Matters
(Example: mass coral mortality)

- 10 % of coral reef fishes are coral dependent, so directly affected by coral loss
- But, 75% of fish species declined following coral decline
- 50% of fish species declined by >50%



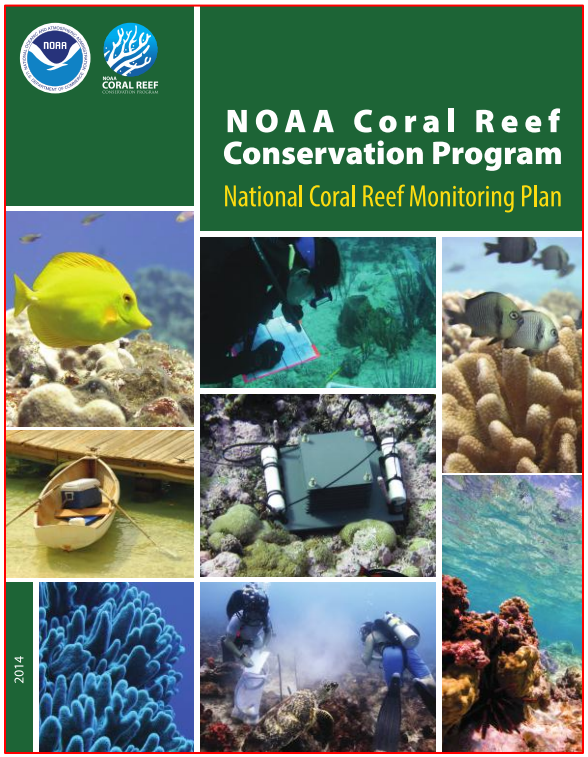
Wilson et al. 2006 Global Change Biology 12, 2220-2234





Slide courtesy Phil Munday (JCU)

NCRMP



In the Pacific Islands Region, NCRMP has been implemented thru the Pacific Reef Assessment and Monitoring Program (Pacific RAMP) since 2000/2001.

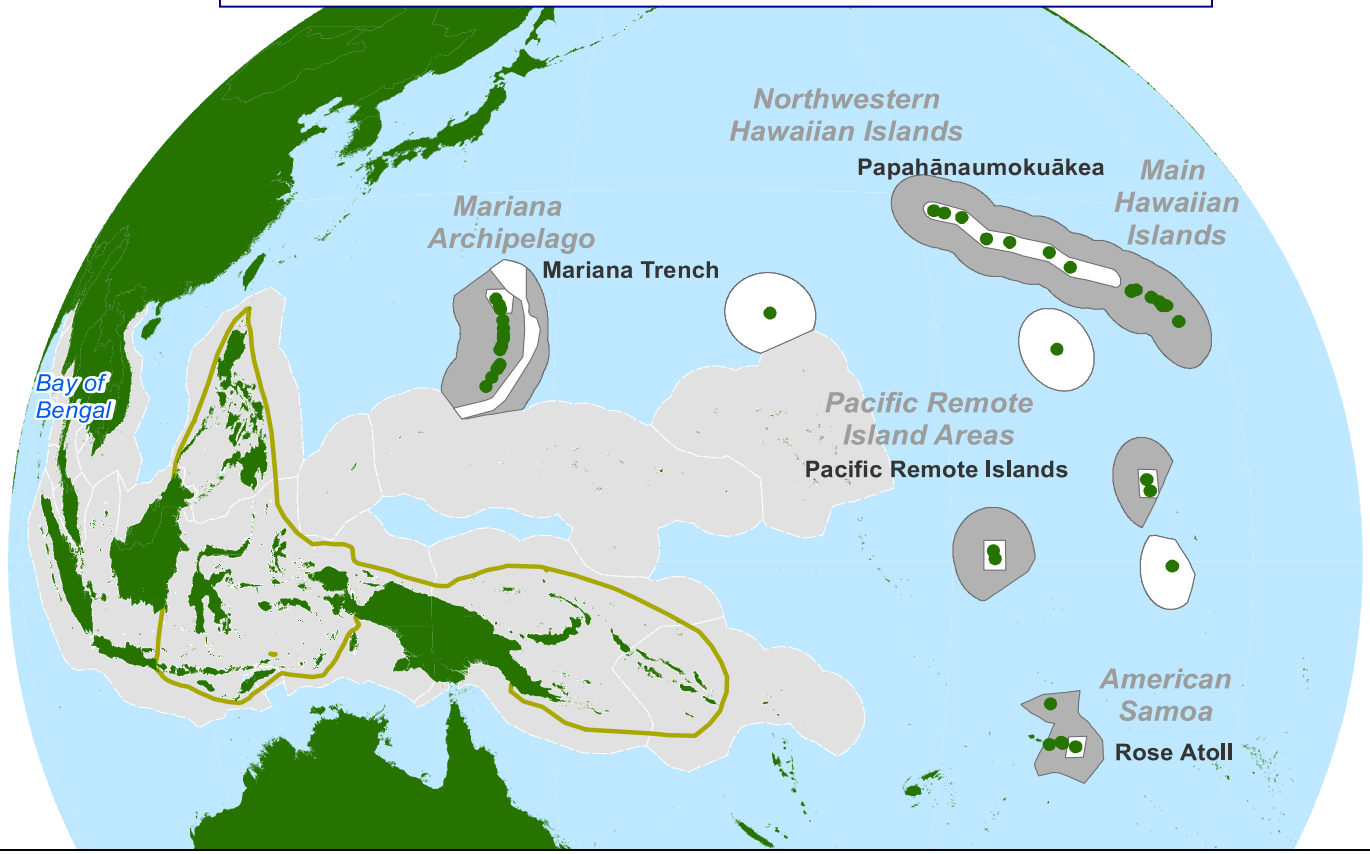
Table 1. NCRMP general themes and core indicators recommended by the Working Group and committed to implementation by the NOAA Coral Reef Conservation Program. * indicates Tier 2 (Important) indicators included in the NCRMP via partnership with the NOAA Ocean Acidification Program.

Monitoring Themes	Tier 1 (Critical) Indicators
Biological	
• **Coral and Benthos**	• Coral abundance and size structure • Coral condition (bleaching and disease incidence, mortality) • Benthic percent cover • Benthic key species • Rugosity
• **Reef Fish**	• Fish abundance and size structure • Fish diversity • Fish key species
Climate	
• **Thermal Stress**	• Temperature/thermal stress • Vertical thermal structure
• **Ocean Acidification**	• Carbonate chemistry
• **Ecological Impacts***	• Coral growth rate* • Bioerosion rate* • Community structure* (cryptofauna diversity)
Socioeconomics	• Knowledge, attitudes, and perceptions of coral reefs and management strategies • Participation in coral reef activities • Population changes and distribution • Economic dependence on coral reefs

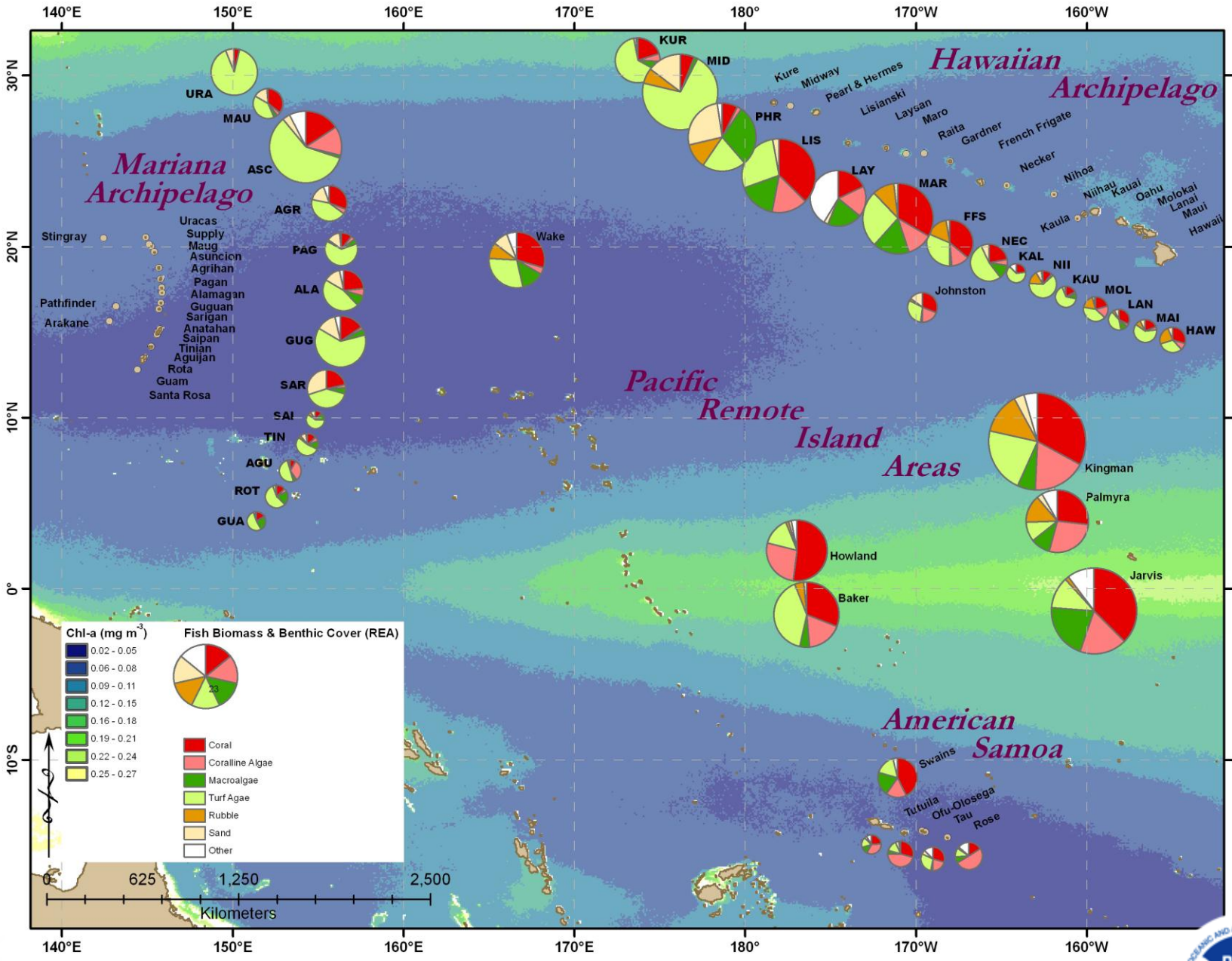
Written by the National Coral Reef Monitoring Plan (NCRMP) Working Group:
Rusty Brainard, Chris Caldow, Mark Eakin, Steve Gittings, Dwight Gledhill, Ron Hill, Chris Jeffrey, Jocelyn Karazsia, Randy Kosaki, Christy Loper, Derek Manzello, Margaret Miller, Greg Piniak, Bob Schroeder, Jennifer Schull, Bernardo Vargas-Angel, and Ivor Williams.

Editor: Jessica Morgan

Pacific RAMP



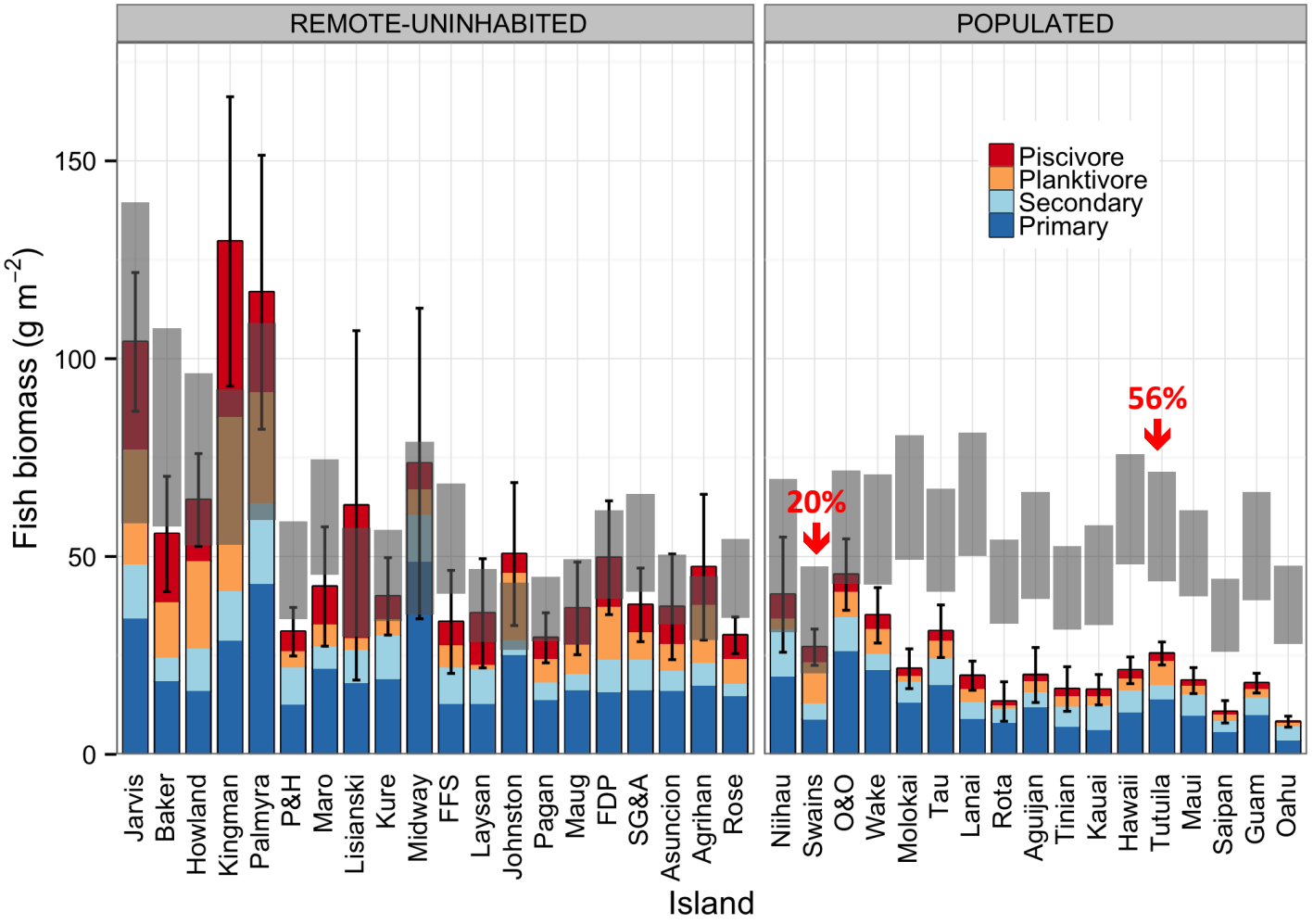
- Long-term Monitoring of Abundance, Distribution, Diversity, Condition of reef fishes, corals, invertebrates, & algae
- Monitoring ocean acidification & warming
- 'Wide-but-thin' approach to monitor shallow (<30m) reefs
- Consistent, repeatable, comparable methods
- Robust change detection at 'island scale'



NOAA CORAL REEF CONSERVATION PROGRAM

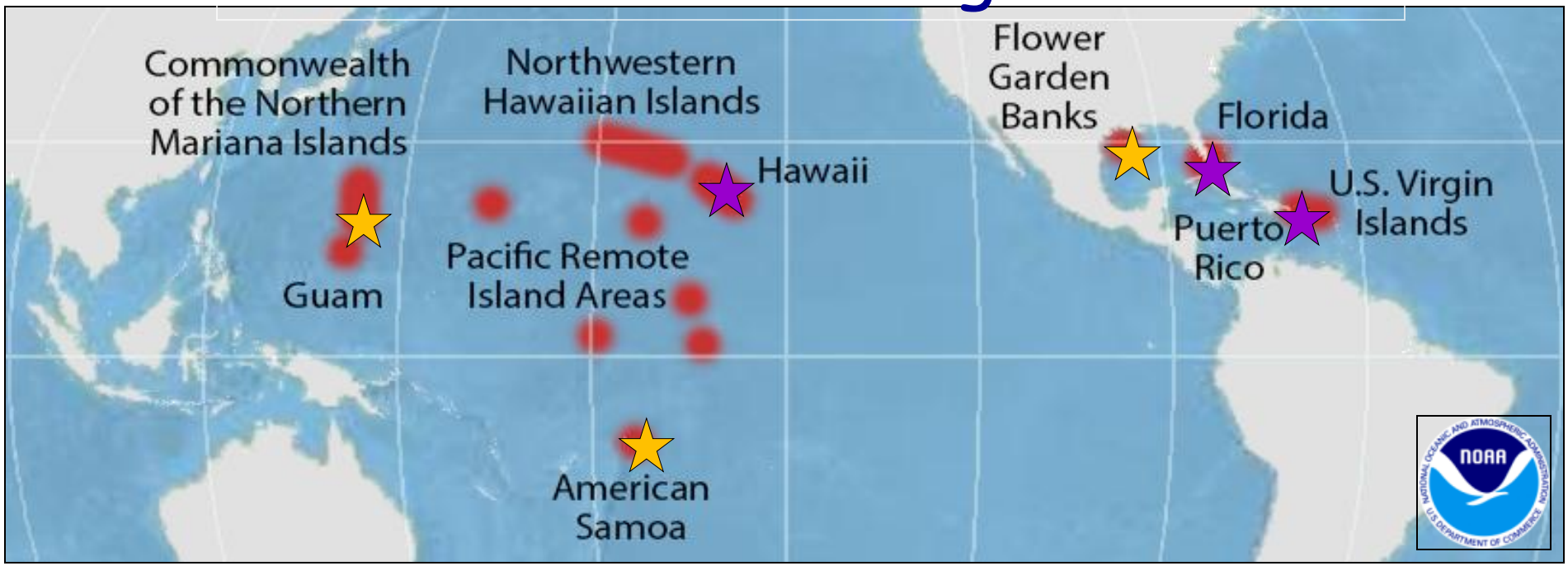
Brainard et al, 2010

Pristine Fish Biomass Reference



Williams et al., (in review)

NCRMP Ocean Acidification Monitoring

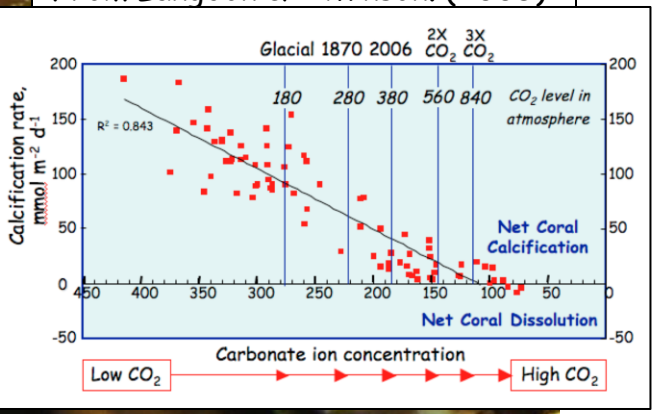


- **Goals**:
  - Scientifically sound, consistent methods
  - Strong partnerships
  - Geographically comprehensive status & trends data
  - Deliver products & tools to support decision making
- **OA Objective:** Document & track a suite of metrics long-term *most valuable towards discerning specific attribution* of changes in coral reef ecosystems in response to ocean acidification (OA).

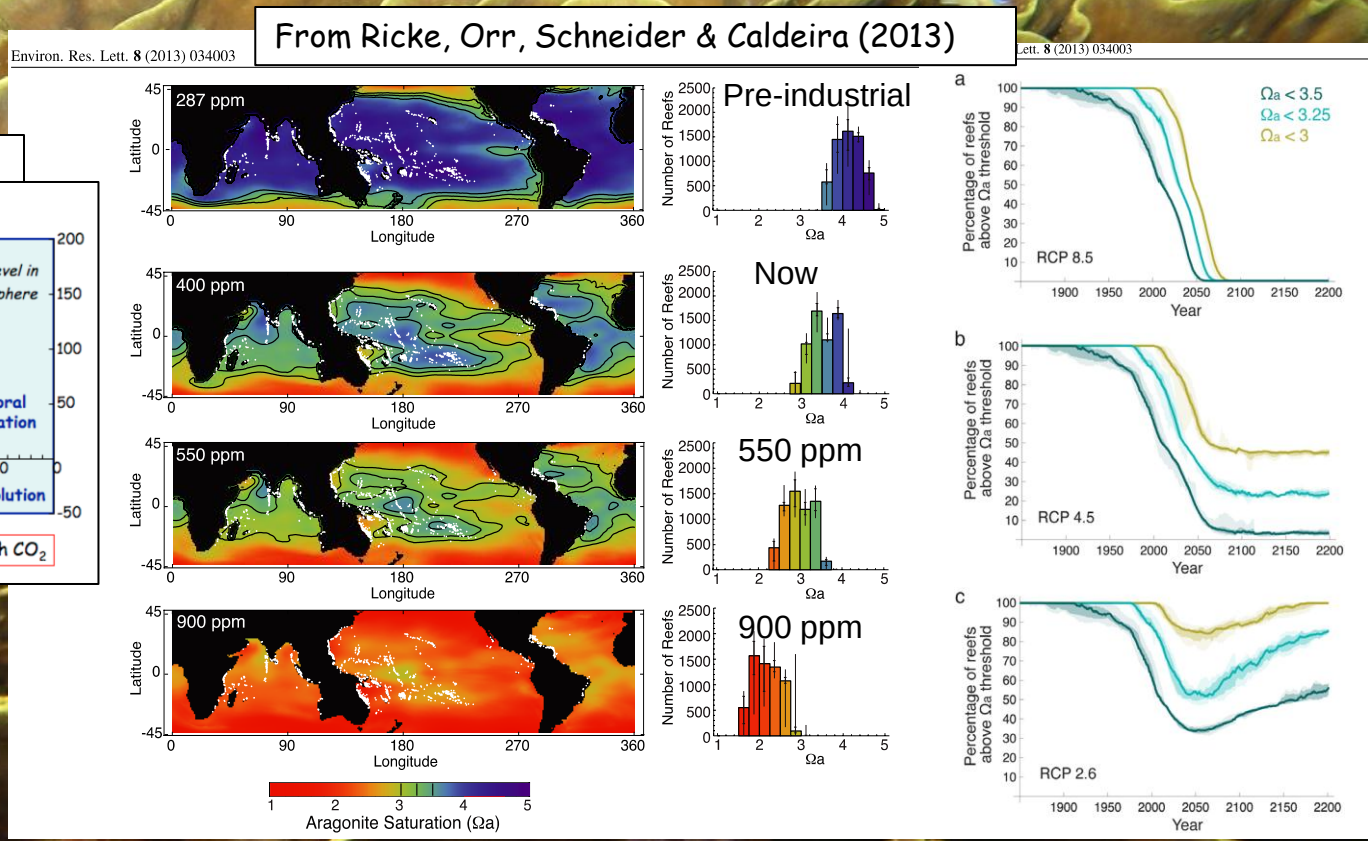
Calcification/Recruitment

- Simplified experiments/models have shown corals and reef-building crustose coralline algae are highly vulnerable to OA:
  - Reduced calcification/growth
  - Reduced settlement/recruitment
- Will this happen in nature? Or,, does nature provide more resilience?
  → need long-term global observations

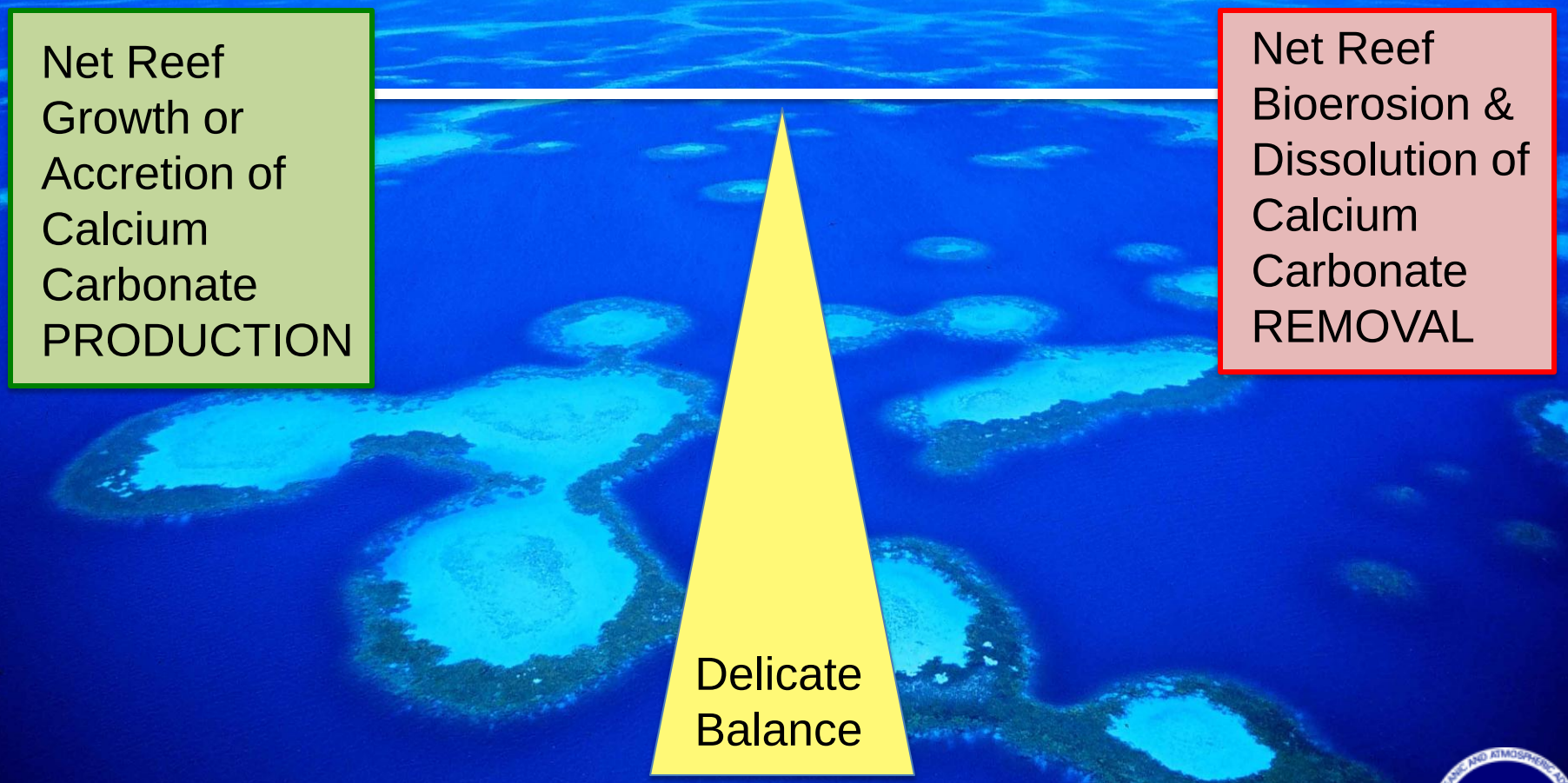
From Langdon & Atkinson. (2005)



From Ricke, Orr, Schneider & Caldeira (2013)

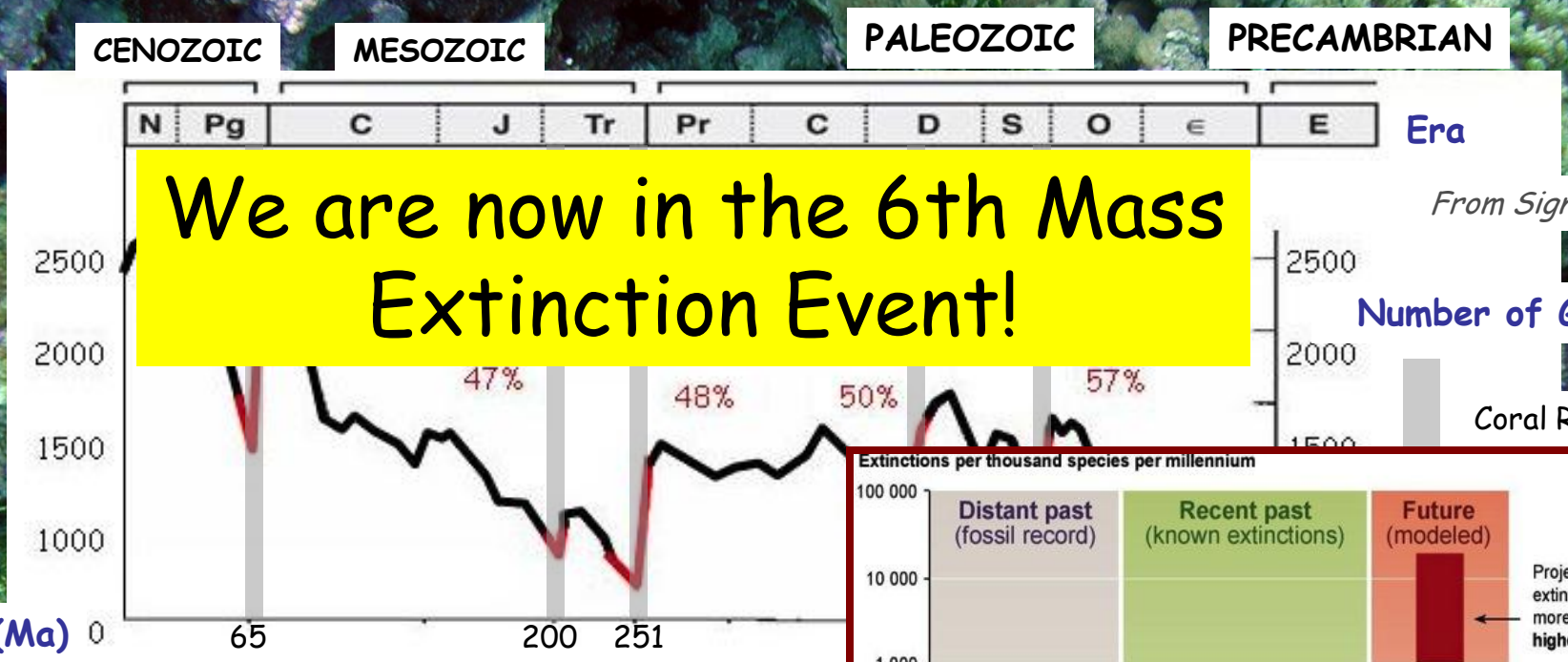


Reef Survival Requires Balance

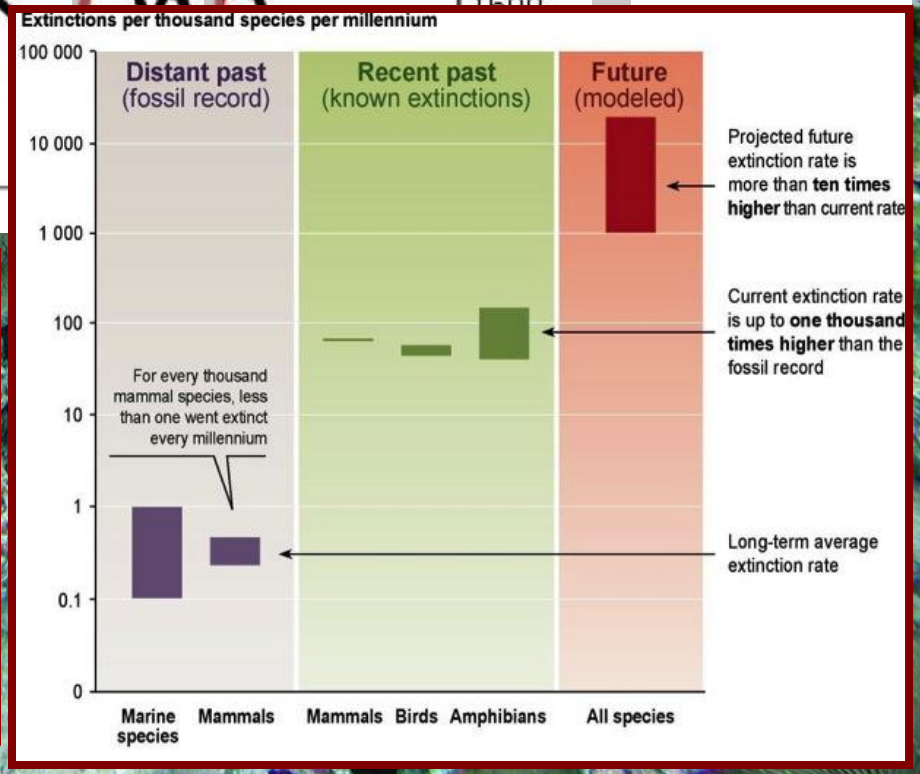


→ need long-term global observations in nature

Biodiversity Loss



We are now in the 6th Mass Extinction Event!



- Extinction rates have already increased ~100X
- Predicted to increase >100X this century

→ Lost Resilience?
→ lost function?
→ lost ecosystem services?

OPEN ACCESS Freely available online

PLoS one

The Diversity of Coral Reefs: What Are We Missing?

Laetitia Plaisance[1,2]*, M. Julian Caley[3], Russell E. Brainard[4], Nancy Knowlton[1,2]

1 Department of Invertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, D.C., United States of America, 2 Centre for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California, United States of America, 3 Australian Institute of Marine Science, Townsville, Australia, 4 Coral Reef Ecosystem Division, Pacific Islands Fisheries Science Center, National Oceanic and Atmospheric Administration, Honolulu, Hawaii, United States of America

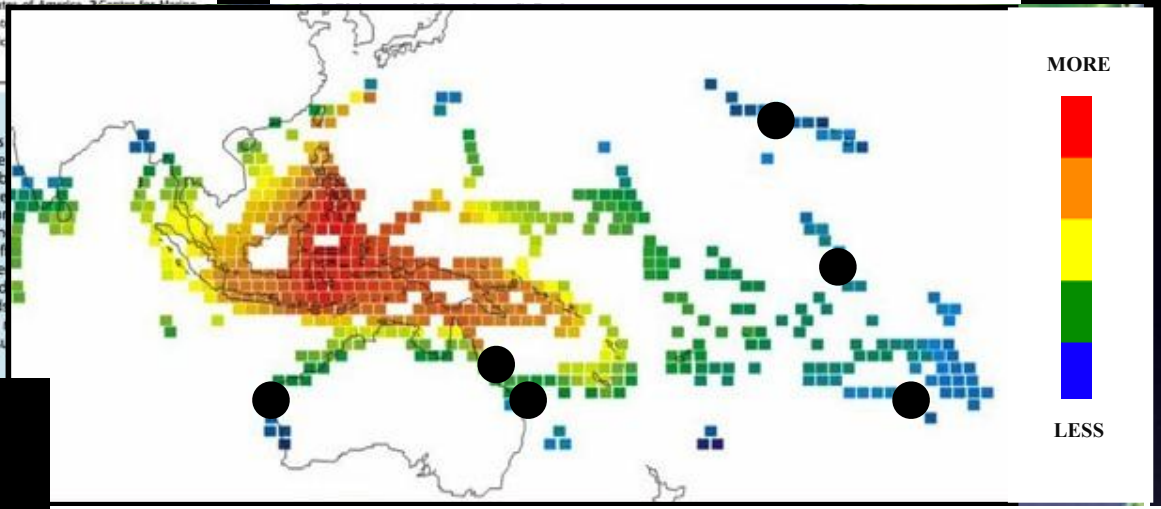
Abstract

Tropical reefs shelter one quarter to one third of all marine species but one third of the coral species now at risk of extinction. Because traditional methods for assessing reef diversity are extremely time expertise for many groups is lacking, and marine organisms are thought to be less vulnerab discussions of reef conservation focus on maintenance of ecosystem services rather than biodive involving the three major oceans with reef growth, we provide new biodiversity estimates based o and DNA barcoding. We focus on crustaceans, which are the second most diverse group of marin exceptionally high numbers of crustacean species associated with coral reefs relative to sampling ef combined, globally distributed sample area of 6.3 m^2). The high prevalence of rare species (38% e the low level of spatial overlap (81% found in only one locality) and the biogeographic patterns of d West Pacific>Central Pacific>Caribbean) are consistent with results from traditional survey method a reliable and efficient method for assessing and monitoring biodiversity. The finding of such large small total area suggests that coral reef diversity is seriously under-detected using traditional su implication, underestimated.

Coral Reefs (2009) 28:977–986
DOI 10.1007/s00338-009-0543-3

REPORT

Reef-associated crustacean fauna: biodiversity estimates using semi-quantitative sampling and DNA barcoding



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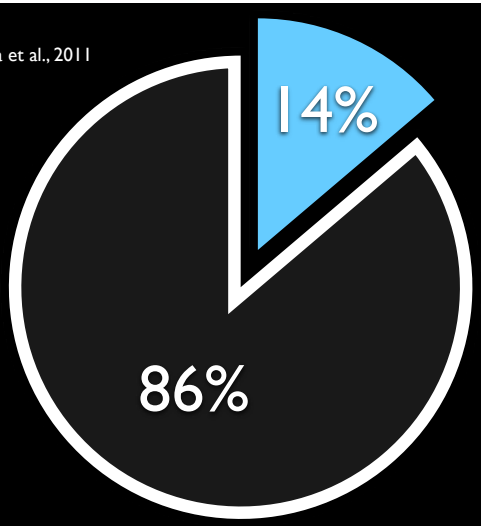
PLoS BIOLOGY

How Many Species Are There on Earth and in the Ocean?

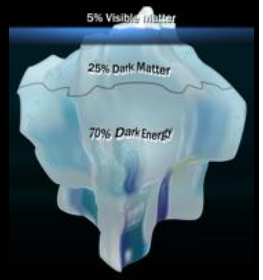
Camilo Mora[1,2]*, Derek P. Tittensor[1,3,4], Sina Adl[1], Alastair G. B. Simpson[1], Boris Worm[1]

1 Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada, 2 Department of Geography, University of Hawaii, Honolulu, Hawaii, United States of America, 3 United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, United Kingdom, 4 Microsoft Research, Cambridge, United Kingdom

Mora et al., 2011



known
unknown



1.5 done,
7.2 million to go

National Geographic

Report

Current Biology

Species Richness on Coral Reefs and the Pursuit of Convergent Global Estimates

Highlights

- We estimate that there are 830,000 (550,000–1,330,000) species on coral reefs worldwide
- Species richness and asymmetrical uncertainties were estimated using expert knowledge
- Uncertainties differ among taxa and should guide future research effort

Authors

Rebecca Fisher, Rebecca A. O'Leary, ..., Russell E. Brainard, M. Julian Caley

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In Brief

Fisher et al. use expert taxonomic

Fisher et al., 2015, Current Biology 25, 500–505
February 16, 2015
http://dx.doi.org/10.1016/j.cub.2014.12.022

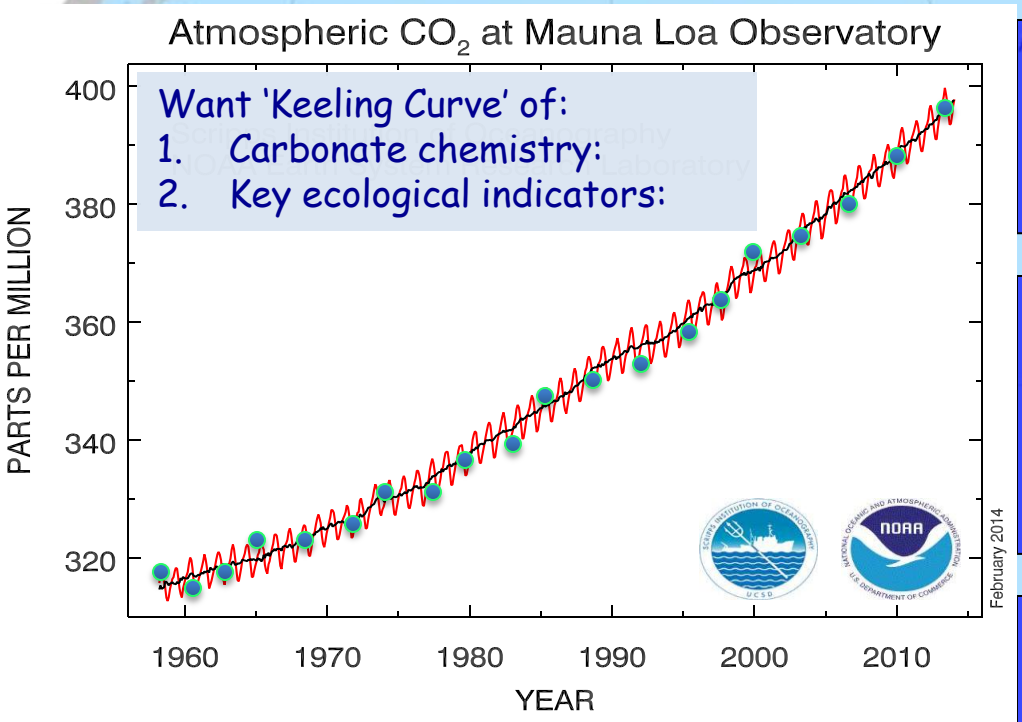
CrossMark

CellPress

Monitoring Ecological Impacts of OA

Establishing baseline observations to monitor long-term changes of:

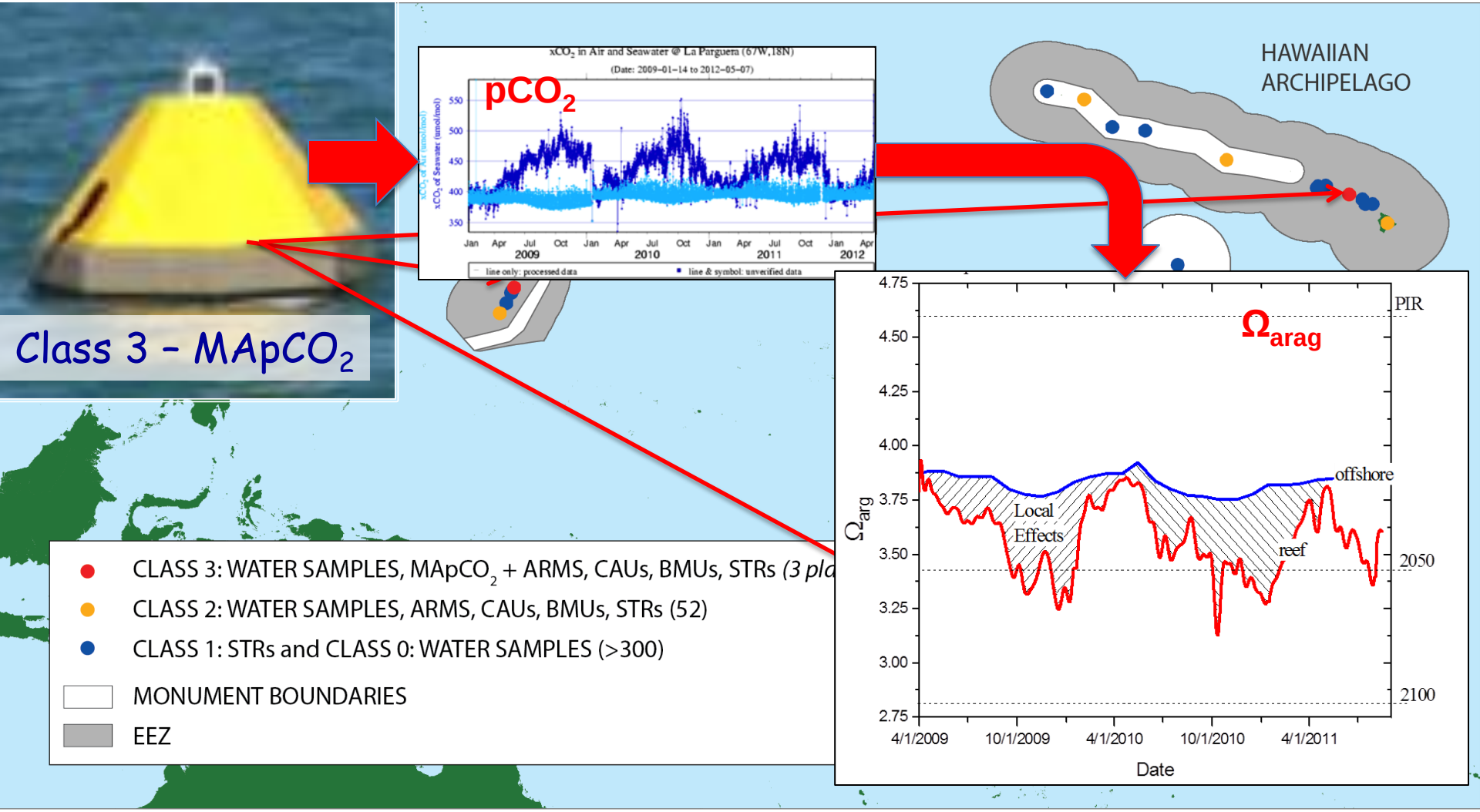
- Carbonate chemistry DIC, TA, S → pH, Ω
- Calcification rates (Coring, CAUs)
- Bioerosion rates (BMUs)



- Crytobiota diversity (ARMS)
- Microbial diversity (environmental water sampling)
- Benthic rugosity

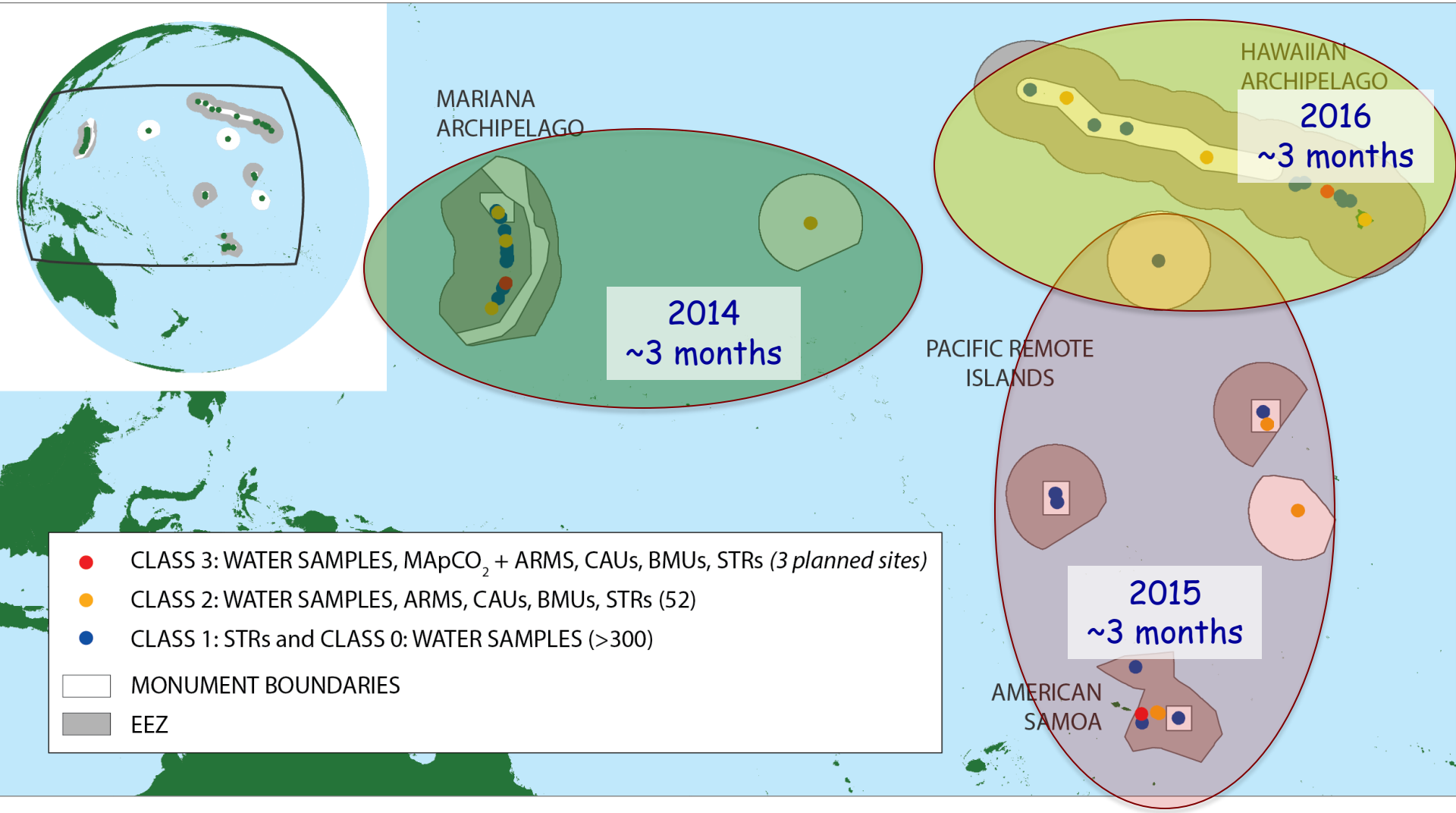
→ Spatially distributed, consistent, repeatable, long-term observations of key indicators to robustly document changes in natural coral reefs attributable to OA

Pacific RAMP OA Hierarchical Observing Network



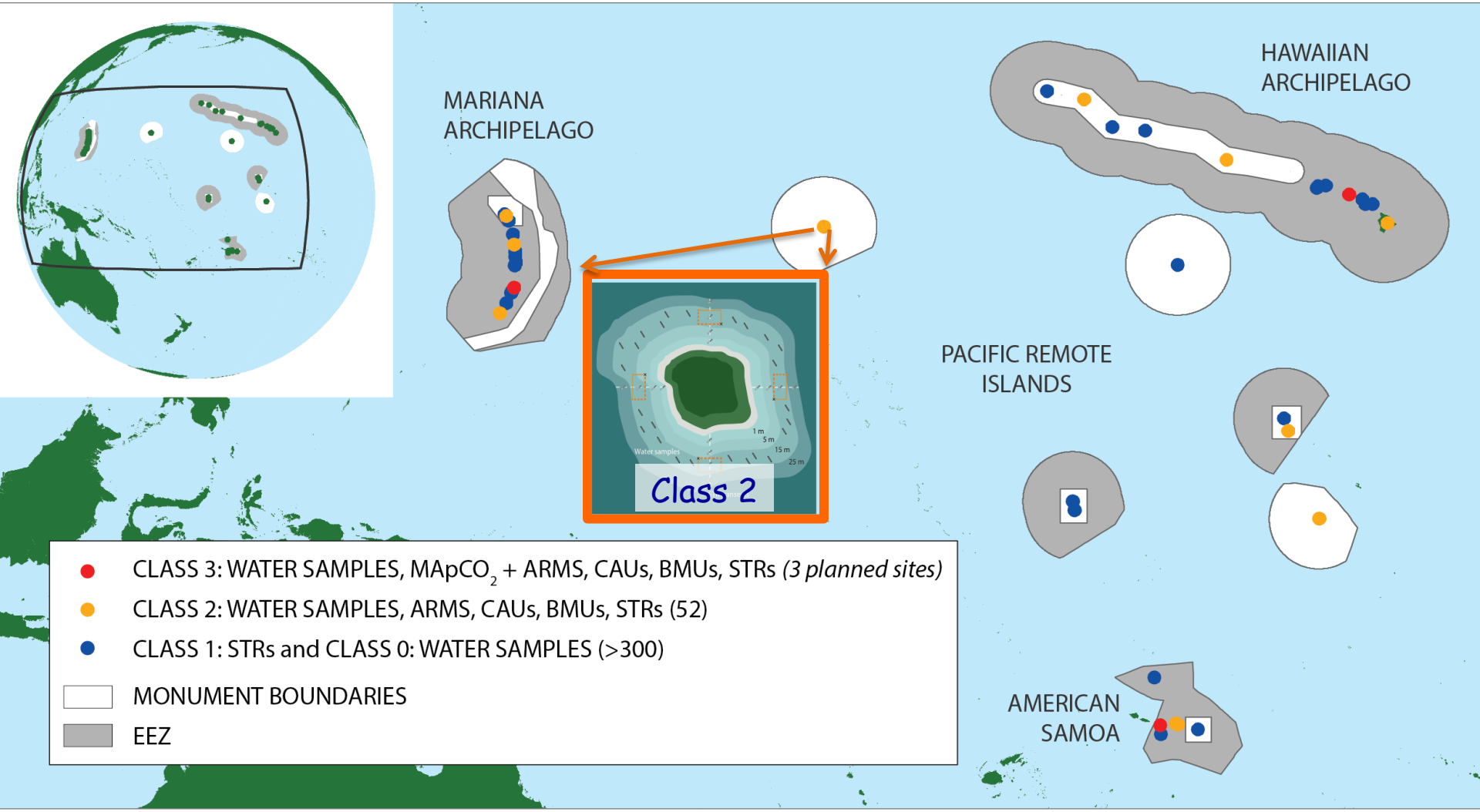
Observing across gradients of environmental/oceanographic conditions, biodiversity, human uses and impacts

Pacific RAMP OA
3-Year Observing Cycle



Observing across gradients of environmental/oceanographic conditions, biodiversity, human uses and impacts

Pacific RAMP OA Class 2 Sites



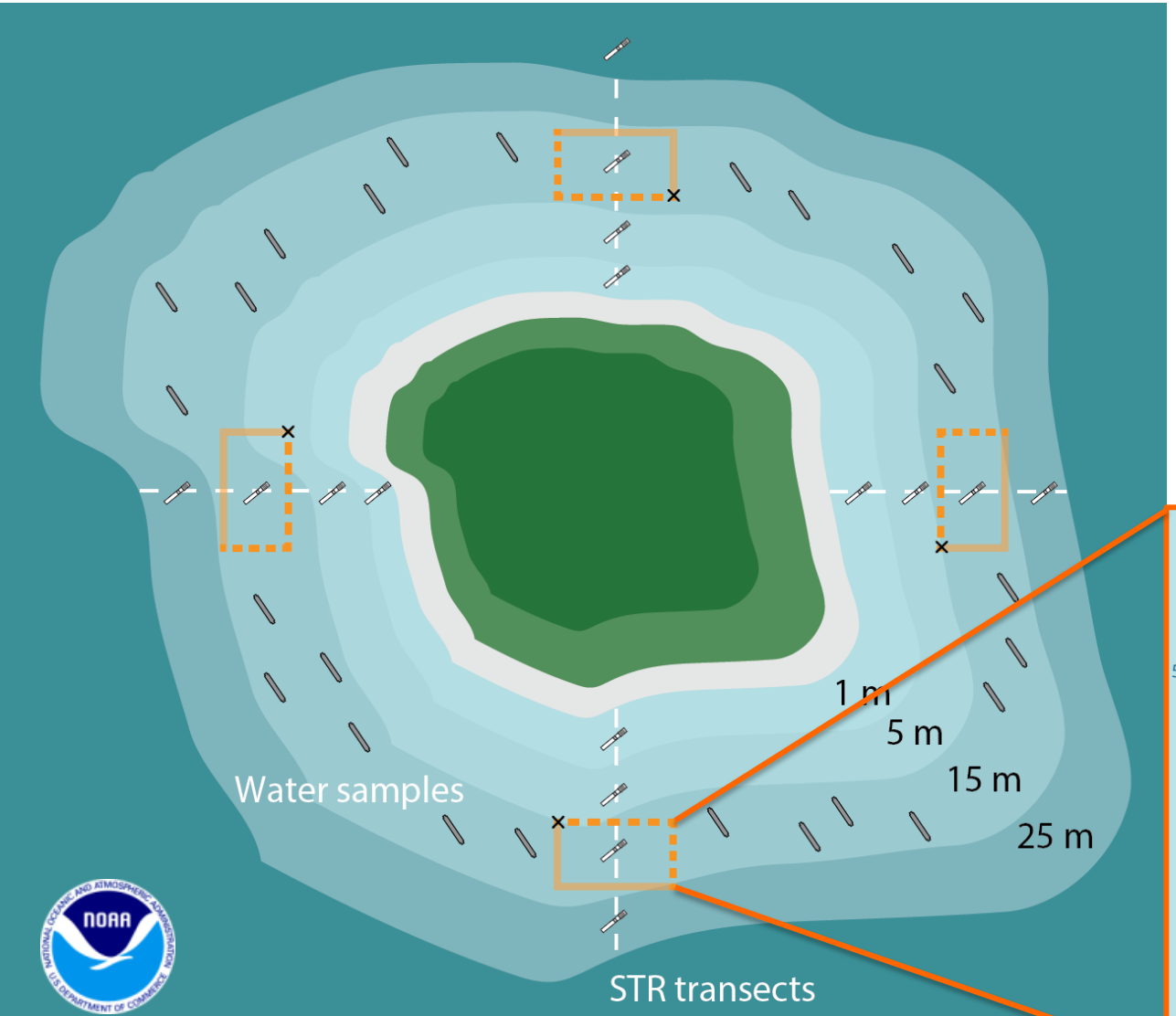
Observing across gradients of environmental/oceanographic conditions, biodiversity, human uses and impacts

Island-scale Survey Design

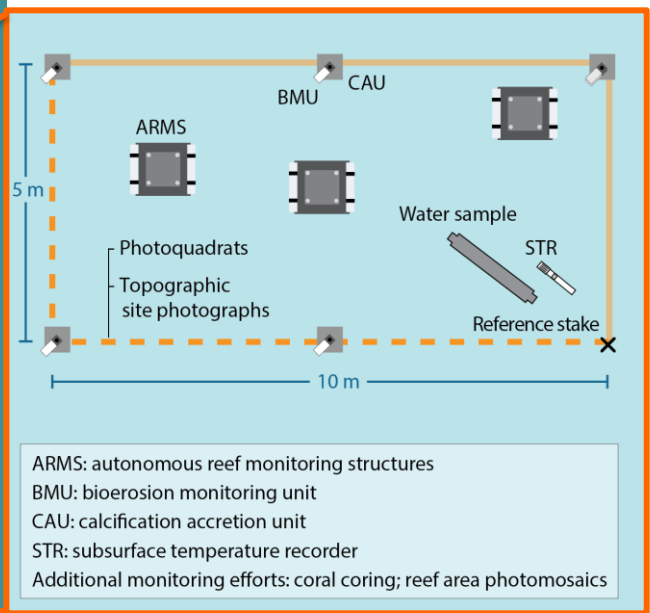
Sampling for DIC, TA, T, S, Chl *a*, nutrients, microbes.

- Surface & Reef
- Onshore-offshore
- Derive pH, Ω, NEC, NEP

Upstream DIC/TA sampling

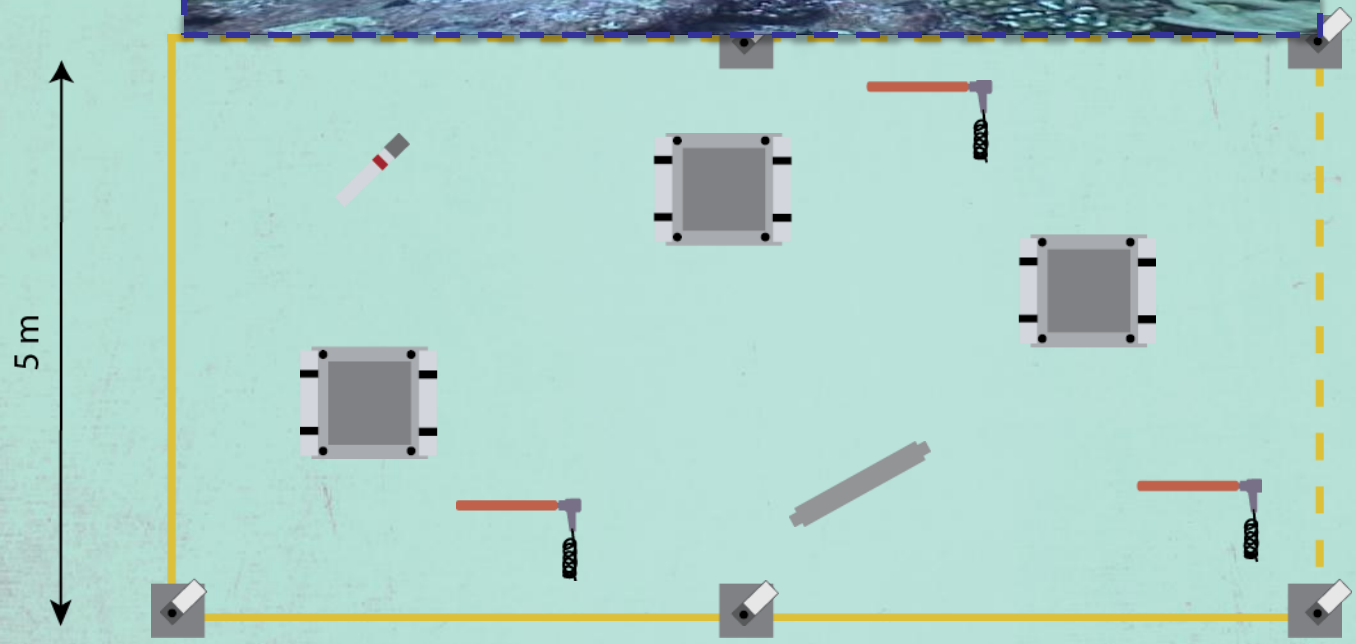


NCRMP CLASS 2 SITE



ARMS: autonomous reef monitoring structures
BMU: bioerosion monitoring unit
CAU: calcification accretion unit
STR: subsurface temperature recorder
Additional monitoring efforts: coral coring; reef area photomosaics

NCRMP MONITORING STATION - Class 2



STR
ARMS
CAU
BMU
Photoquad
Topographic Complexity
Water Sample
CTDs
Coral Coring

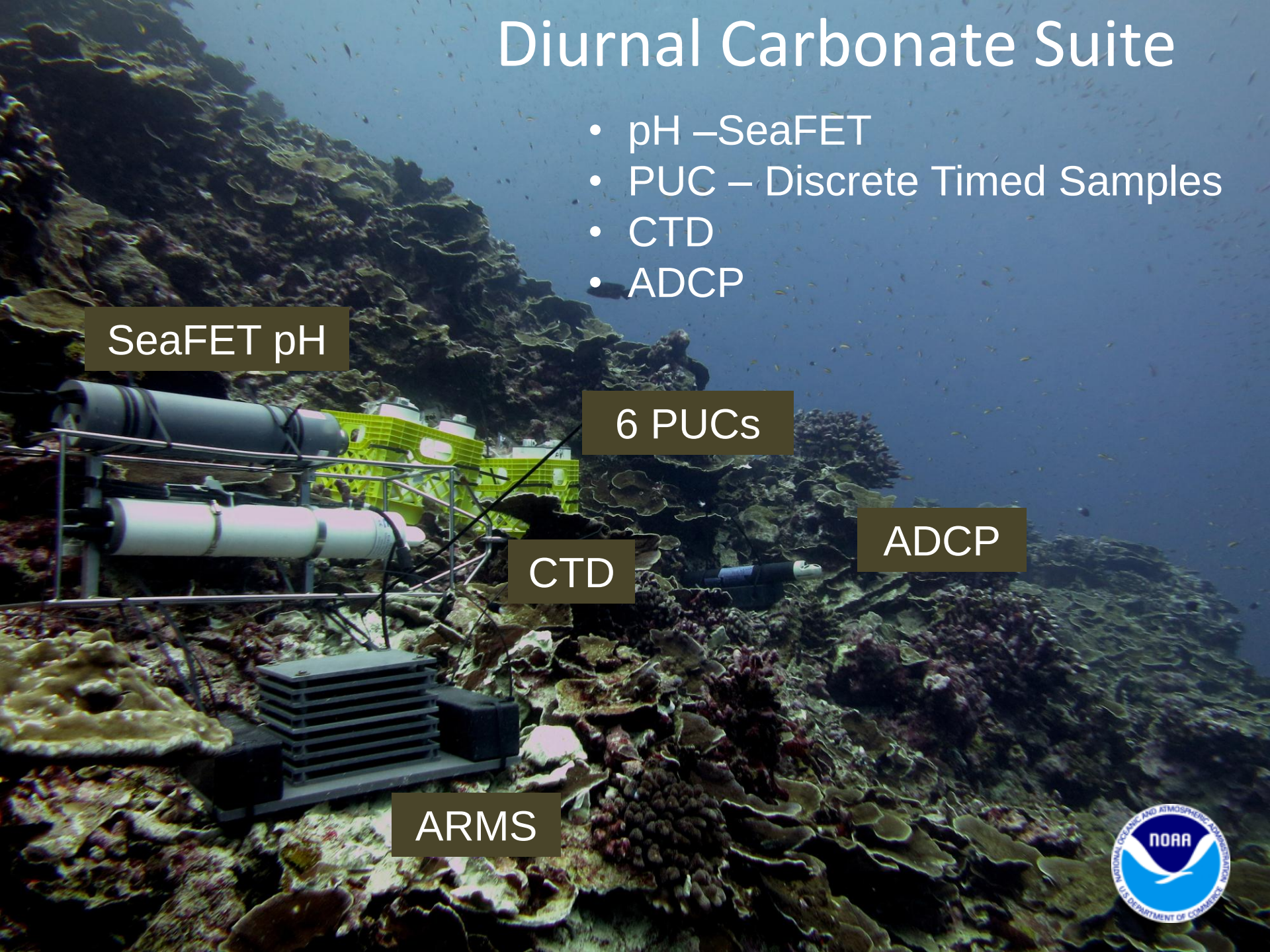
- Diurnal water sampling (~4 hours) DIC, TA, S with Langdon sampler (PUC) or RAS
- Diurnal pH with SeaFET sensor

Site-scale Sampling Design

NOAA OCEAN ACIDIFICATION PROGRAM

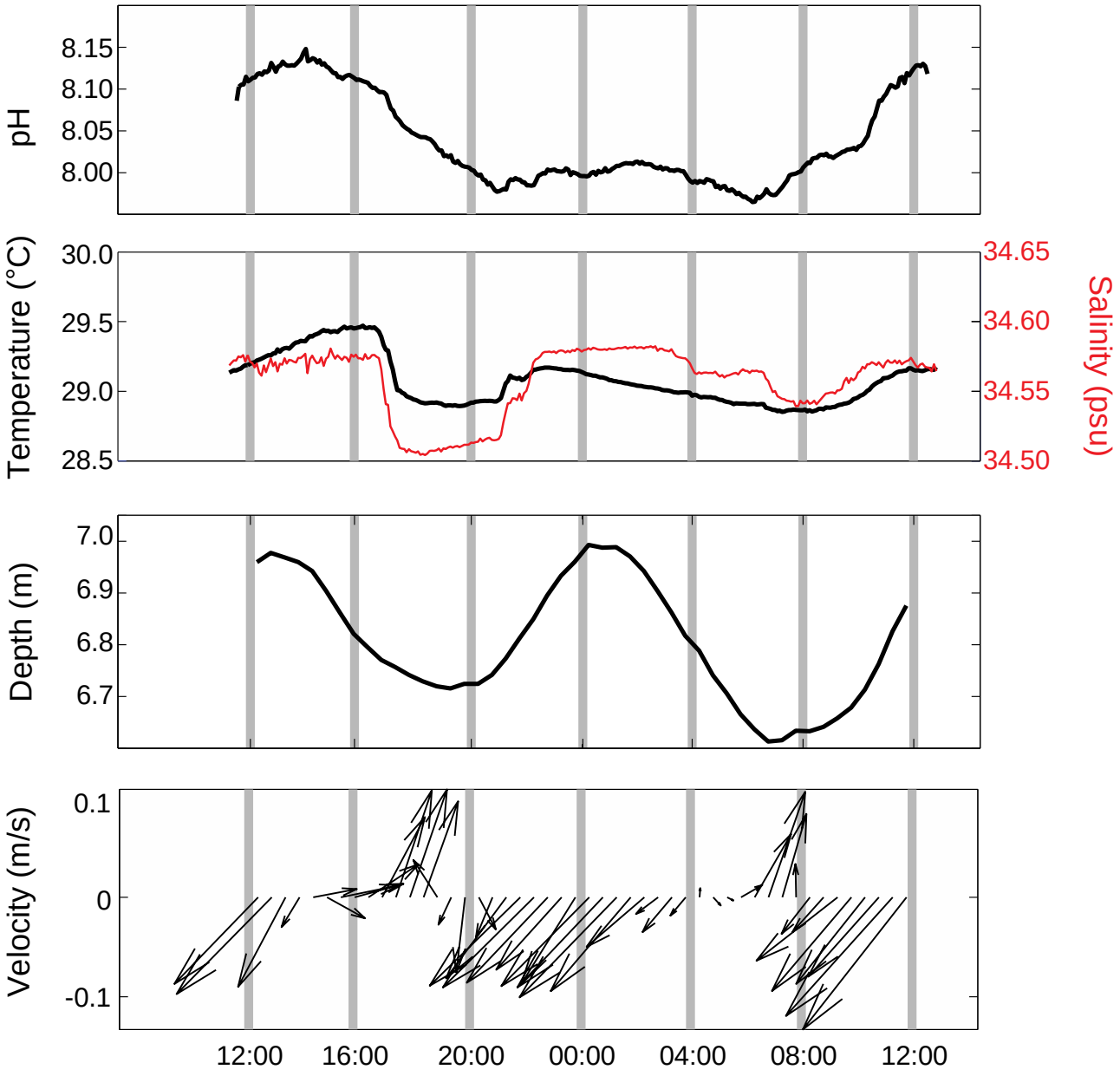
NOAA CORAL REEF CONSERVATION PROGRAM

NCRMP Climate Station Installation

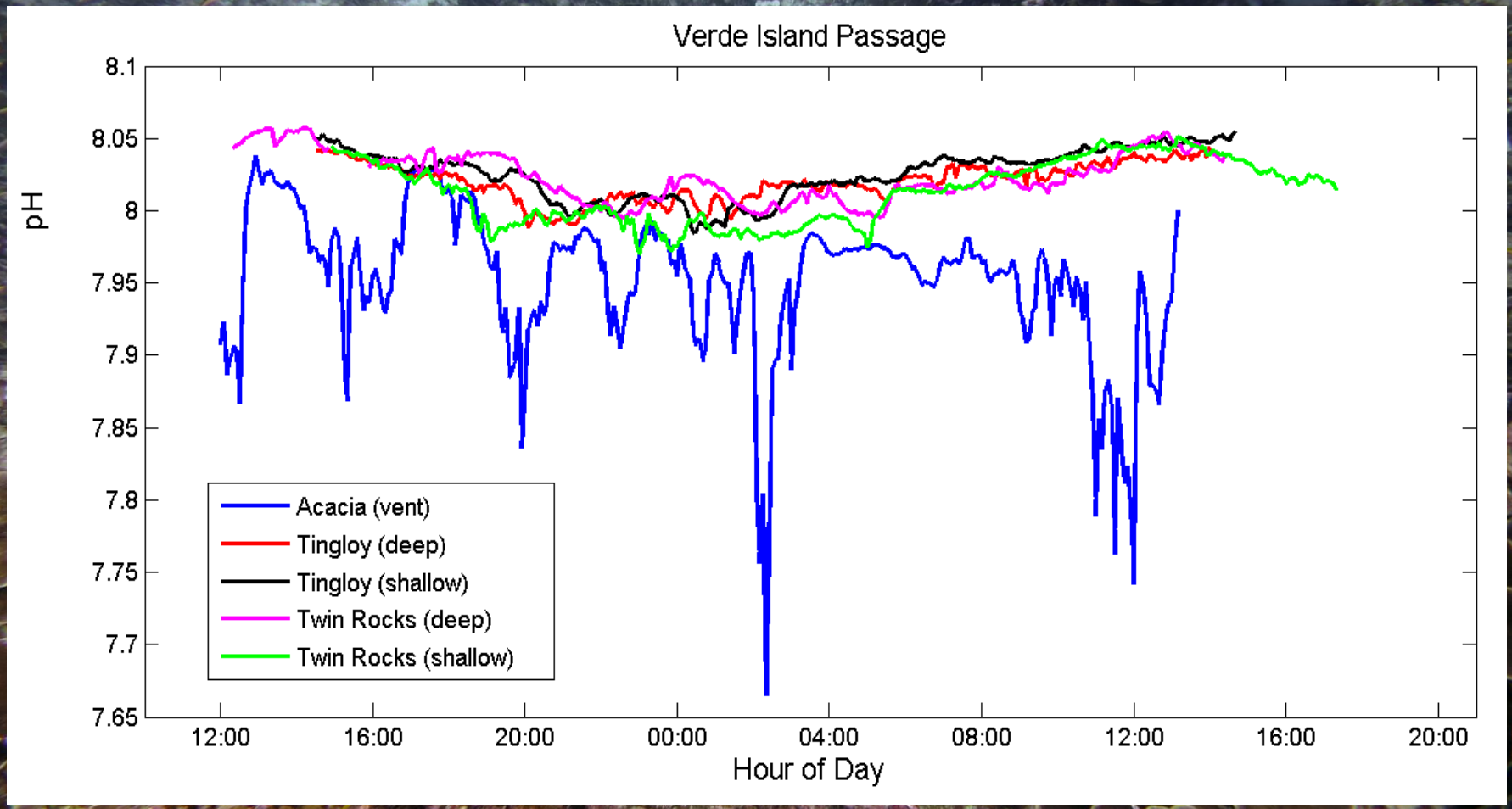

Diurnal Carbonate Suite
• pH –SeaFET
• PUC – Discrete Timed Samples
• CTD
• ADCP
SeaFET pH
6 PUCs
ADCP
CTD
ARMS


5 CAU
3 ARMS
ADCP
CTD
SeaFET pH
6 PUCs

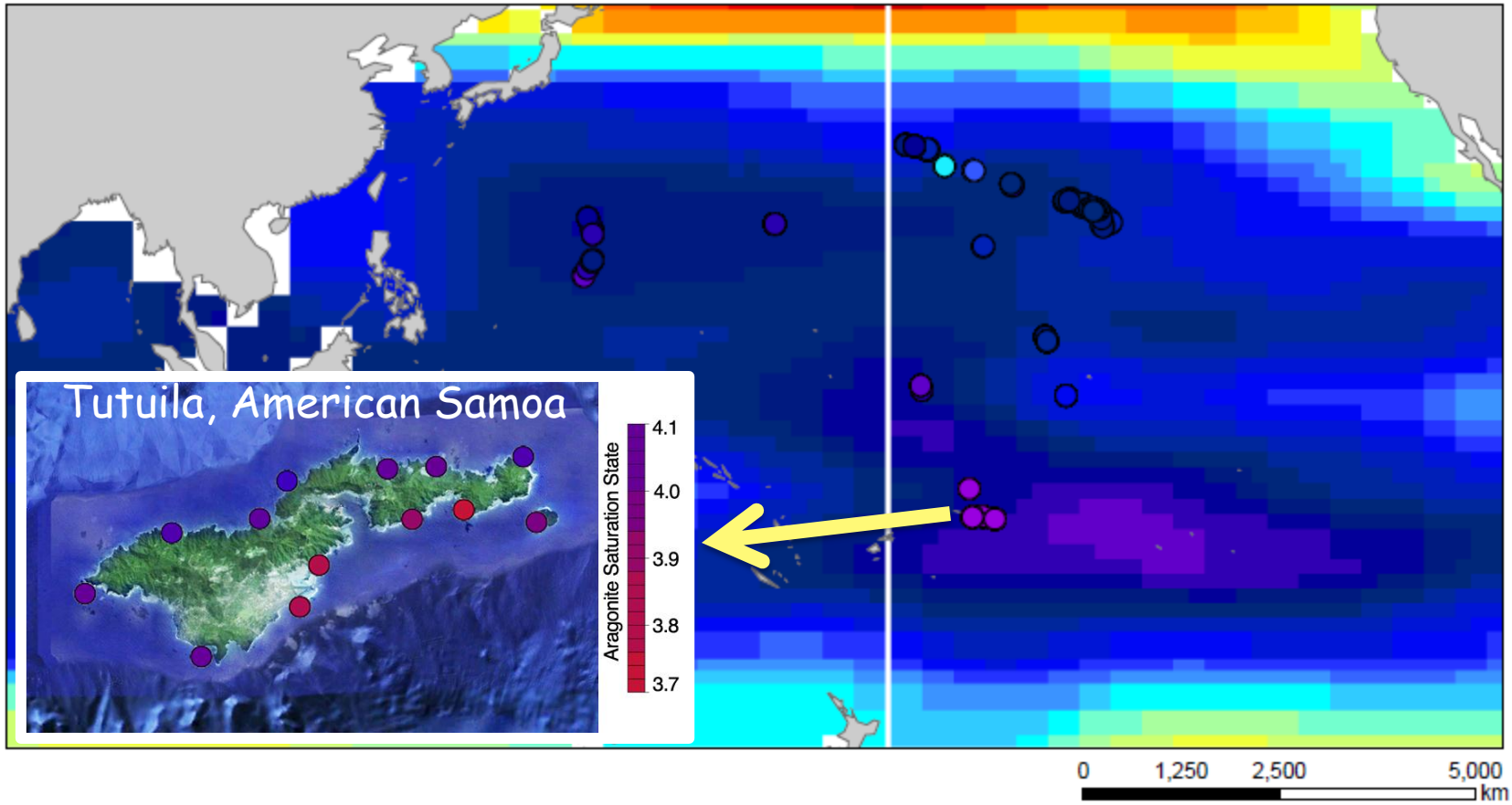
Kingman


pH
8.15
8.10
8.05
8.00
Temperature (°C)
30.0
29.5
29.0
28.5
34.65
34.60
34.55
34.50
Salinity (psu)
Depth (m)
7.0
6.9
6.8
6.7
Velocity (m/s)
0.1
0
-0.1
12:00
16:00
20:00
00:00
04:00
08:00
12:00

Vent Site in Philippines



Ω_{arag} Pacific-wide



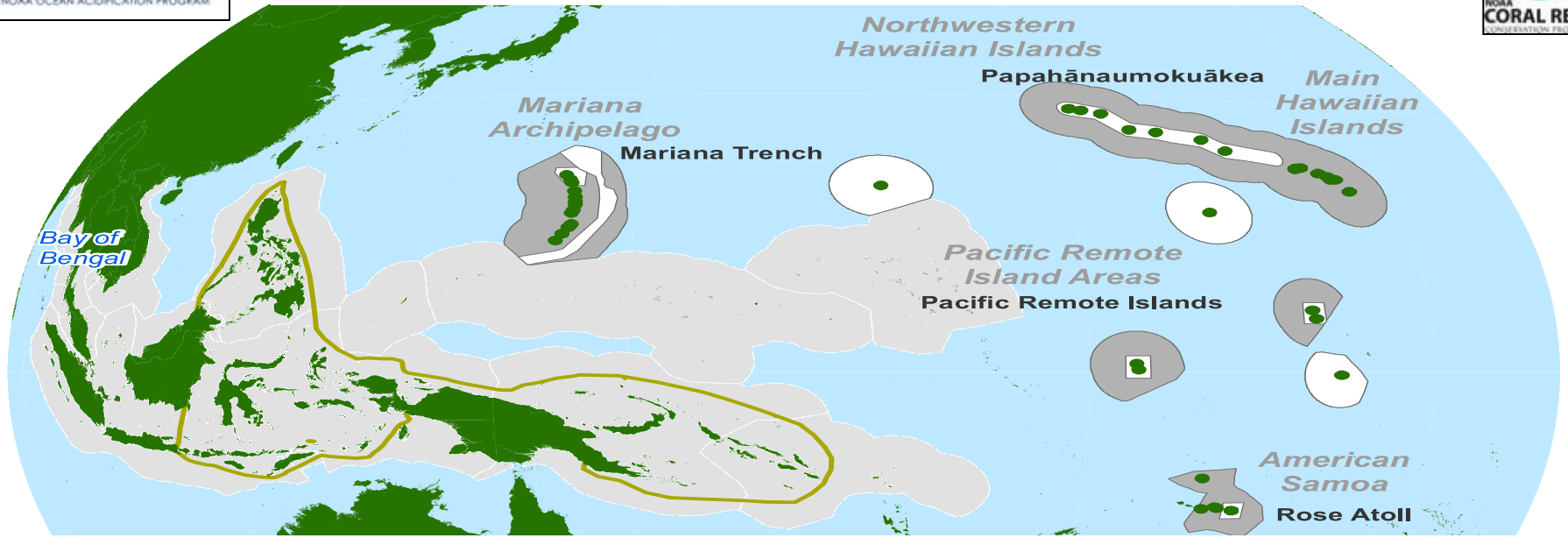
Ω_{ARG}

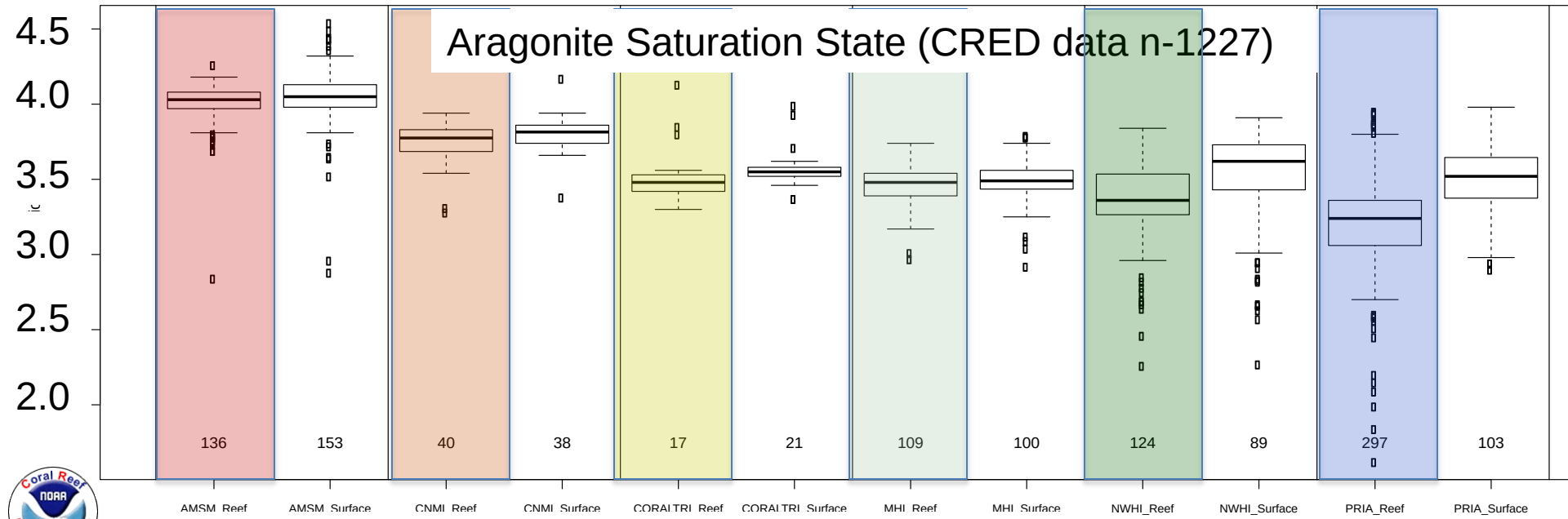
1.62 - 1.70 1.71 - 1.80 1.81 - 1.90 1.91 - 2.00 2.01 - 2.10 2.11 - 2.20 2.21 - 2.30 2.31 - 2.40 2.41 - 2.50 2.51 - 2.60 2.61 - 2.70 2.71 - 2.80 2.81 - 2.90 2.91 - 3.00 3.01 - 3.10 3.11 - 3.20 3.21 - 3.30 3.31 - 3.40 3.41 - 3.50 3.51 - 3.60 3.61 - 3.70 3.71 - 3.80 3.81 - 3.90 3.91 - 4.00 4.01 - 4.10 4.11 - 4.20 4.21 - 4.30 4.31 - 4.40 4.41 - 4.50 4.51 - 4.54

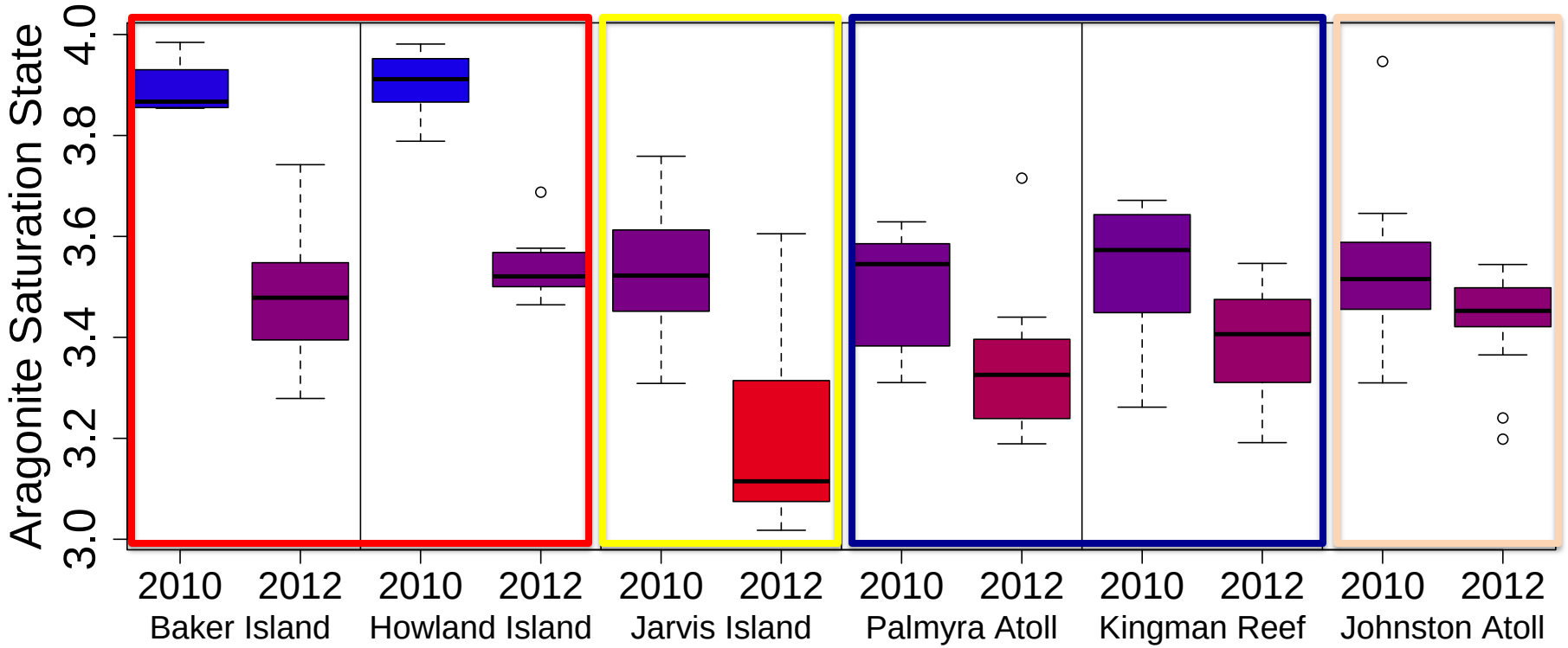
Estimated Aragonite Saturation State

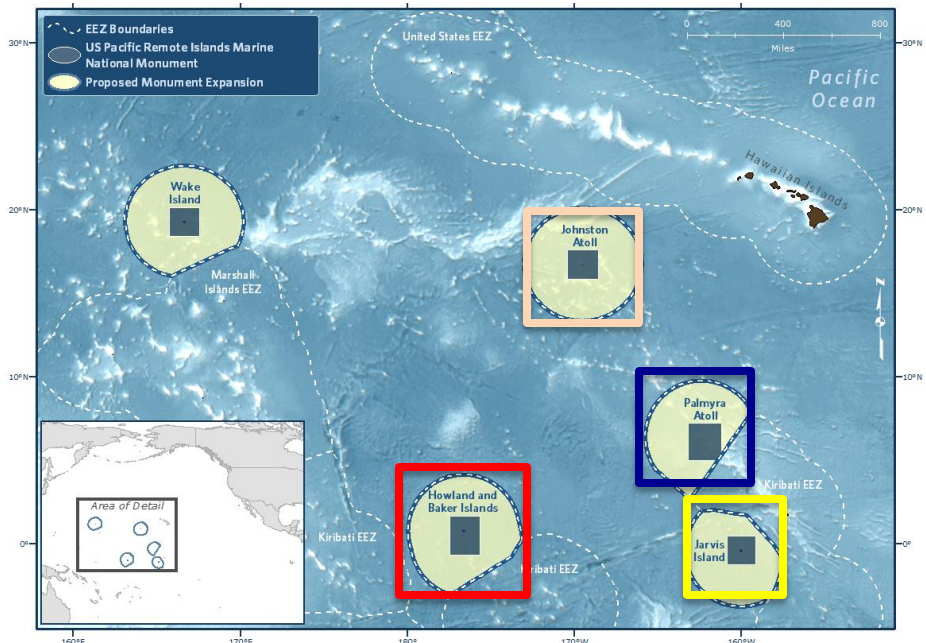
1.03 - 1.2 1.21 - 1.4 1.41 - 1.6 1.61 - 1.7 1.71 - 1.8 1.81 - 1.9 1.91 - 2 2.01 - 2.1 2.11 - 2.2 2.21 - 2.3 2.31 - 2.4 2.41 - 2.5 2.51 - 2.6 2.61 - 2.7 2.71 - 2.8 2.81 - 2.9 2.91 - 3 3.01 - 3.1 3.11 - 3.2 3.21 - 3.3 3.31 - 3.4 3.41 - 3.5 3.51 - 3.6 3.61 - 3.7 3.71 - 3.8 3.81 - 3.9 3.91 - 4 4.01 - 4.1 4.11 - 4.2

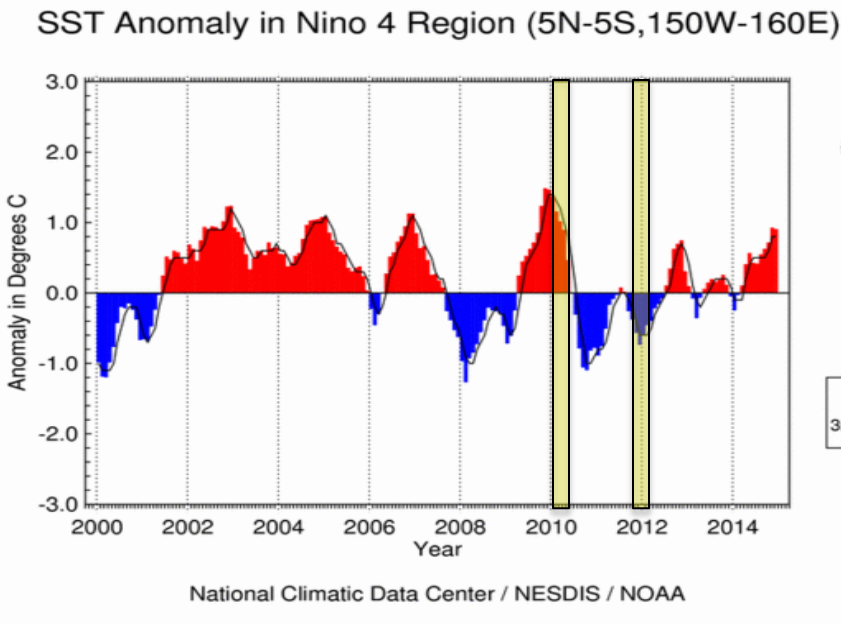
CRED Carbonate Chemistry



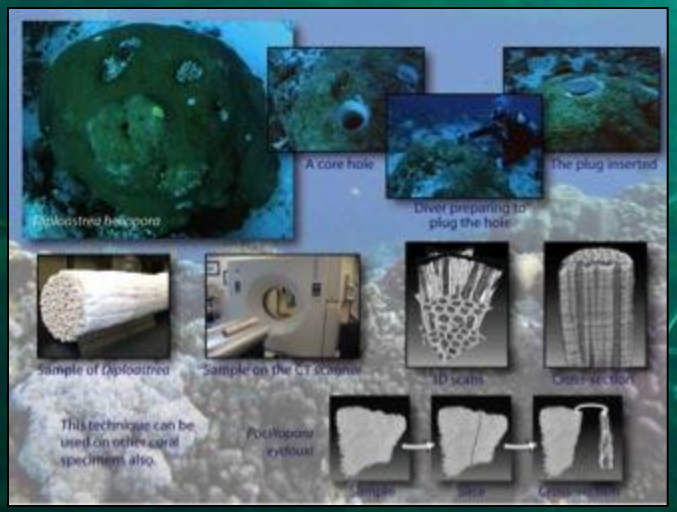


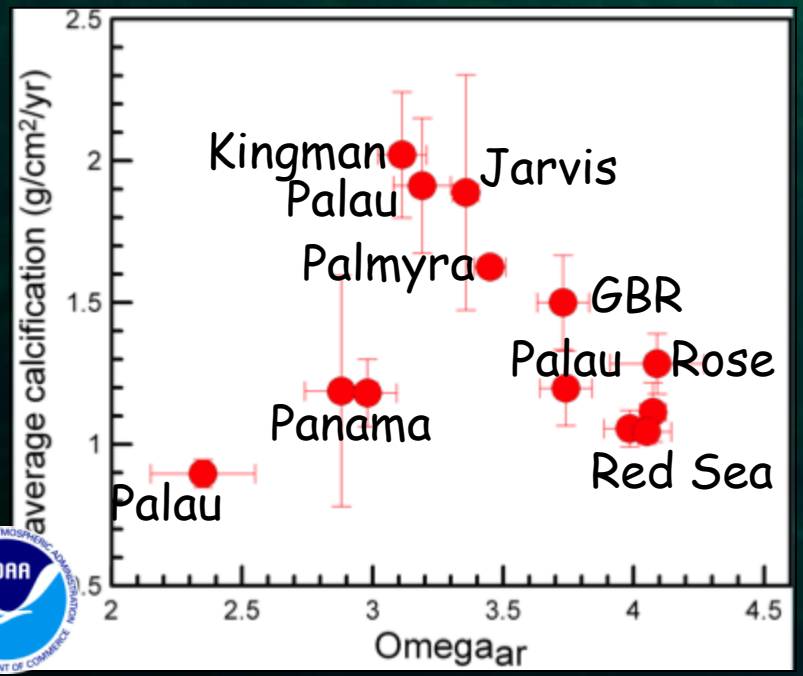

Aragonite Saturation State
4.0
3.8
3.6
3.4
3.2
3.0
2010
2012
Baker Island
Howland Island
Jarvis Island
Palmyra Atoll
Kingman Reef
Johnston Atoll

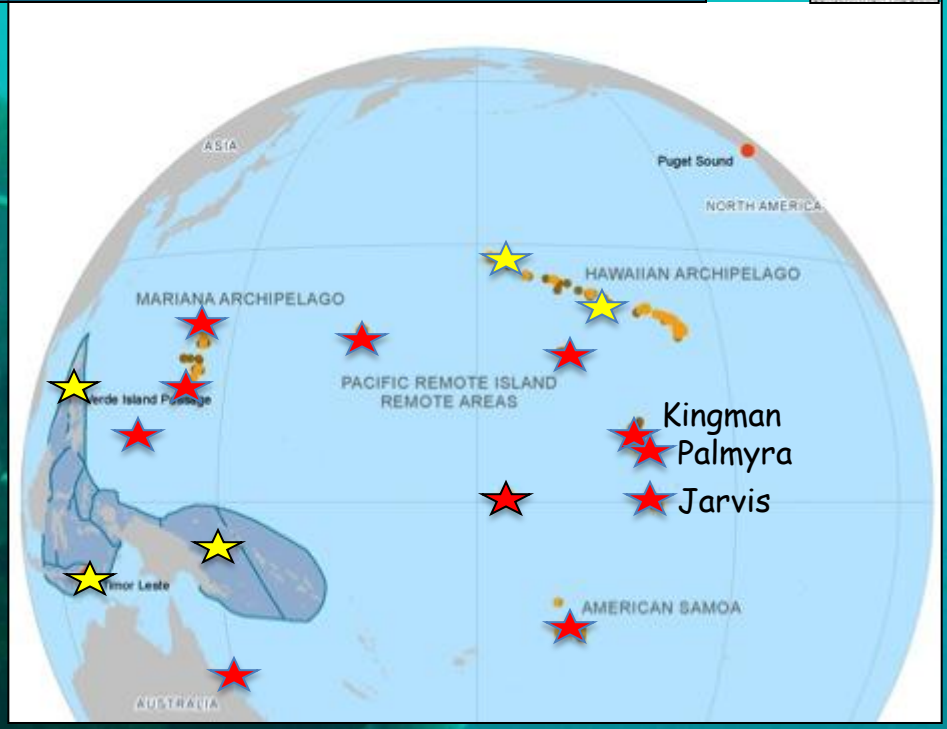

EEZ Boundaries
US Pacific Remote Islands Marine National Monument
Proposed Monument Expansion
United States EEZ
Pacific Ocean
Hawaiian Islands
Wake Island
Marshall Islands EEZ
Johnston Atoll
Palmyra Atoll
Kiribati EEZ
Howland and Baker Islands
Jarvis Island
Area of Detail


SST Anomaly in Nino 4 Region (5N-5S,150W-160E)
Anomaly in Degrees C
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
2000
2002
2004
2006
2008
2010
2012
2014
Year
National Climatic Data Center / NESDIS / NOAA

Coral Calcification Rates





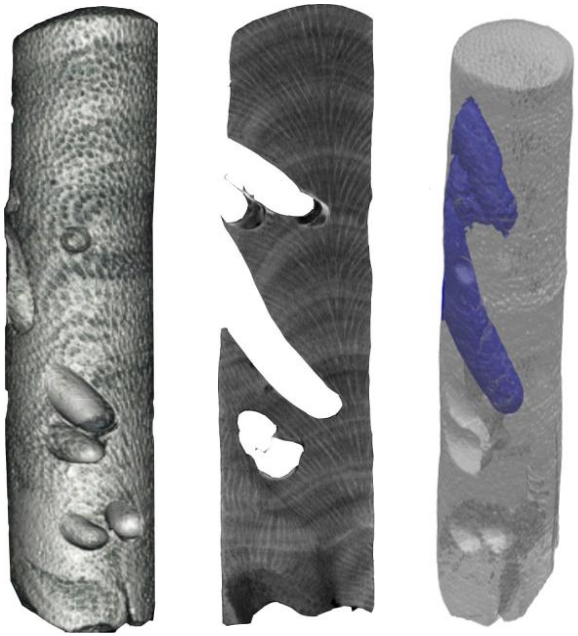


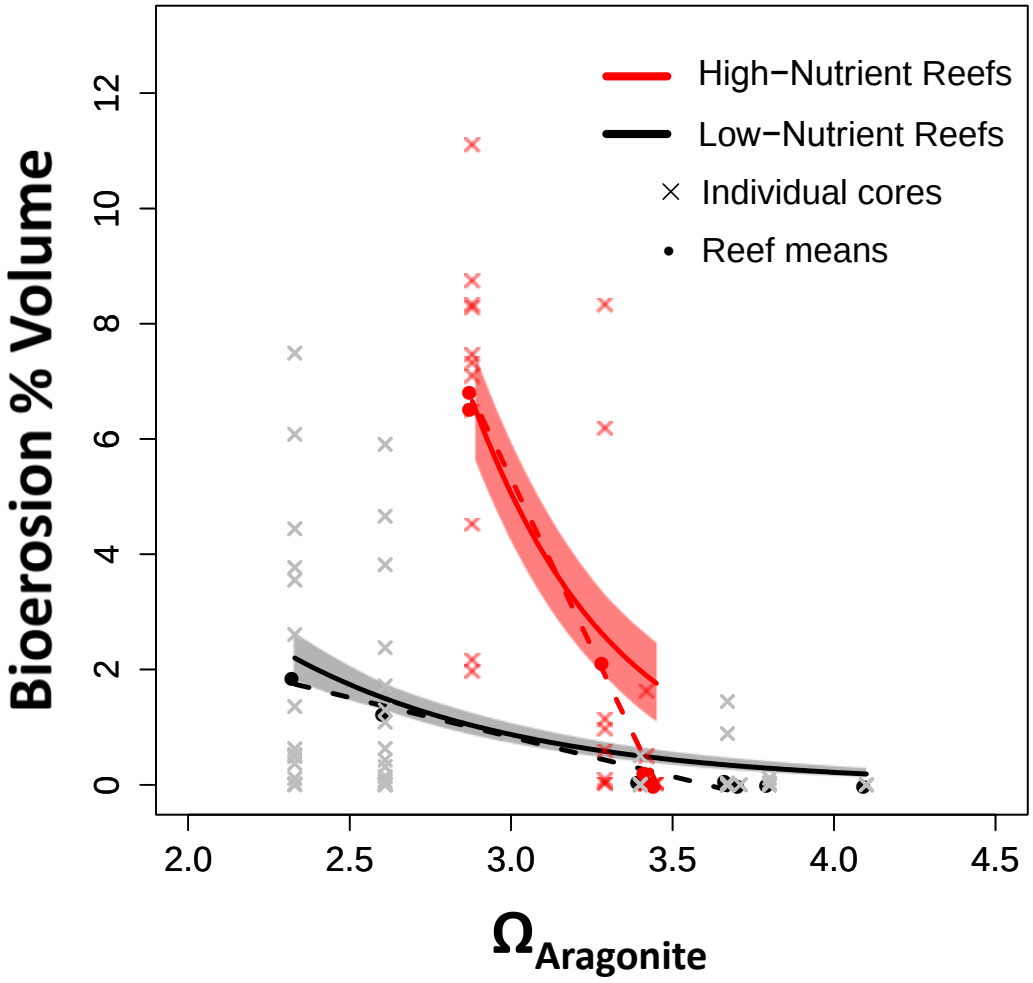
- Calcification rates of massive reef-building corals not a function only of saturation state.
- Also a function of food supply provided by upwelling.

With Anne Cohen's Lab WHOI

Coral Bioerosion is Higher at Low Saturation State & High Nutrients

A core of skeleton is removed from a live coral (above) and CT scanned (below)



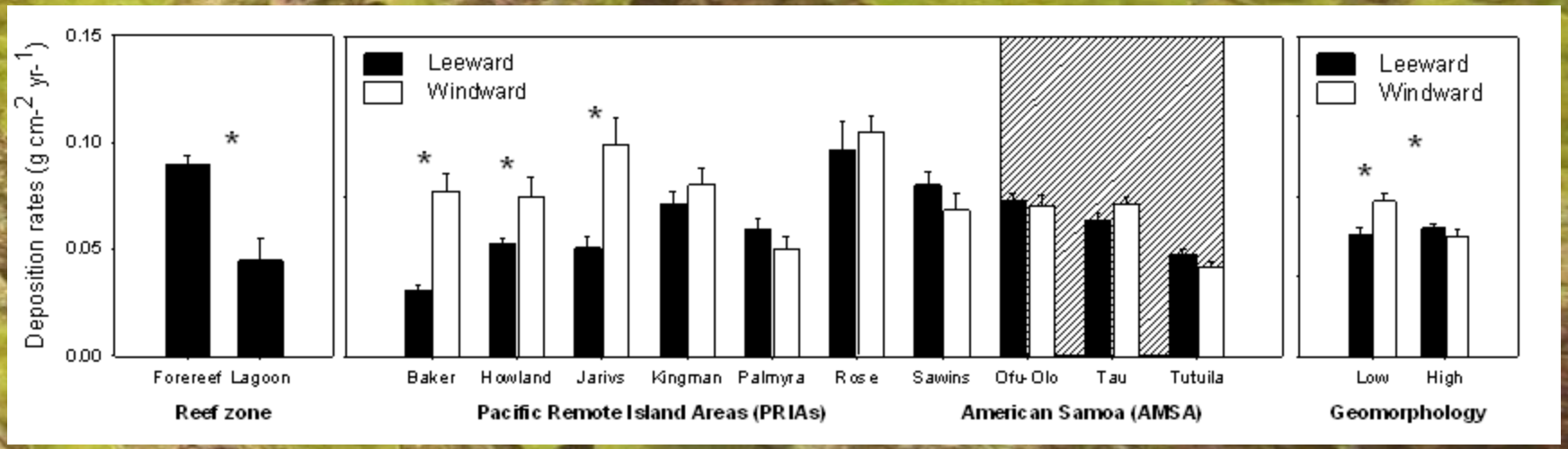


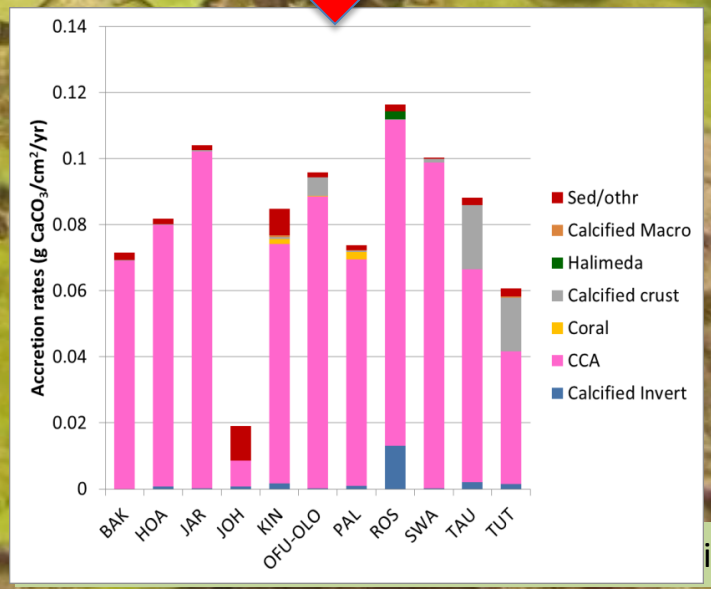
Cohen Lab, WHOI

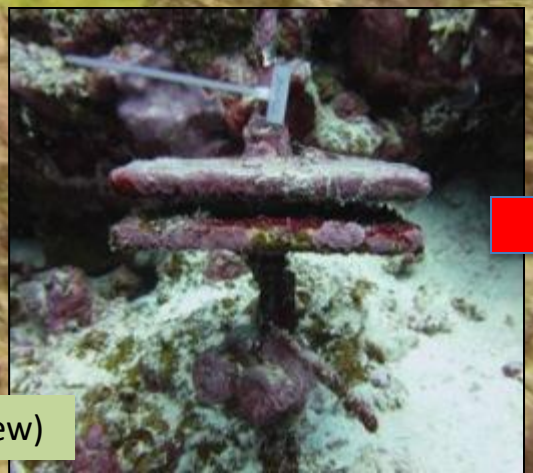
DeCarlo *et al.* (2014) *Geology*

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Calcification Accretion Units (CAUs)
Bioerosion Monitoring Units (BMUs)







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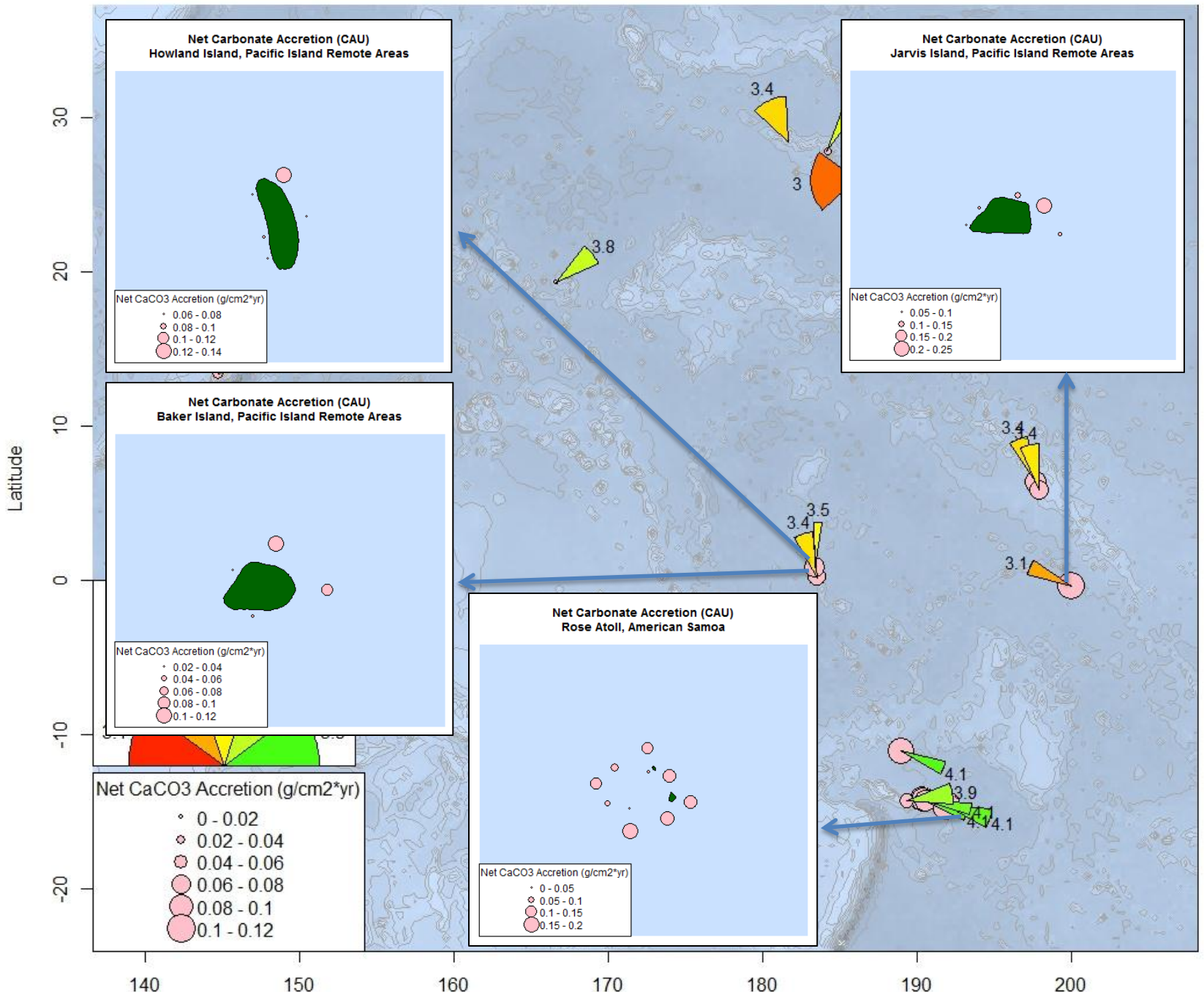
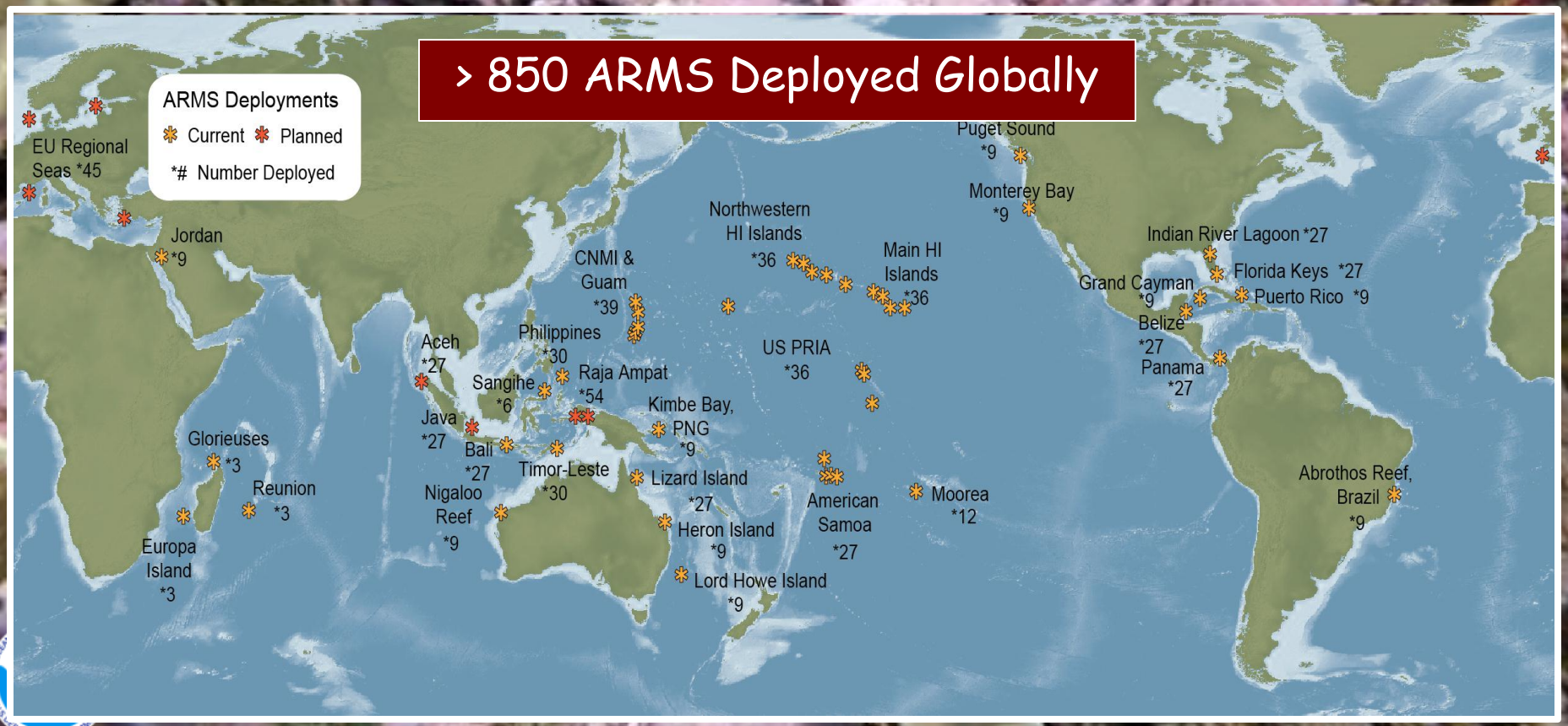
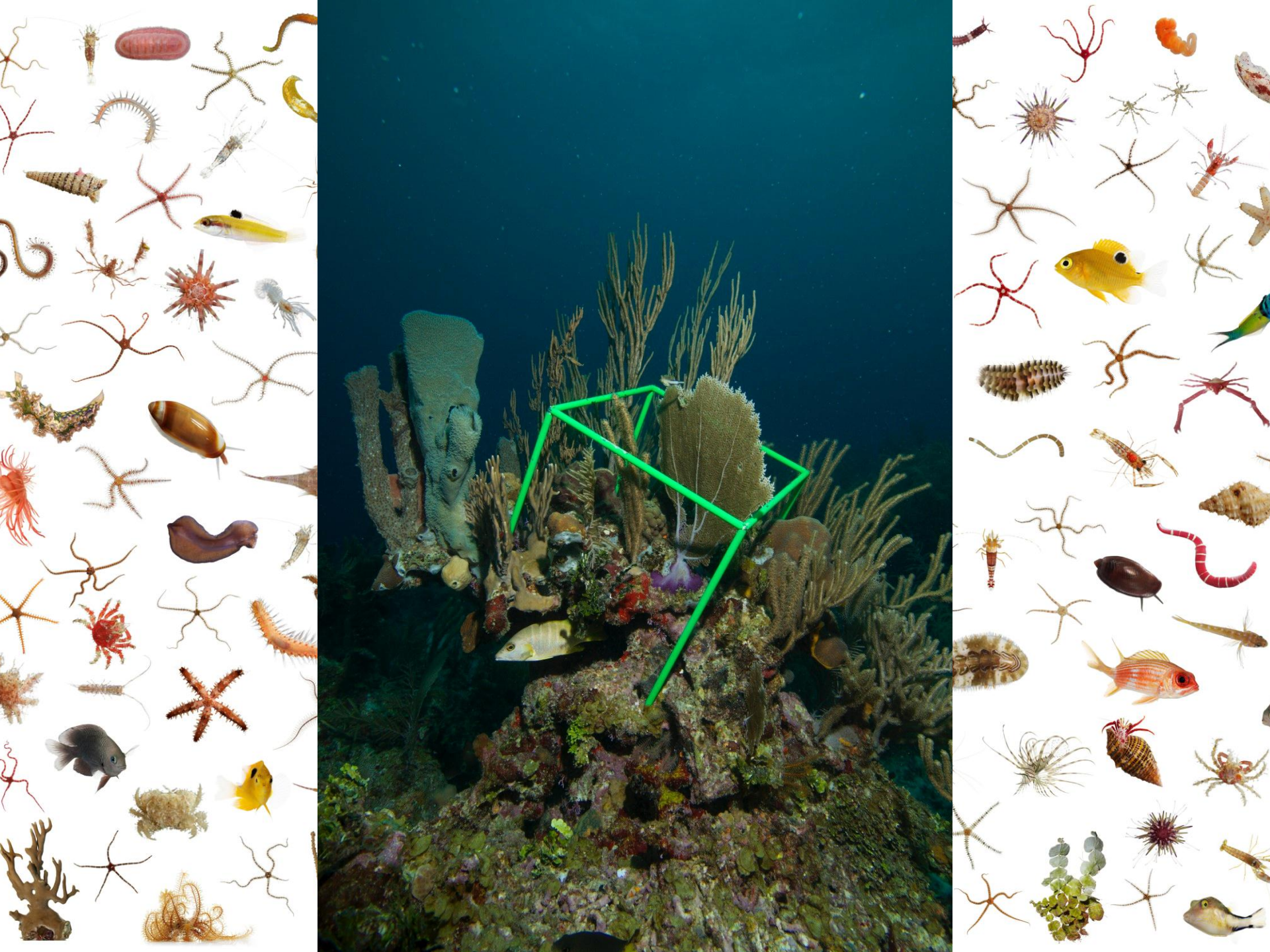

Net Carbonate Accretion
Central Pacific
Net Carbonate Accretion (CAU)
Howland Island, Pacific Island Remote Areas
Net CaCO3 Accretion (g/cm2*yr)
0.06 - 0.08
0.08 - 0.1
0.1 - 0.12
0.12 - 0.14
Net Carbonate Accretion (CAU)
Jarvis Island, Pacific Island Remote Areas
Net CaCO3 Accretion (g/cm2*yr)
0.05 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.25
Net Carbonate Accretion (CAU)
Baker Island, Pacific Island Remote Areas
Net CaCO3 Accretion (g/cm2*yr)
0.02 - 0.04
0.04 - 0.06
0.06 - 0.08
0.08 - 0.1
0.1 - 0.12
Net Carbonate Accretion (CAU)
Rose Atoll, American Samoa
Net CaCO3 Accretion (g/cm2*yr)
0 - 0.05
0.05 - 0.1
0.1 - 0.15
0.15 - 0.2
Net CaCO3 Accretion (g/cm2*yr)
0 - 0.02
0.02 - 0.04
0.04 - 0.06
0.06 - 0.08
0.08 - 0.1
0.1 - 0.12
Latitude
30
20
10
0
-10
-20
140
150
160
170
180
190
200
3.4
3
3.8
3.4
3.4
3.5
3.4
3.1
4.1
3.9
4.1
4.1

Biodiversity Shifts: ARMS

Autonomous Reef Monitoring Structures (ARMS) are a systematic tool to assess and monitor changes in indices of biodiversity. On-going development of both taxonomic and genetic analytical approaches to robustly detect biodiversity shifts.





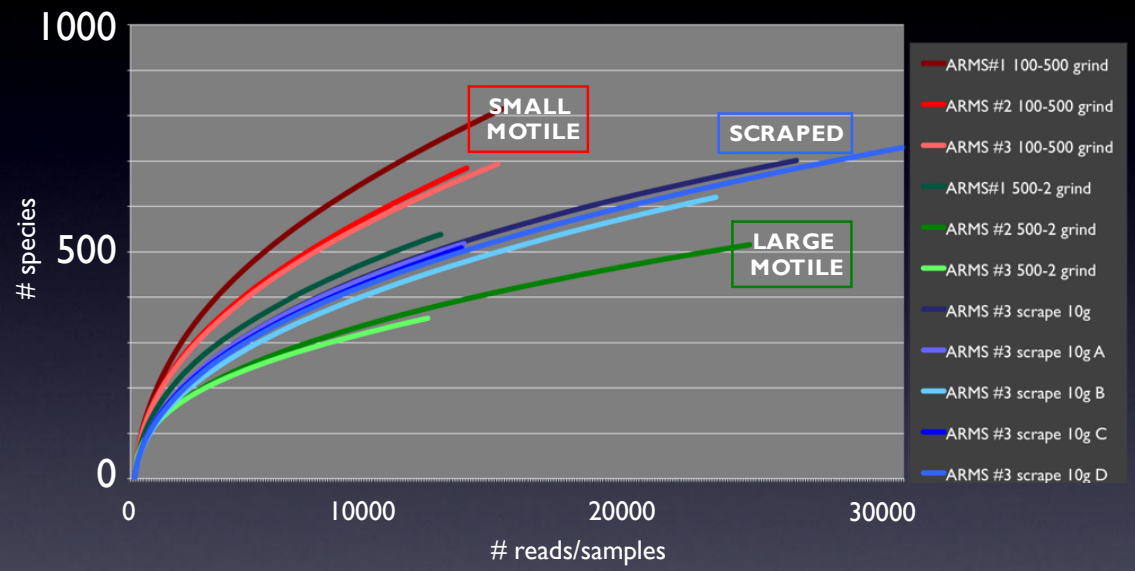

Video by David Liittschwager


Video by David Liittschwager

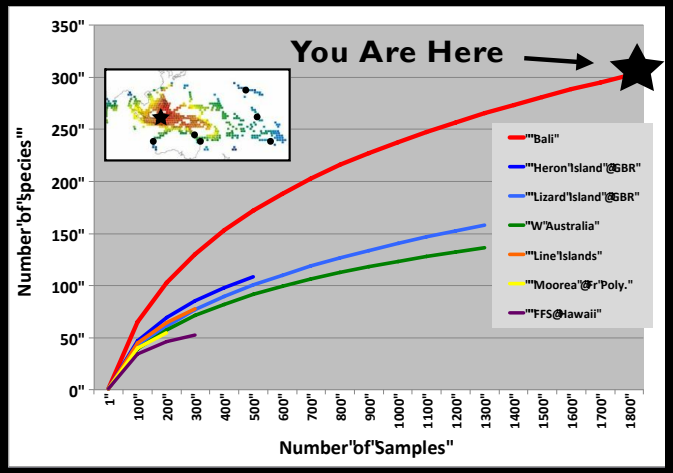
FIND & GRIND → GRIND & FIND

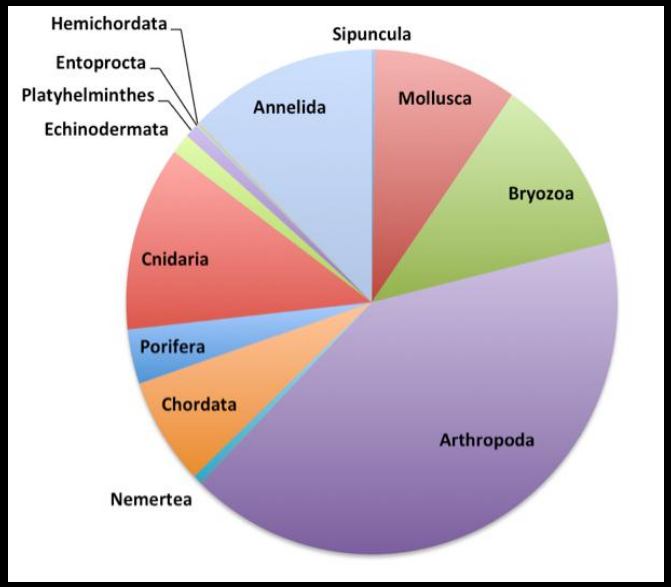
Video by David Liittschwager

Diversity on ARMS



>1000 species/ARMS

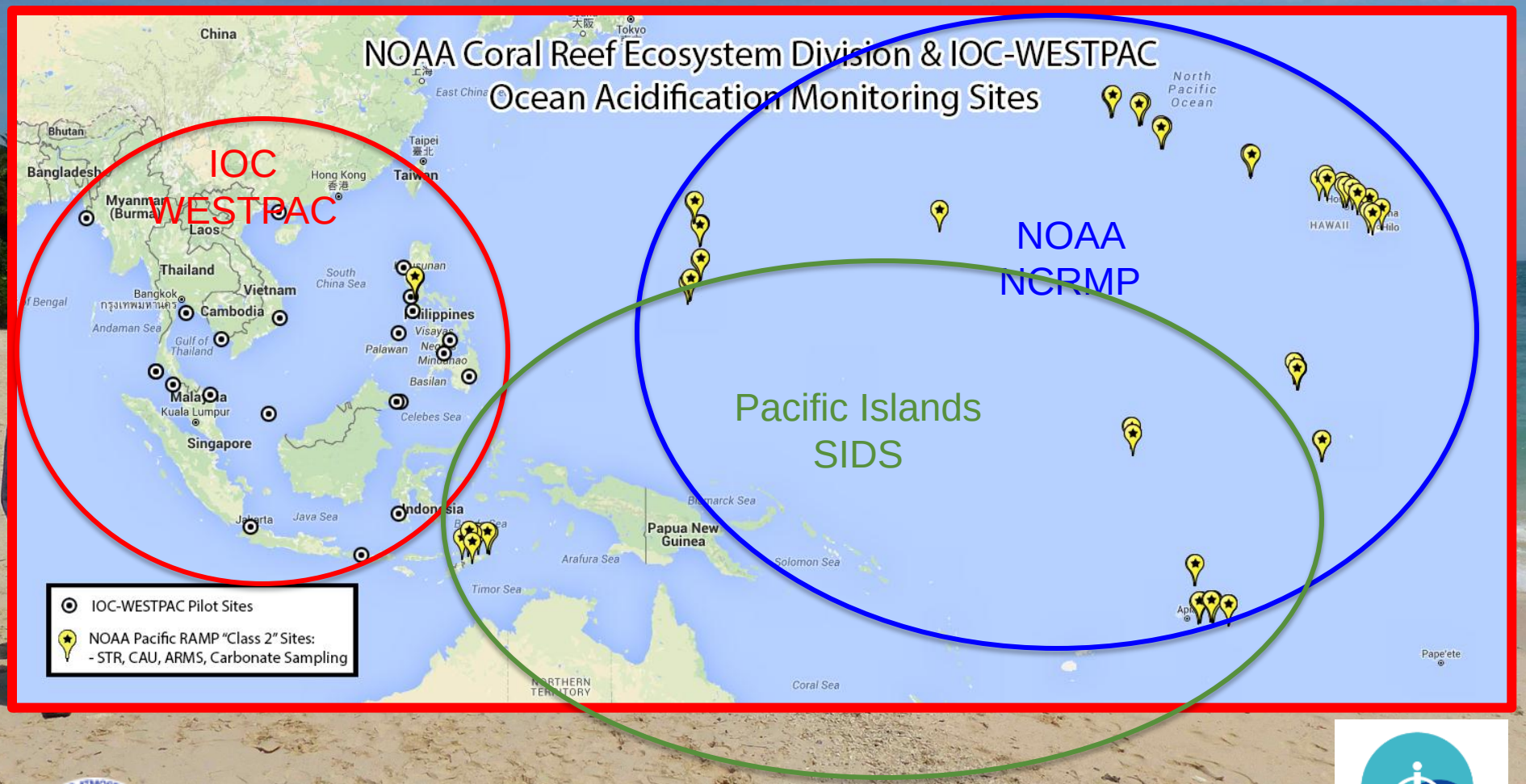





Pacific Islands Region
NOAA FISHERIES SERVICE
BE A TAXONOMIST
BRYOZOA
MOLLUSCA
NEMERTEA
TUNICA
ANNELIDA
ARTHROPODA
PORIFERA
ECHINODERM
SIPUNCULA
PLATYHEMINTHES

Pacific-wide OA Observing Network

NOAA + IOC WESTPAC + PI-SIDS



NOAA

NOAA OCEAN ACIDIFICATION PROGRAM

GOA-ON
Global Ocean Acidification Observing Network

Intergovernmental Oceanographic Commission

Conclusions

- Ocean Acidification will increasingly impact coral reefs, biodiversity, fisheries, coastal protection & communities in the Pacific Islands countries!
- Need simple, consistent/systematic, cost-effective time series observations of physical, chemical, ecological, & biological conditions and processes to inform resource management decisions & adaptation strategies
- Leverage resources & capacity to build OA monitoring onto existing efforts, where possible

MAHALO ☺

Rusty.Brainard@noaa.gov 808-725-5419

NOAA CORAL REEF CONSERVATION PROGRAM

OAP NOAA OCEAN ACIDIFICATION PROGRAM

GOA-ON Global Ocean Acidification Observing Network

Intergovernmental Oceanographic Commission