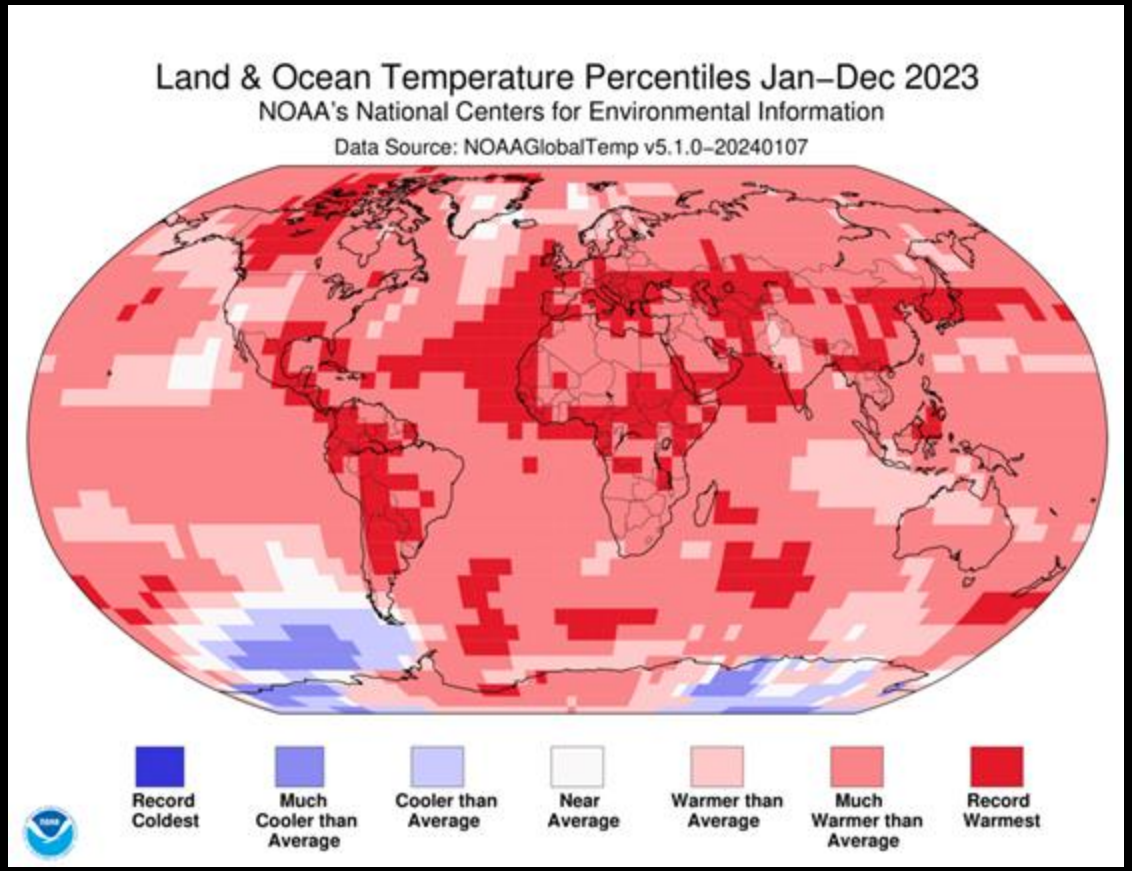
Frontiers in Ocean Biodiversity Observation Through DNA Metabarcoding

Zack Gold, NOAA
Paul Barber, UCLA

Ocean Ecosystems Facing Unprecedented Challenges



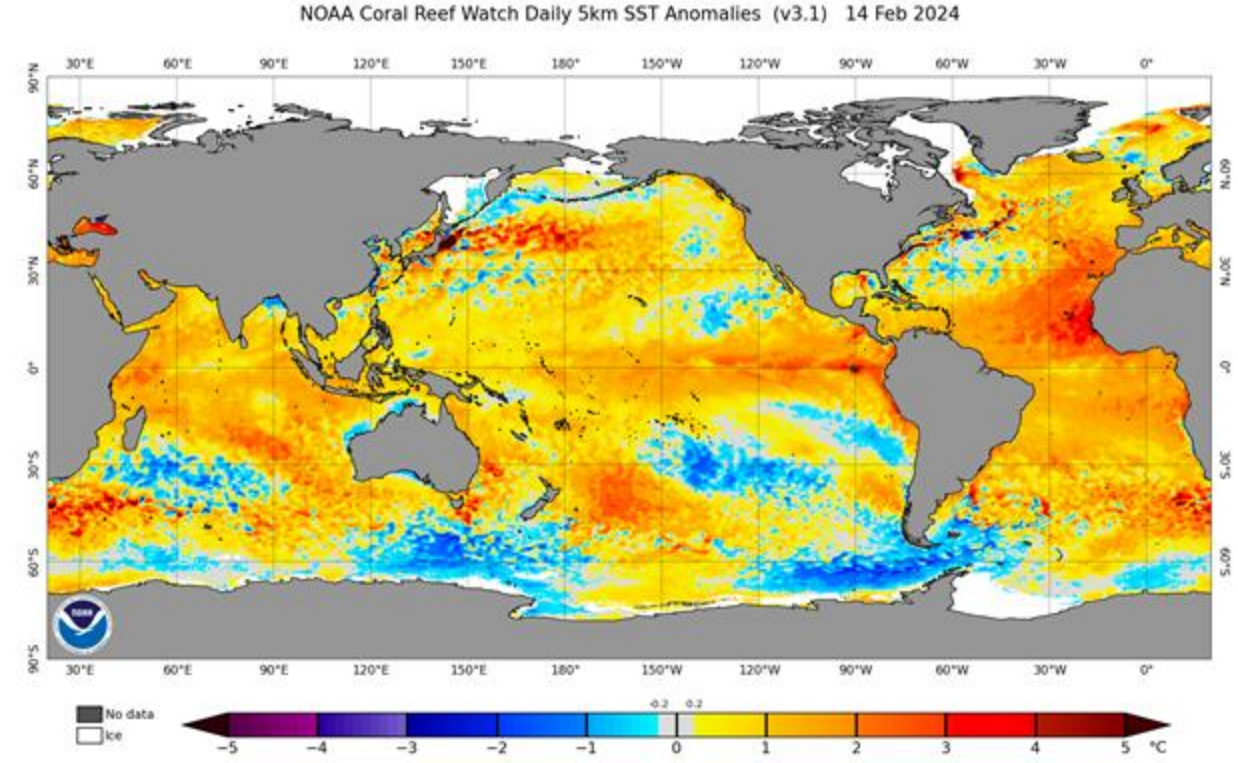
Critical Questions Facing This Decade

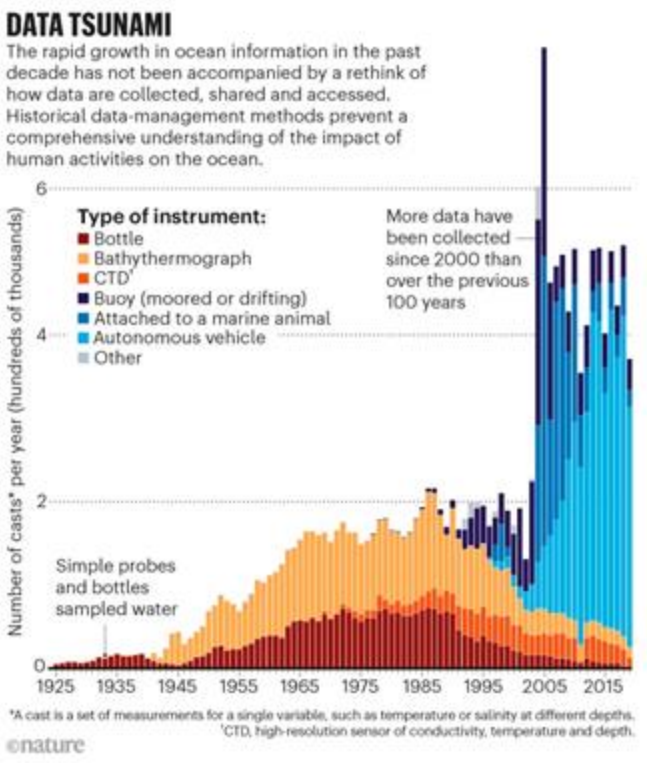
1: Who are the winners & losers of climate change?

2: How are these changes impacting ecosystem function?

3: How can we support ecosystem resilience to anthropogenic change?

Tsunami of Ocean Observation Data



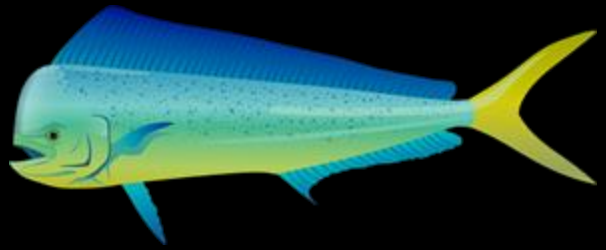


Brett et al. 2020

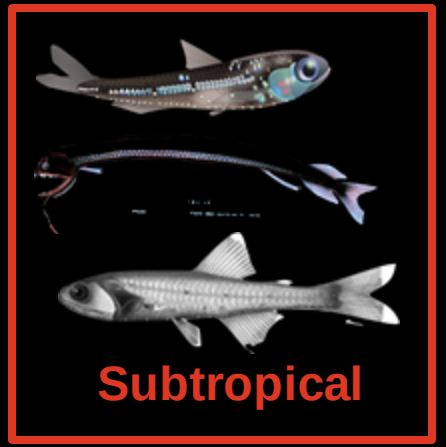
Most Ocean Observation Systems are Blind to Biodiversity

Severe Population Declines

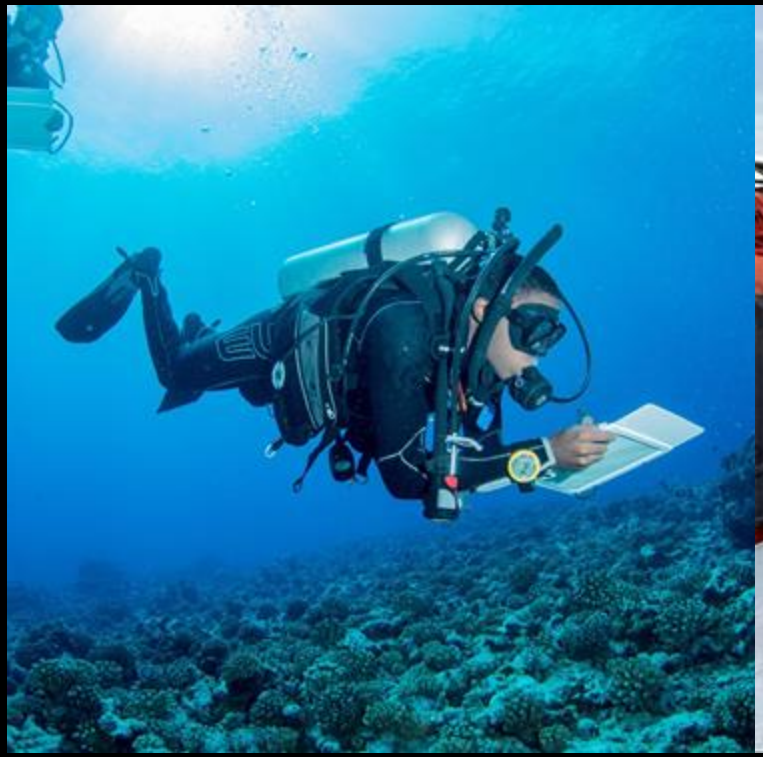
Dramatic Range Shifts



No-Analog Communities



Biodiversity Observation Is People Intensive



Challenges of Marine Ecosystem Monitoring

- Time and Labor intensive
- Expensive
- Requires taxonomic expertise
- Conspicuous species
- Conditions dependent

Future Ocean Biodiversity Observservation Systems Ideally Would:

- Capture entire communities
- Global scale
- In near real time
- Autonomously

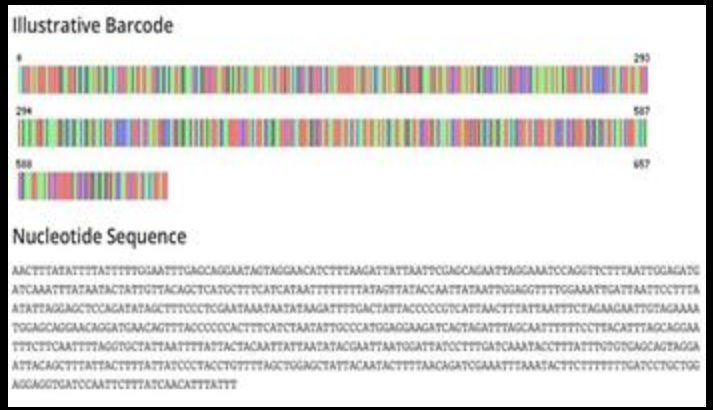
Barcoding

Barcodes use numerical sequence to identify products

=

DNA Barcoding

Identification of species by a DNA sequence



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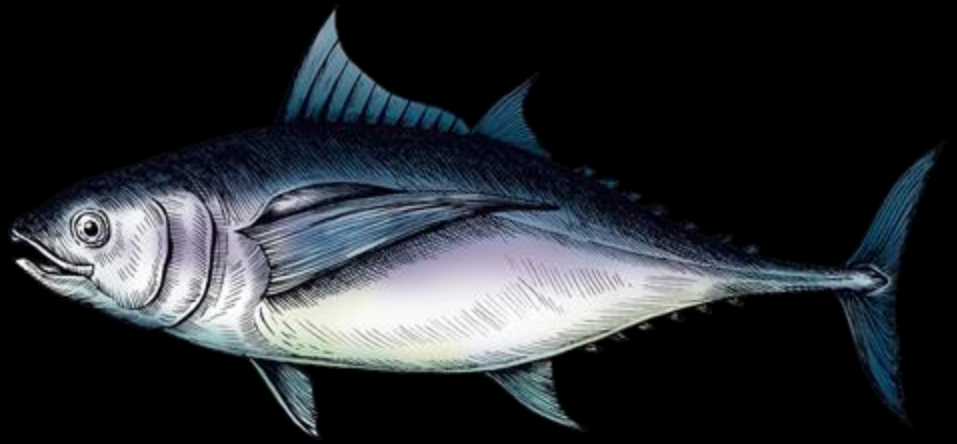


DNA Metabarcoding

Identification of a community through DNA sequences

1000s of Sequences =

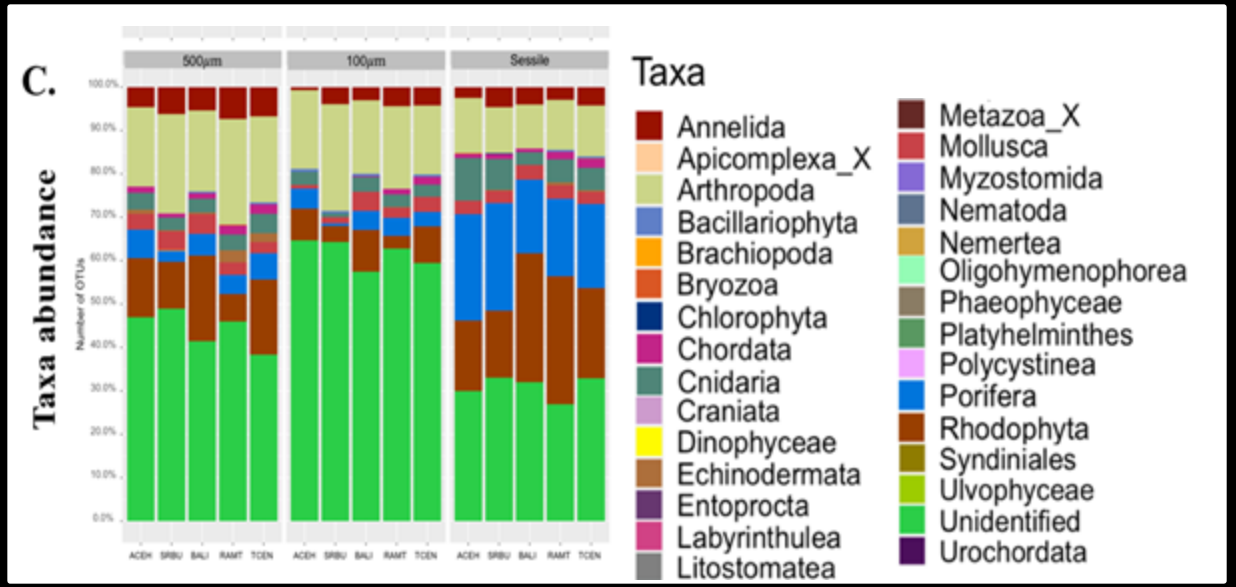
Photo: Chris Meyer

DNA Metabarcoding

Identification of a community through DNA sequences

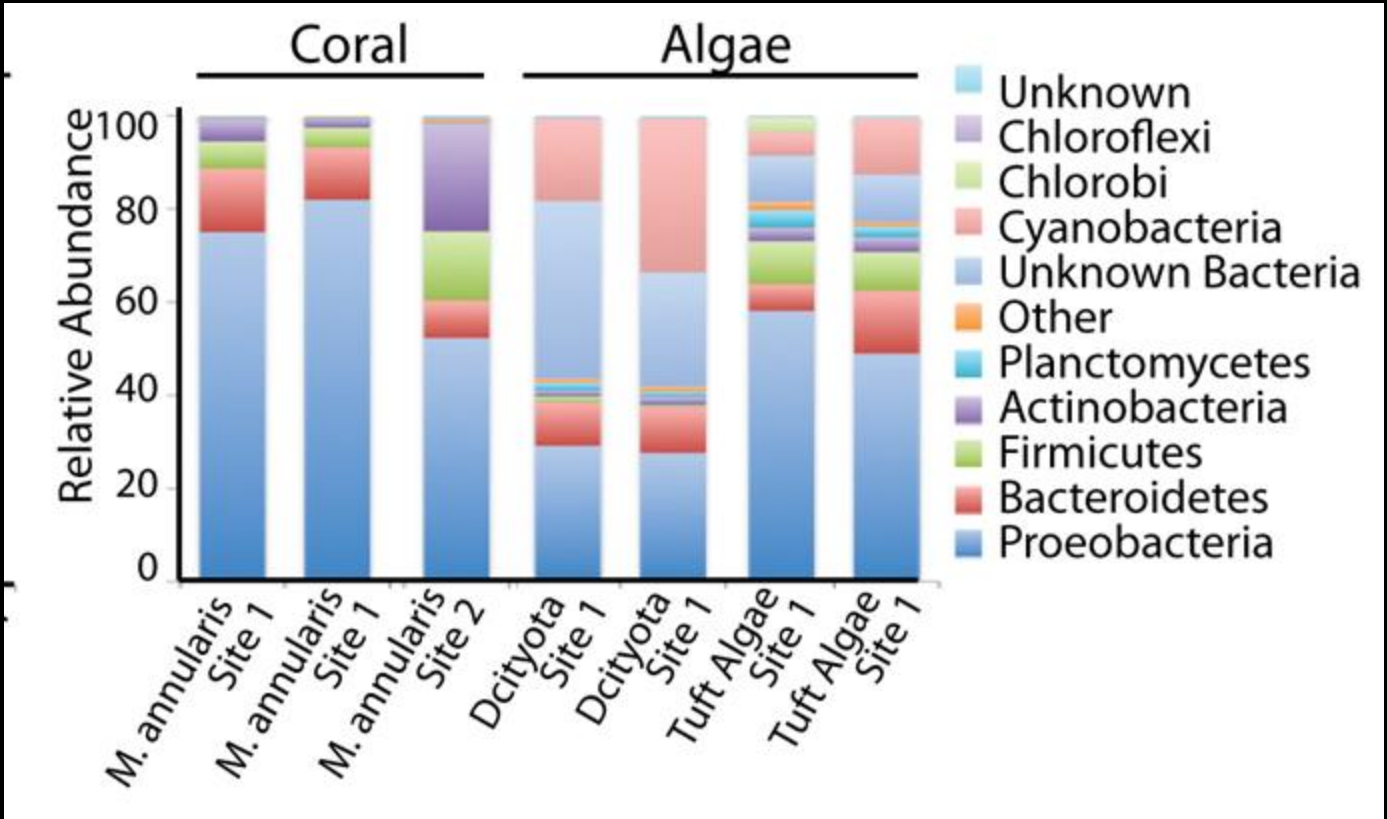
1000s of Sequences

=



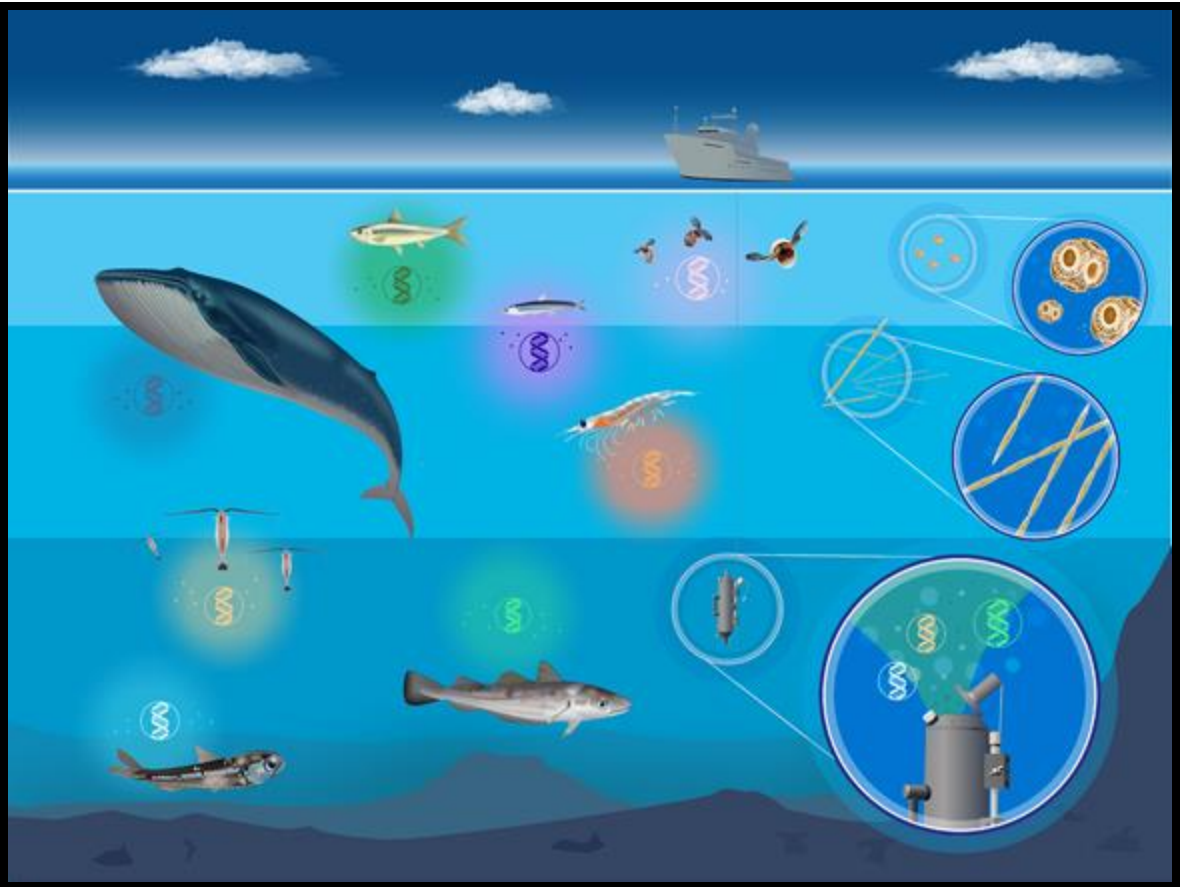
Common approaches to Metabarcoding

Microbial Community Profiling

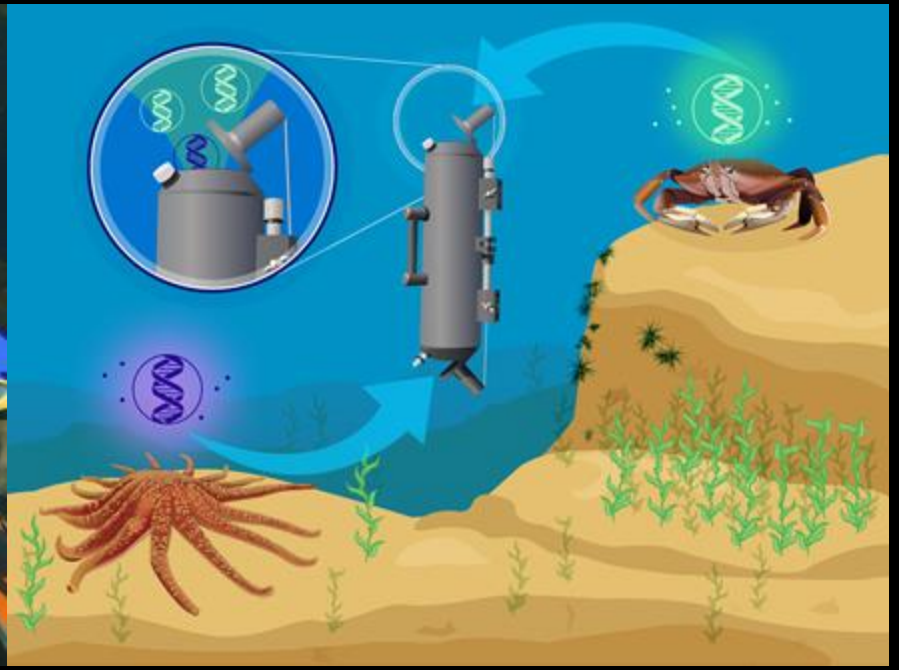


Environmental DNA (eDNA)

Environmental DNA (eDNA)



eDNA: Collect Water (or sediment)



eDNA: Isolate DNA

Autonomous Reef Monitoring Structures

Autonomous Reef Monitoring Structures (ARMS)

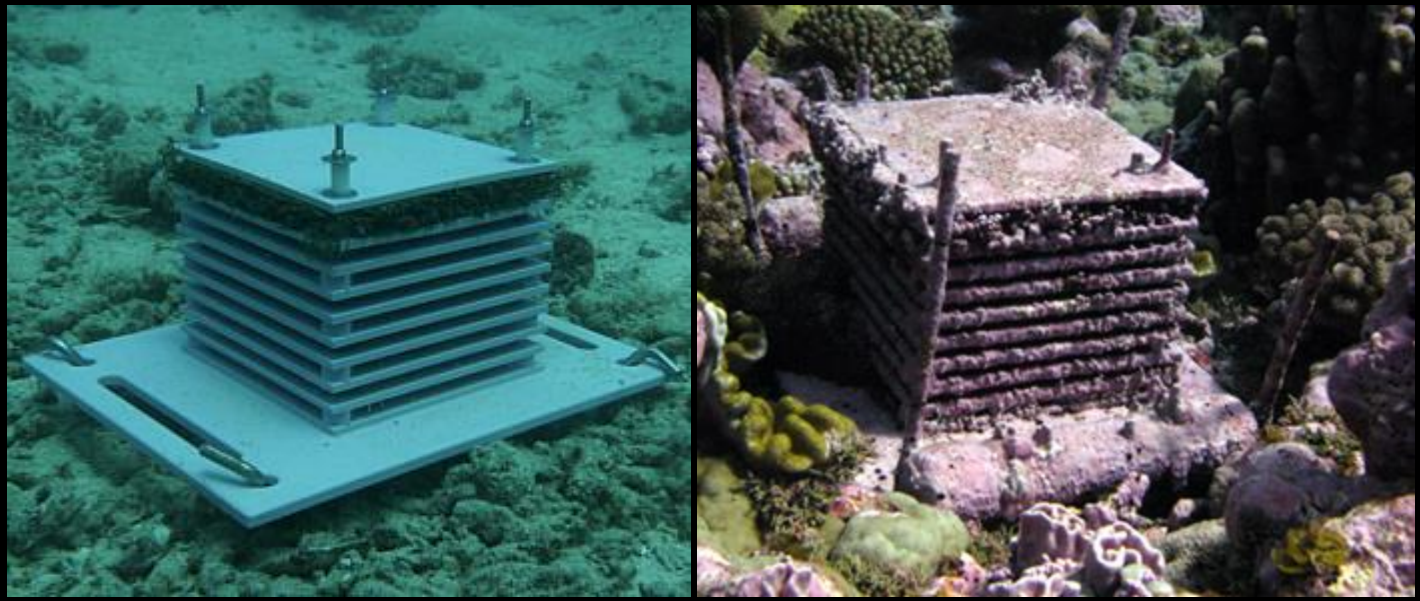


Photo: Chris Meyer

Colonized ARMS Plate

Photo: Chris Meyer

Scrape, Blend, Isolate DNA

Photo: Chris Meyer

Critical Needs in Advancing Marine Biodiversity Monitoring

1: Think holistically about biodiversity monitoring

Monitoring must extend beyond megafauna, commercial species, and foundational species

Monitoring is Limited to Key Species and Megafauna

Channel Islands NPS
Kelp Forest Monitoring Program

56 priority species

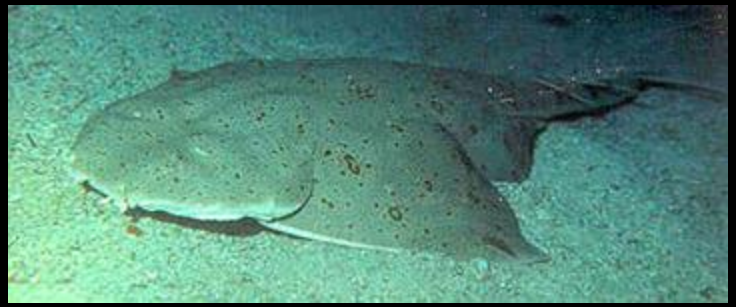
37 sites

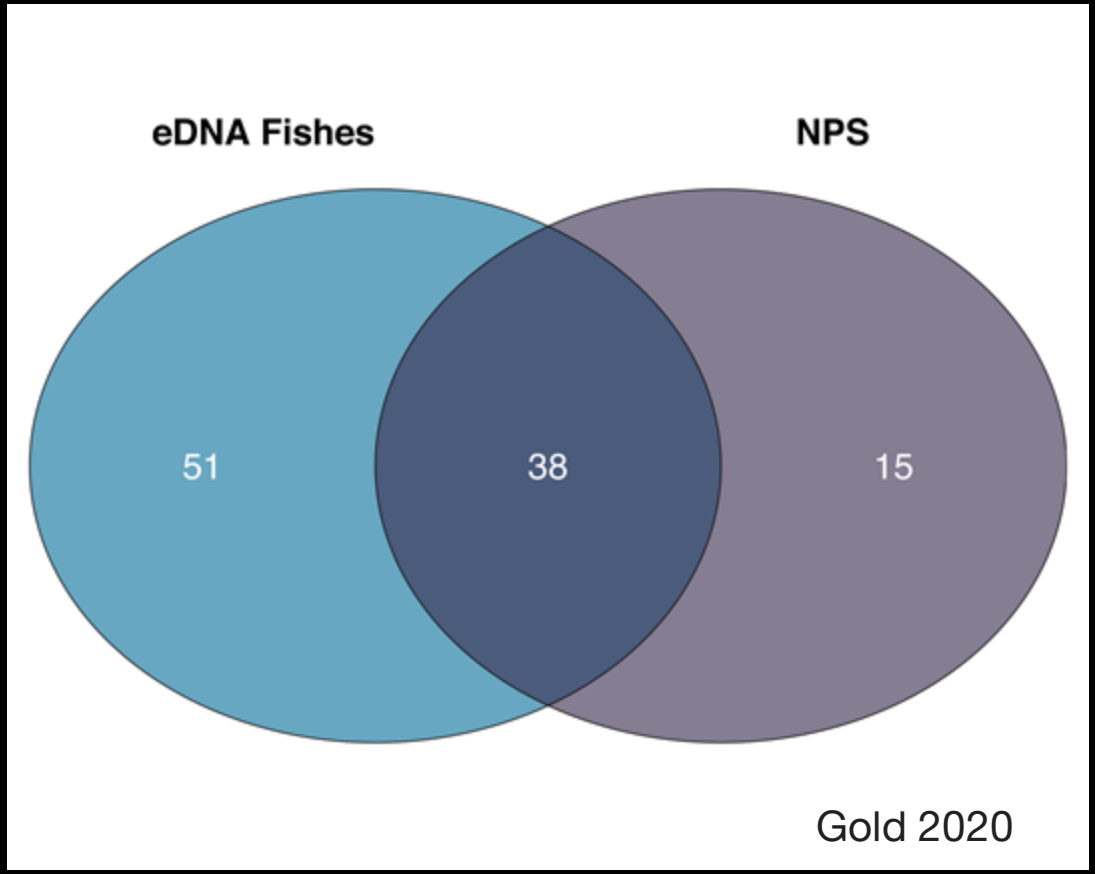
1 survey per year

Monitoring is Limited to Key Species and Megafauna

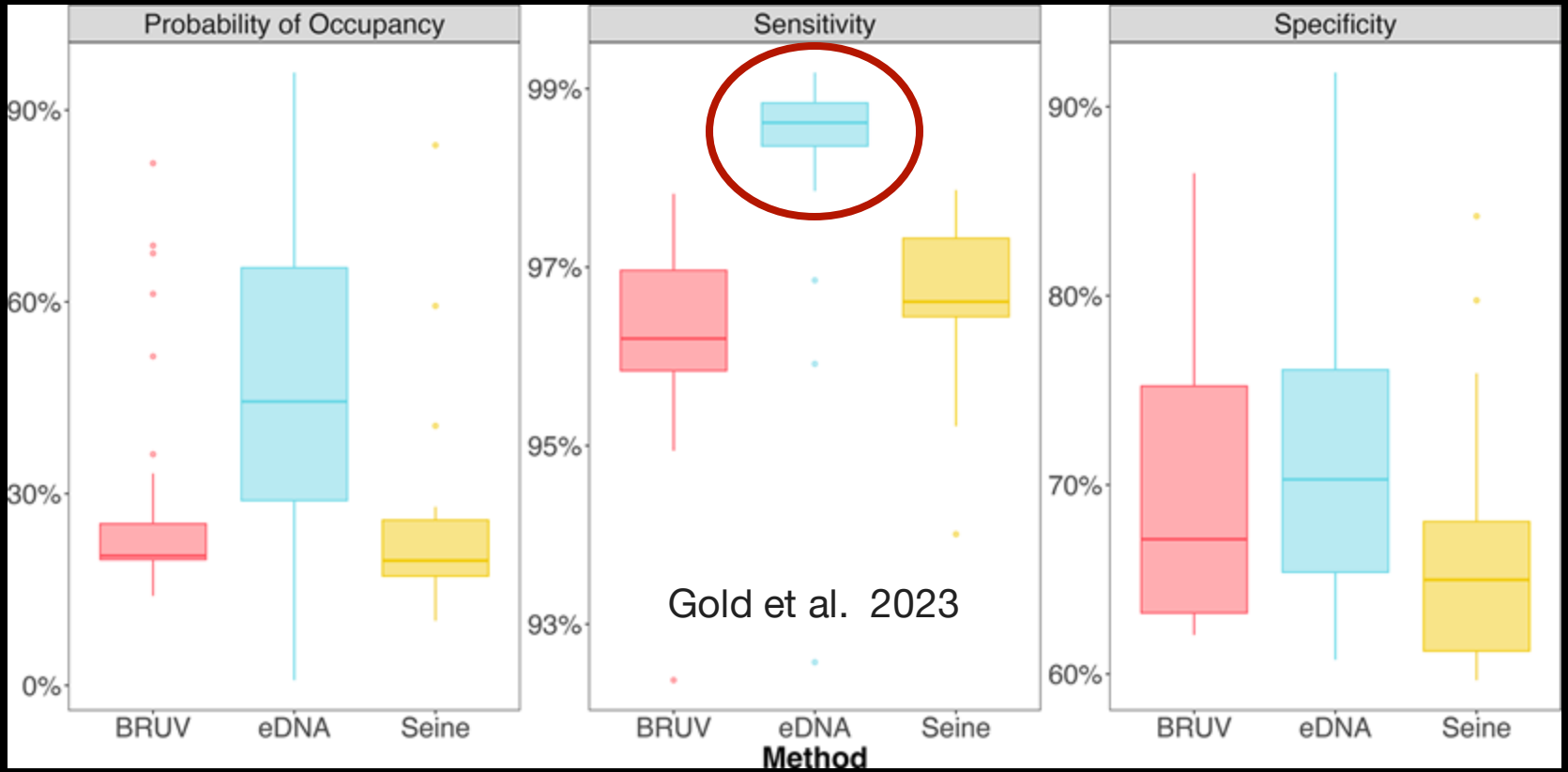
Flying Blind!

eDNA Metabarcoding Outperforms Visual Surveys



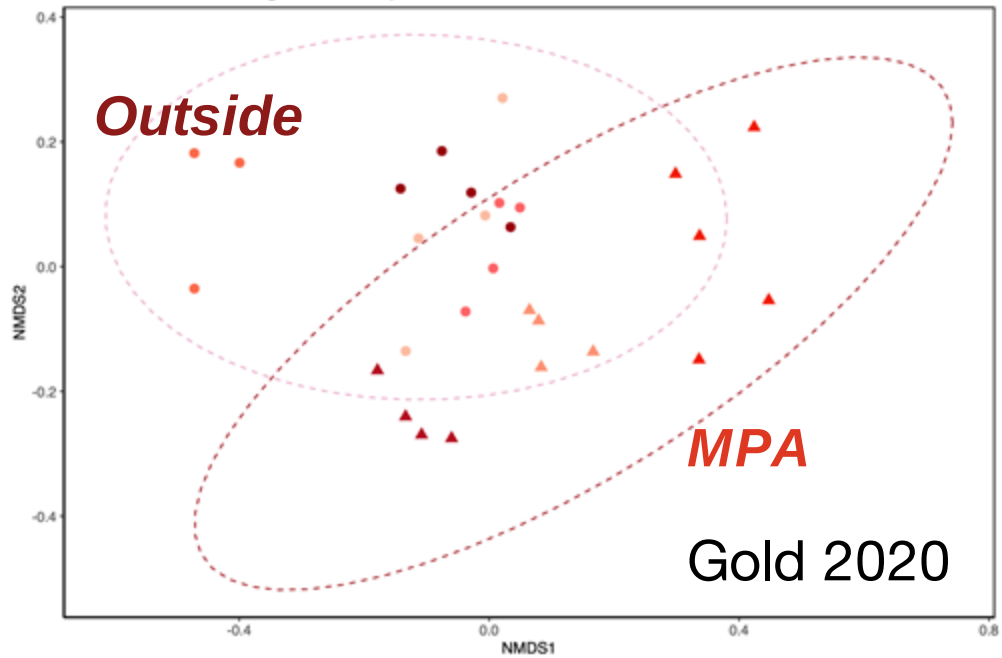


Metabarcoding Outperforms Traditional Sampling Methods

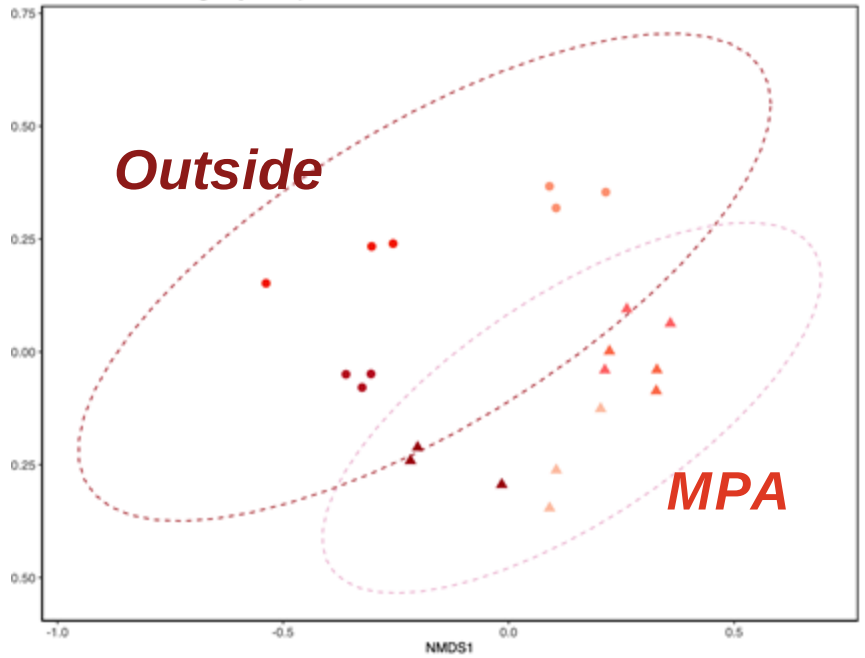


eDNA is An Effective Monitoring Tool

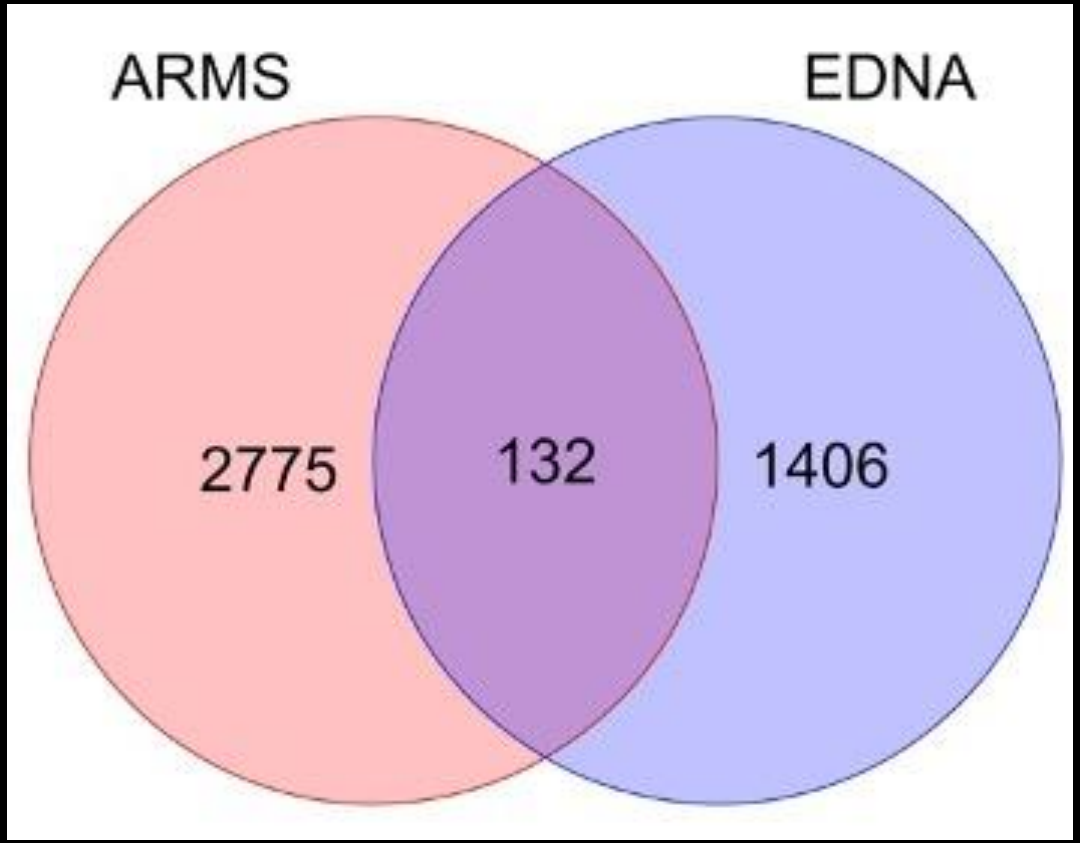
National Park Service
SCUBA Surveys



eDNA
Metabarcoding Surveys

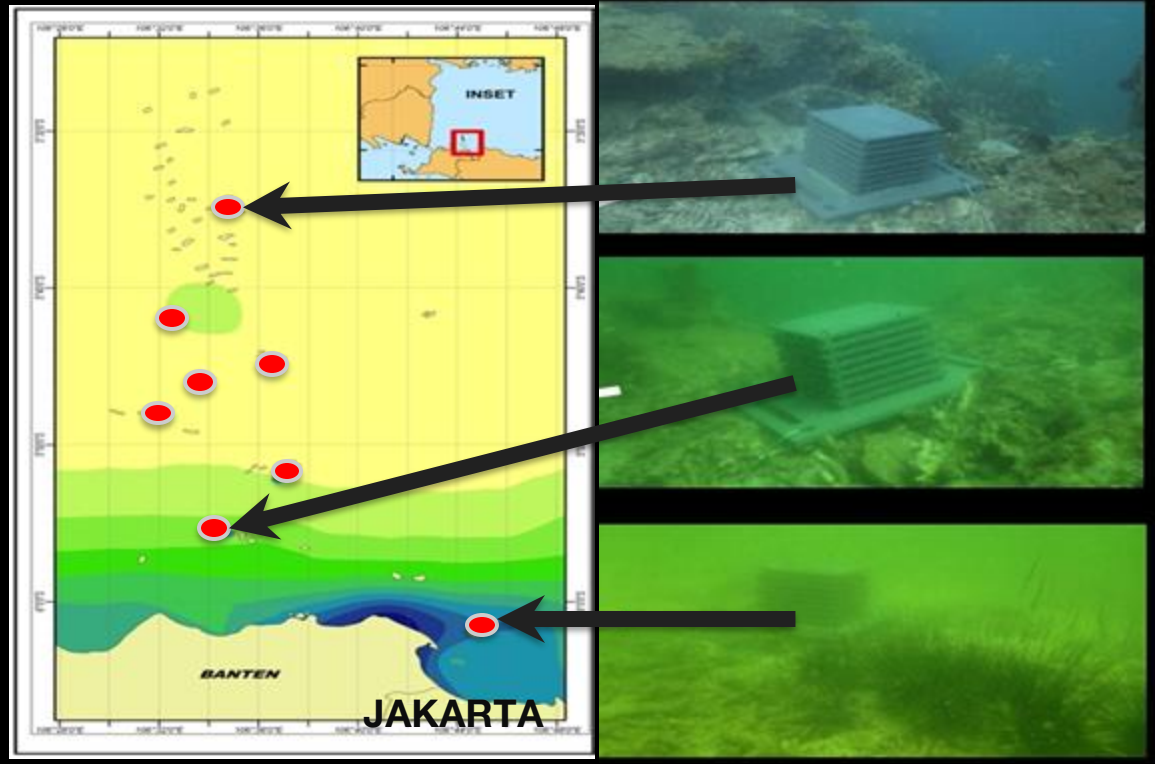


eDNA and ARMS Capture Completely Different Communities



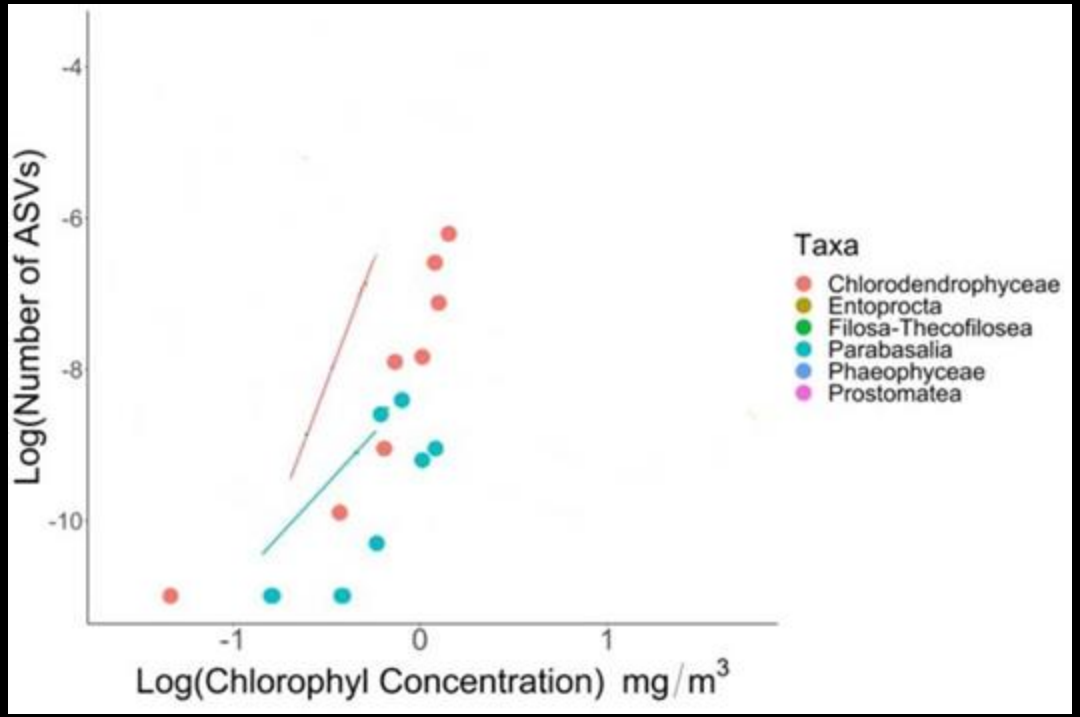
Deployment Across Pollution Gradient

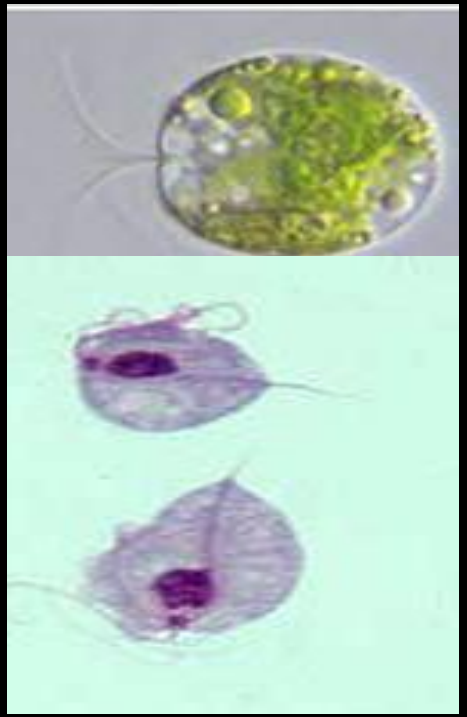
Water quality improves moving away from Jakarta



Taxa Increase Significantly with Poor Water Quality

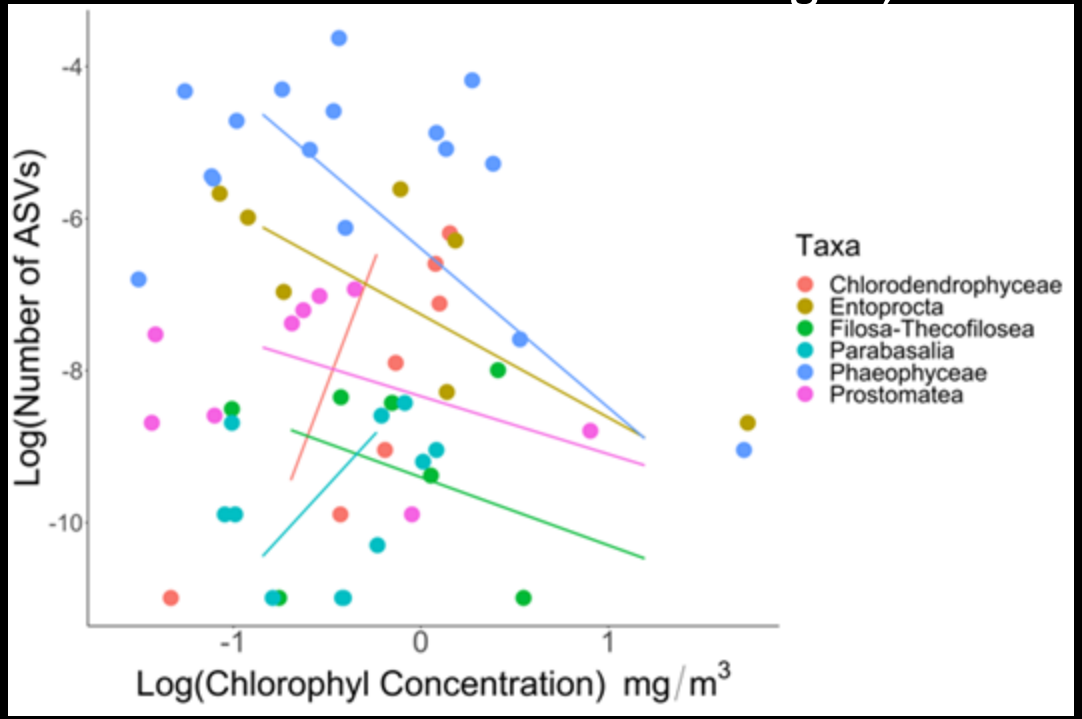
Protists

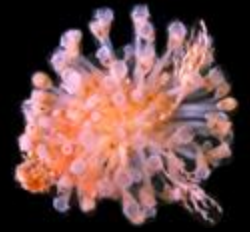


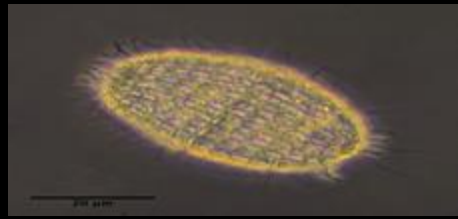


Taxa Decrease Significantly with Poor Water Quality

Brown Algae, Zooids, Ciliates

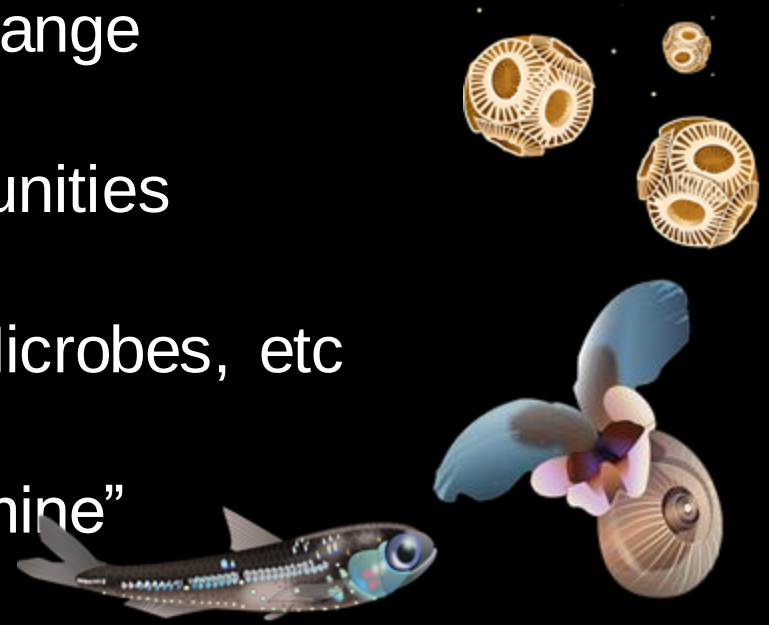






Think Holistically About Biodiversity Monitoring

1. What we currently monitor may not be best indicator of environmental stress or change
2. Move Towards Whole communities
3. Vertebrates, Invertebrates, Microbes, etc
4. Find the “canary in the coal mine”



Critical Needs in Advancing Marine Biodiversity Monitoring

2: Think globally about biodiversity monitoring

Oceans are an interconnected global ecosystem. Monitoring must extend beyond U.S. borders, territories, and exclusive economic zones

Understanding Connectivity is Critical

Opinion TRENDS in Ecology and Evolution Vol.20 No.2 February 2005

Critical science gaps impede use of no-take fishery reserves

Peter F. Sale[1], Robert K. Cowen[2], Bret S. Danilowicz[3], Geoffrey P. Jones[4], Jacob P. Kritzer[5], Kenyon C. Lindeman[6], Serge Planes[7], Nicholas V.C. Polunin[8], Garry R. Russ[4], Yvonne J. Sadovy[9] and Robert S. Steneck[10]

[1]Biological Sciences, University of Windsor, Windsor, ON, Canada, N9B 3P4
[2]Rosensteil School of Marine & Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149-1098, USA
[3]College of Science & Technology, Georgia Southern University, Statesboro, GA 30460, USA
[4]Marine Biology and Aquaculture, James Cook University, Townsville, QLD 4811, Australia
[5]Environmental Defense – Oceans Program, 257 Park Ave. S., New York, NY 10010, USA
[6]Environmental Defense – Oceans Program, 14630 Southwest 144 Terr., Miami, FL 33186-5617, USA
[7]Centre de Biologie et d'Écologie Tropicale et Méditerranée, EPHE ESA 8046 CNRS, Université de Perpignan, Perpignan 66860, France
[8]Marine Sciences & Coastal Management, University of Newcastle, Newcastle upon Tyne, UK, NE1 7RU
[9]Ecology & Biodiversity, The University of Hong Kong, Pok Fu Lam Rd, Hong Kong, China
[10]School of Marine Sciences & Darling Marine Center, University of Maine, Walpole, ME 04573, USA

Protecting a Reserve

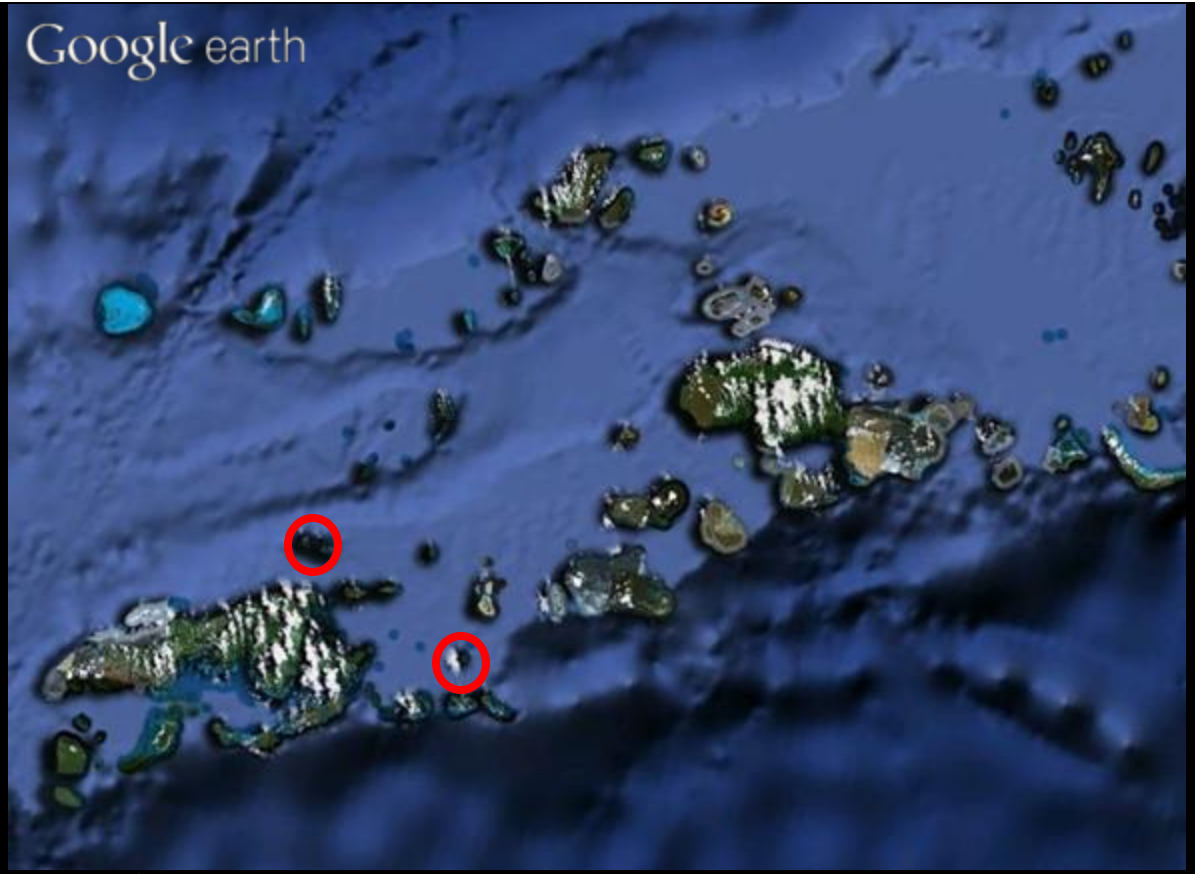
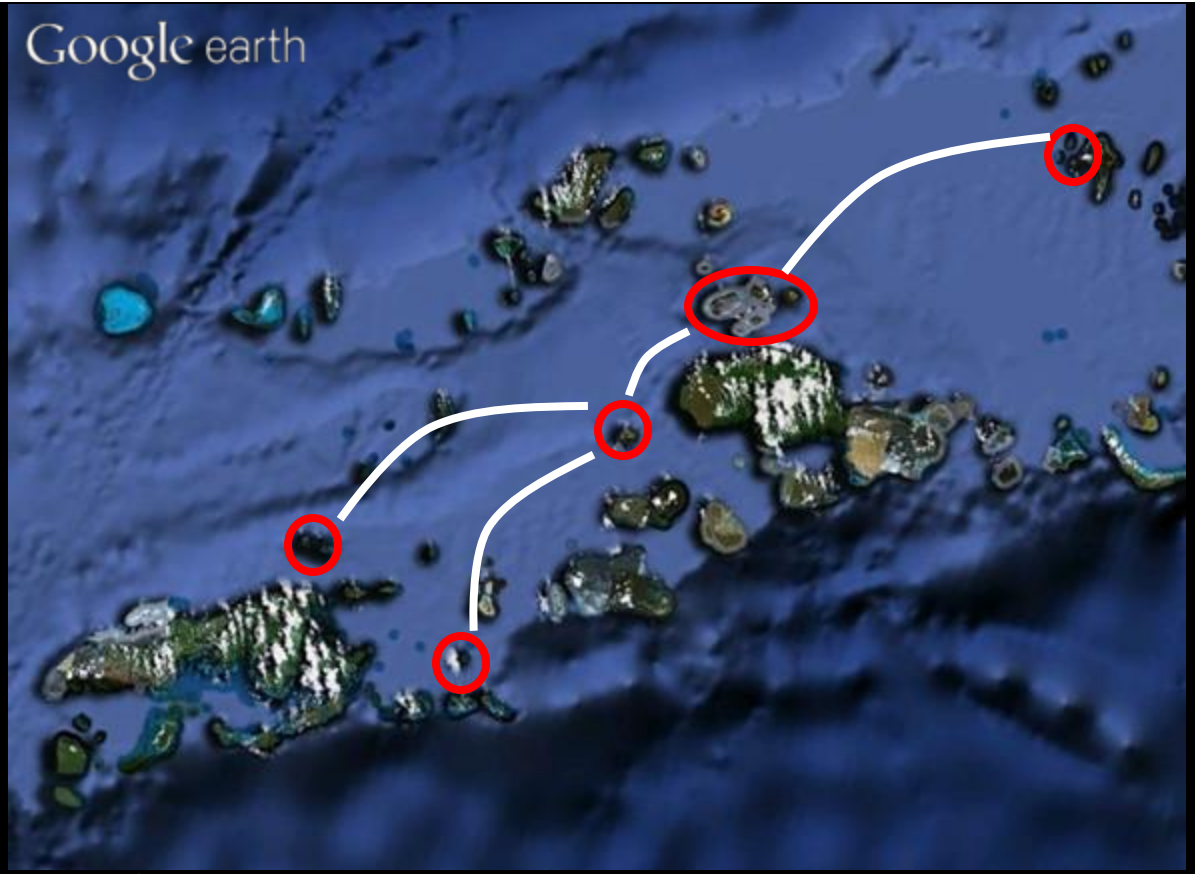
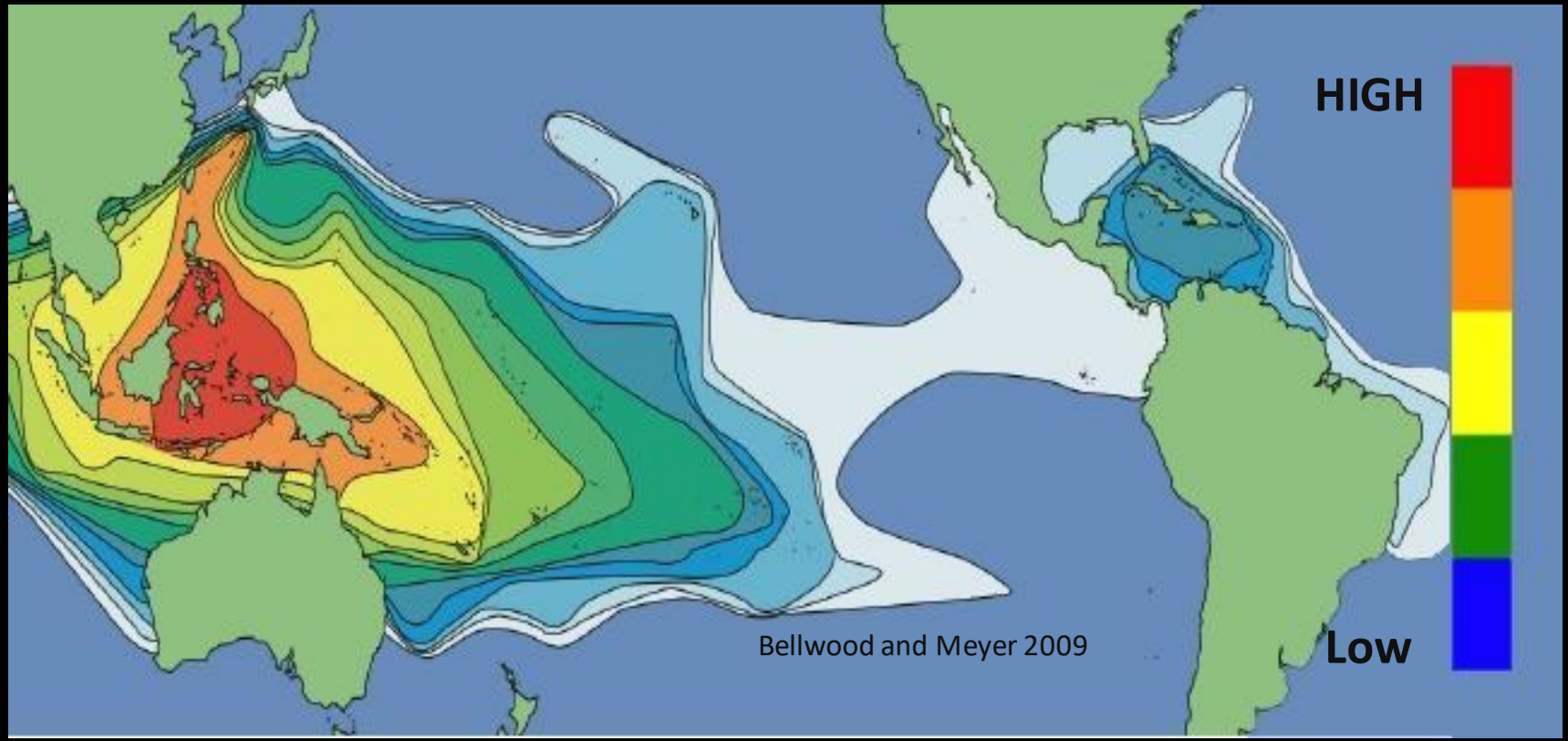


Image Landsat Data SIO, NOAA, U.S. Navy, NGA, BEBCO

Requires Protecting Larval Sources



Marine Biodiversity Peaks in Coral Triangle



The Importance of Biodiversity

"At least **40% of the world's economy** and **80% of the needs of the poor** are derived from biological resources."

Convention on Biodiversity

Nutritional Importance of the Coral Triangle

Home to 363 Million People

>120 Million eat fish for primary protein source

Economic Importance of the Coral Triangle

Supports the livelihoods of >120 million people

Philippines

2.2% Global Fisheries Production

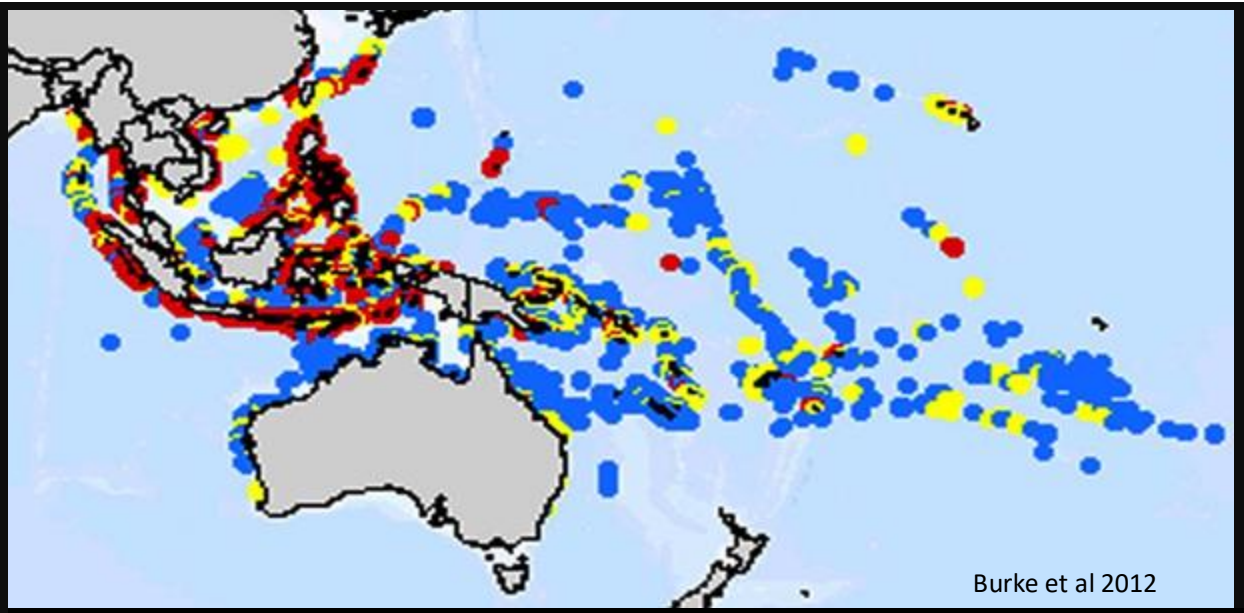
8.4 % of GDP (UN FAO)

Indonesia

4.8% Global Fisheries Production

4.8% of GDP (UN FAO)

Coral Triangle is Critically Endangered



Biodiversity = Food Security

Food Security = Political Stability

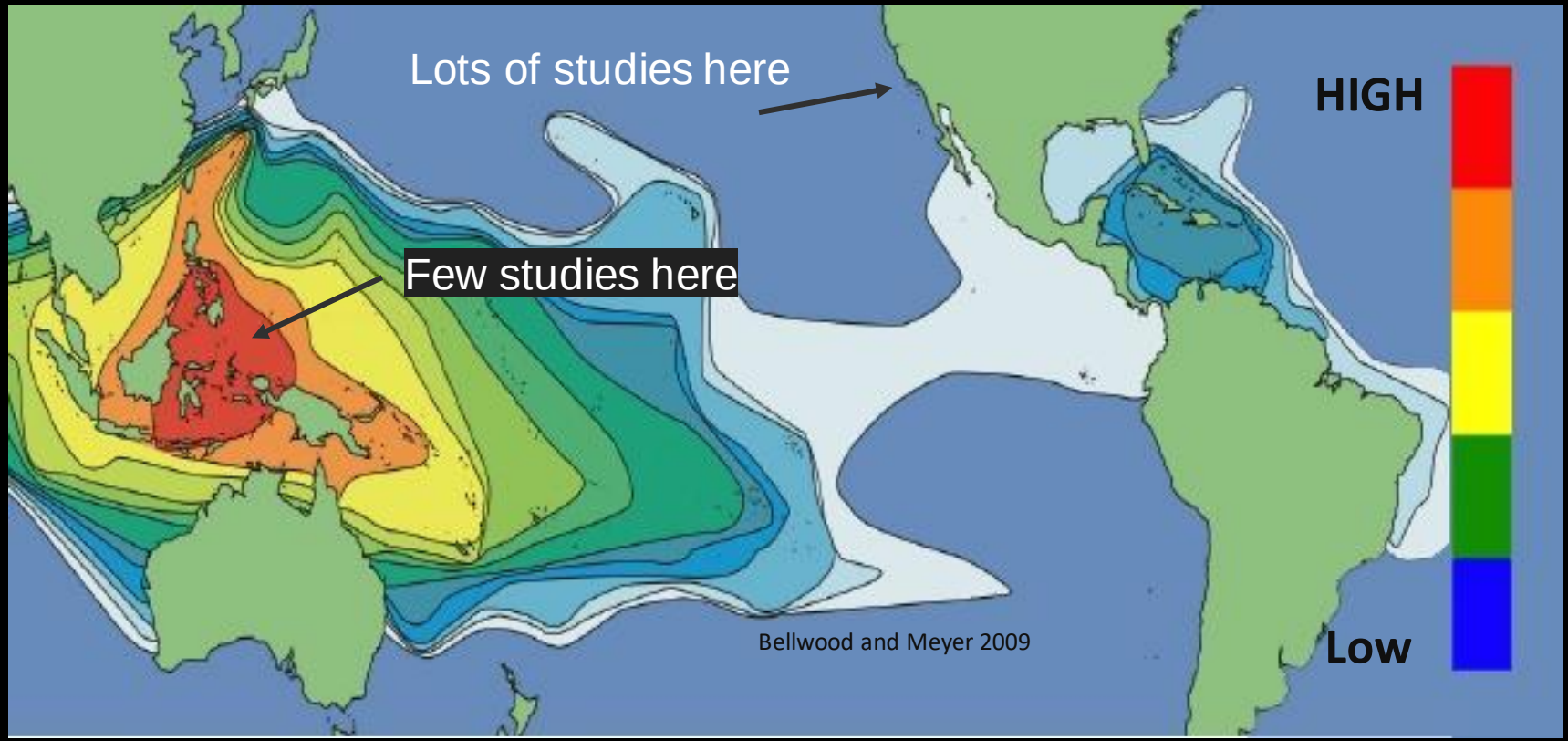
Political Stability = US National Security

Critical Needs in Advancing Marine Biodiversity Monitoring

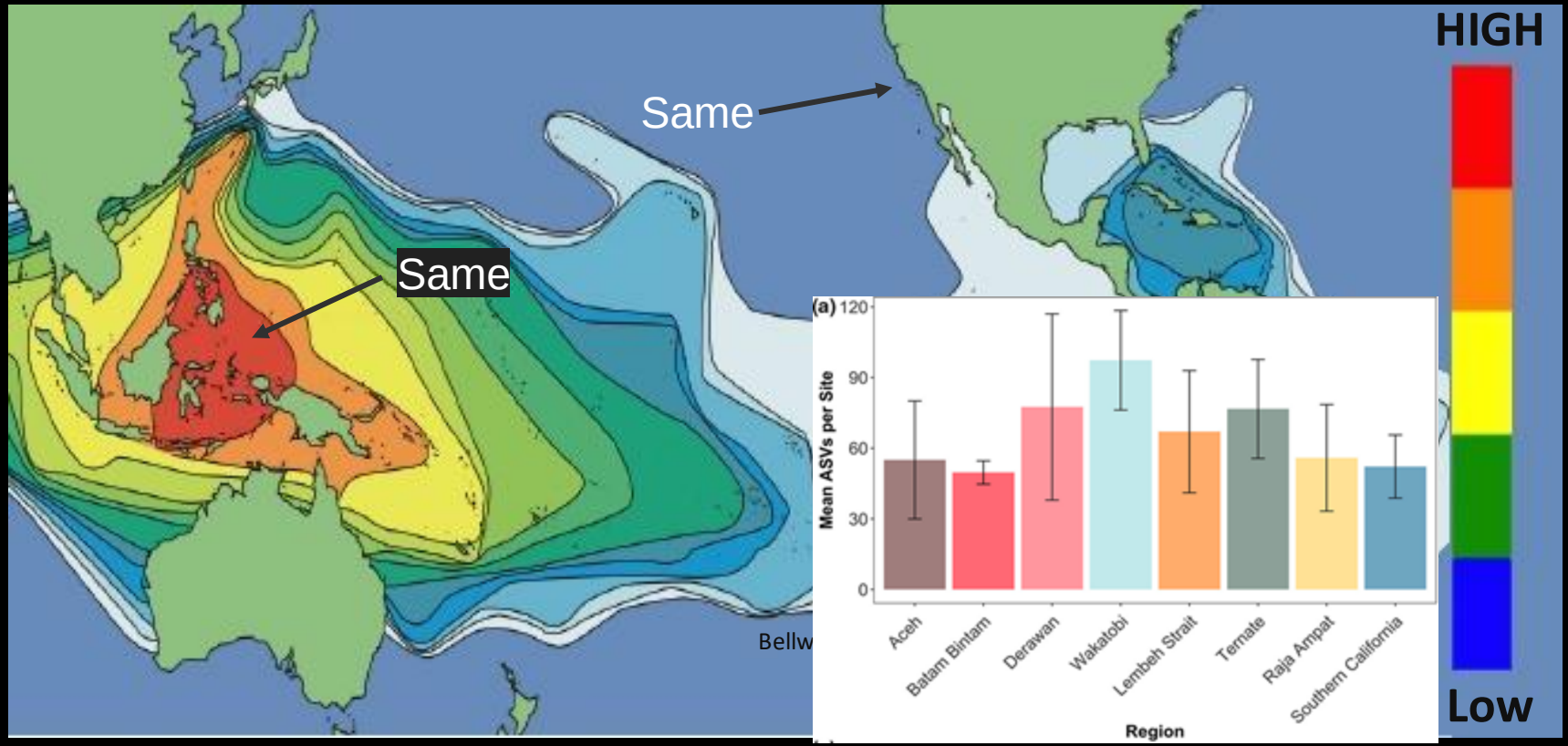
3: Develop Resources and Capacity for Metabarcoding-based Monitoring of Marine Biodiversity

Monitoring will only be as effective as our collective capacity to conduct monitoring

Strong Biases in Research Effort

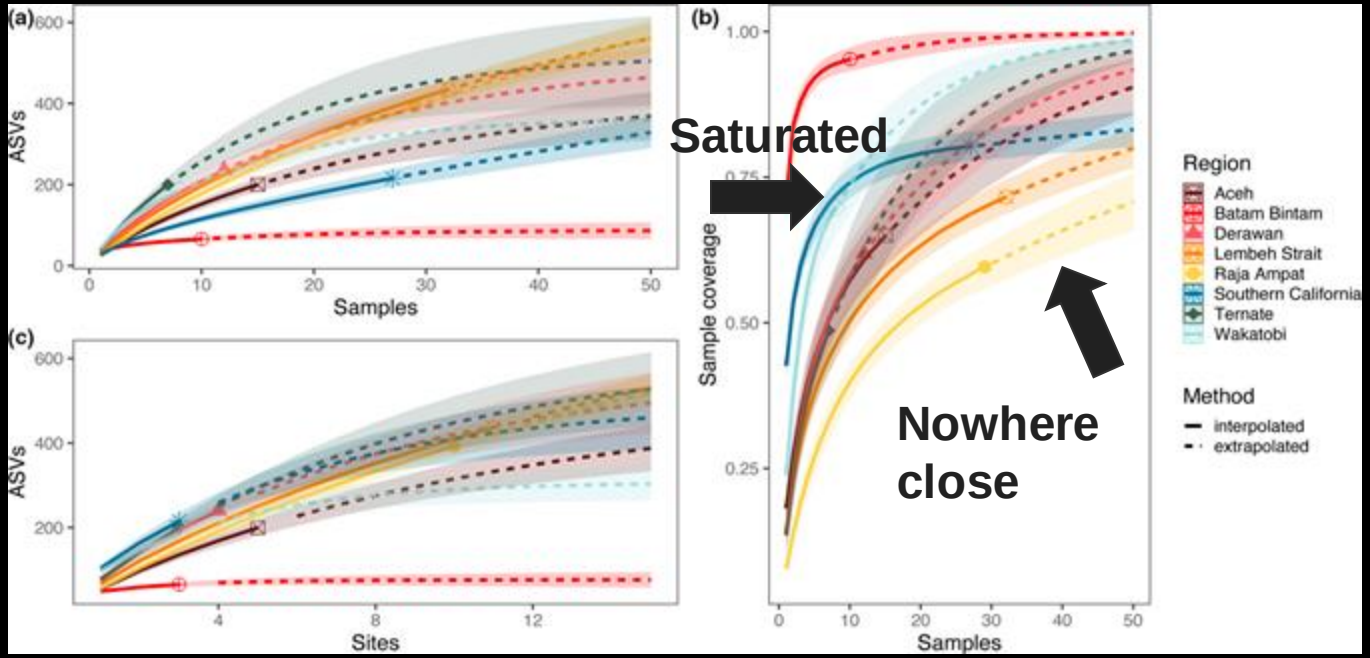


Same # of Species per Liter



Sampling Methods in Temperate Oceans Insufficient in Biodiversity Hotspots

Rarefaction curves plateau in low diversity, but not high diversity ecosystems



Marwayana et al 2021

Databases are Insufficient in Biodiversity Hotspots

A Comparison of Two eDNA studies in Indonesia

Less Complete Database	More Complete Database
31.8% ASVs Identified	80% ASVs Identified
Juhel et al 2020	Marwayana et al 2021

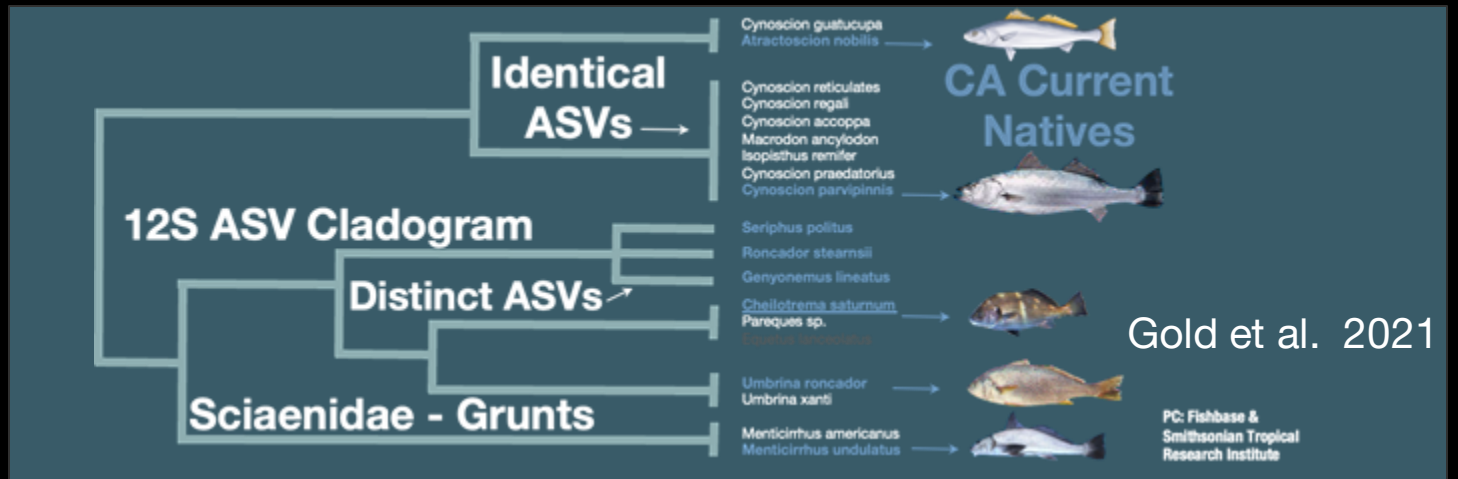
Improving Databases Improves Results

Metric	Before Barcoding	After Barcoding
ASVs Assigned to Species	145	**156**
Reads Assigned to Species	192,808	**248,677**
ASVs Assigned to Native Species	25	**37**

Gold et al. 2021

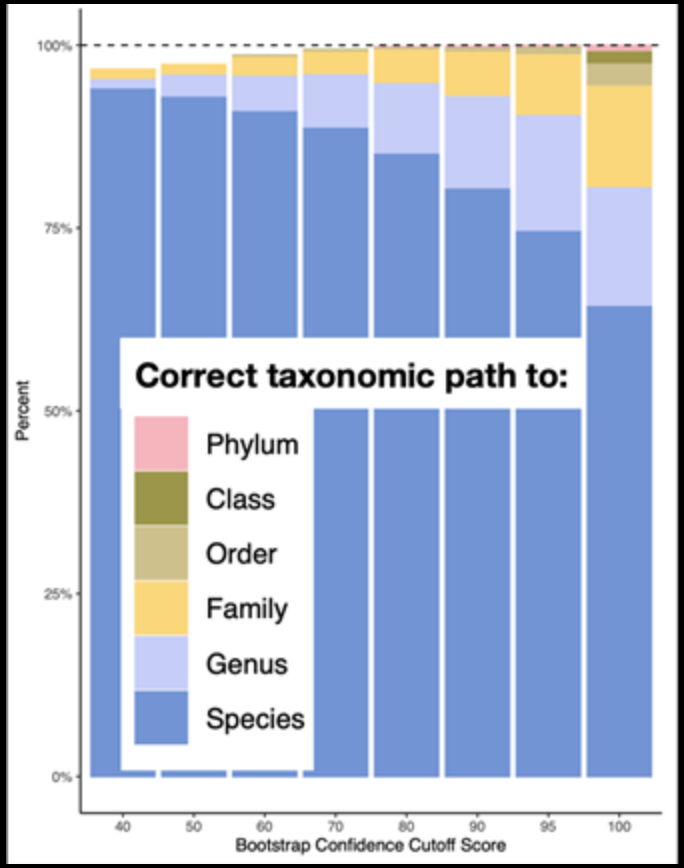
Regional Databases Outperform Global Databases

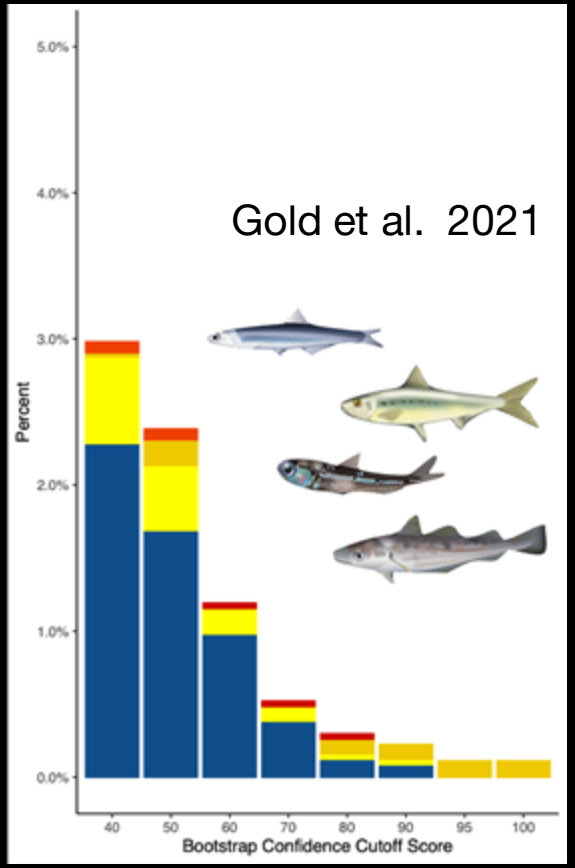
Taxonomic Cross Validation Metric	Assigned by Global	Assigned by Regional
Accuracy	86.5%	**90.9%**
Sensitivity	88.0%	**92.1%**
Specificity	98.2%	**98.7%**



Gold et al. 2021

Need for Defensible Stringent Taxonomic Practices





Invest in PEOPLE as Well as Databases!

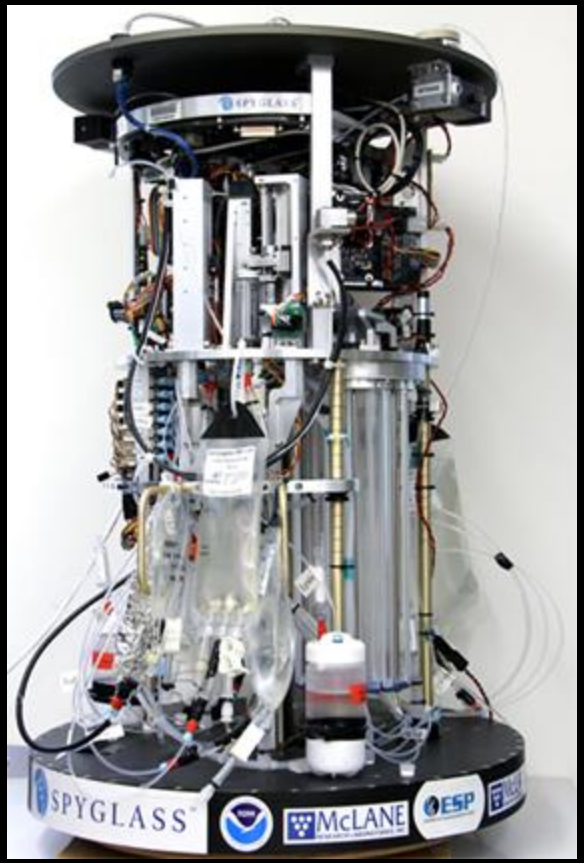
Critical Needs in Advancing Marine Biodiversity Monitoring

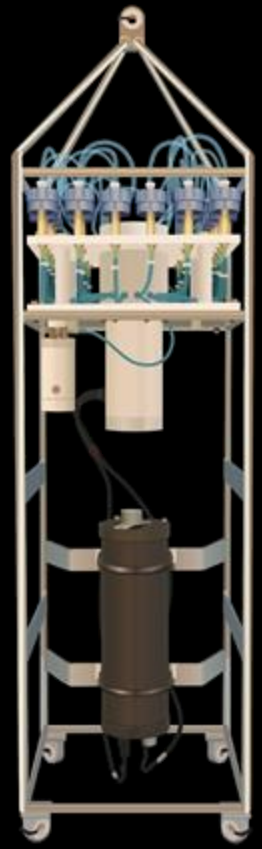
4: Overcome key technical challenges

Automation, and extracting information on abundance and biomass are essential

eDNA: Collect Water (or sediment)

Automation to Scale Biodiversity Observations

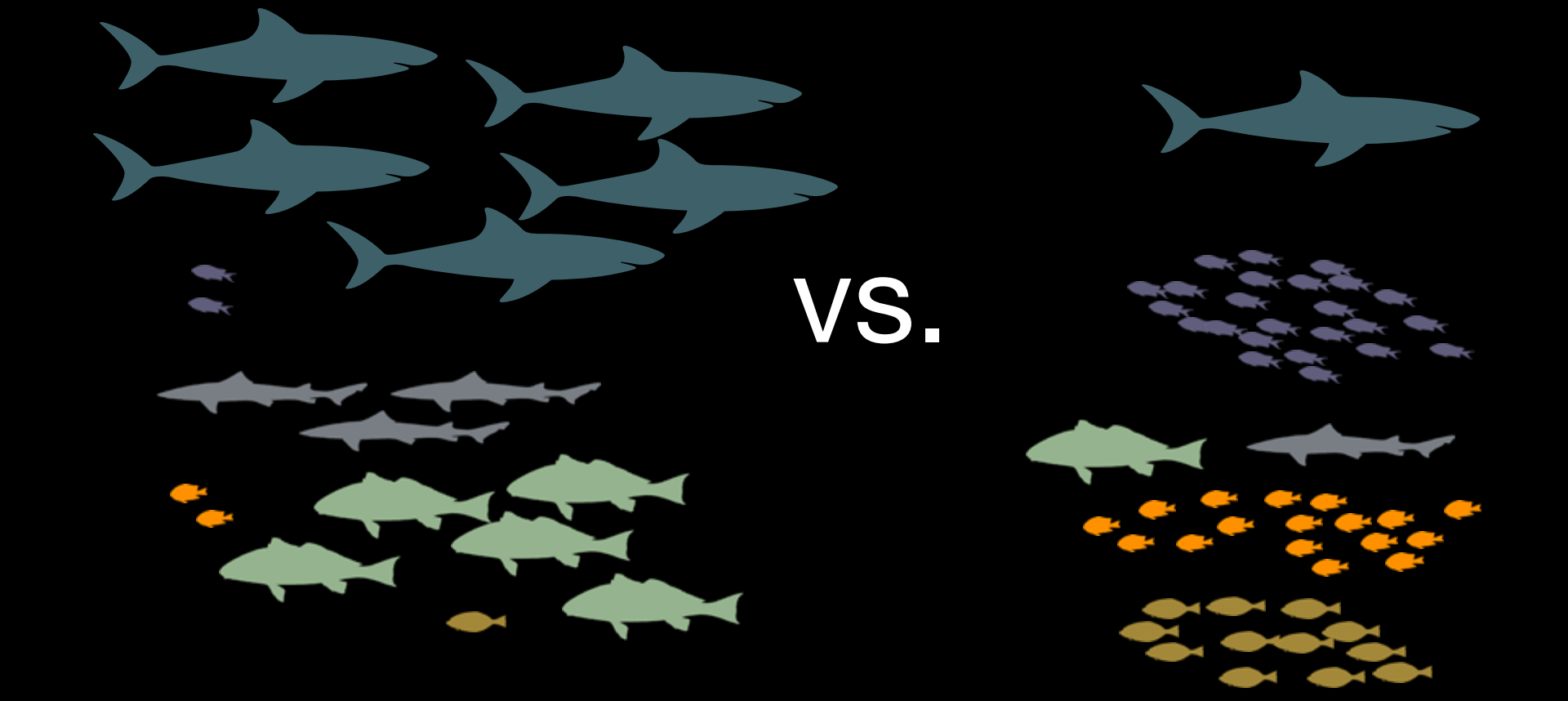




Metabarcoding currently answers WHO is present

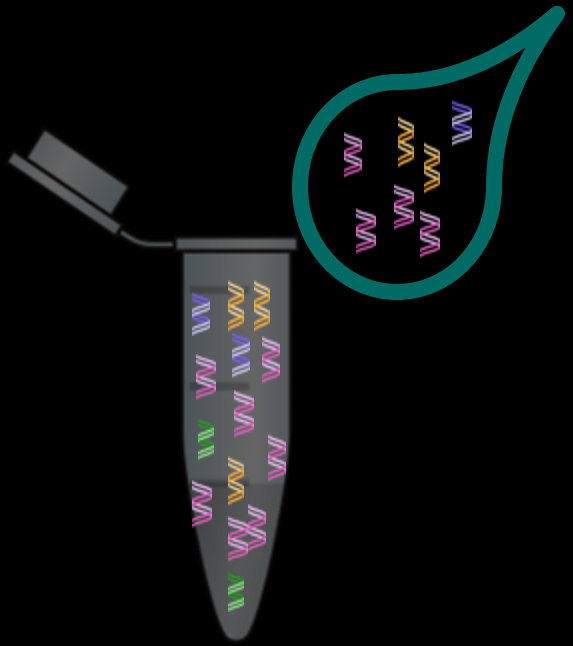
Research is needed to QUANTIFY abundance

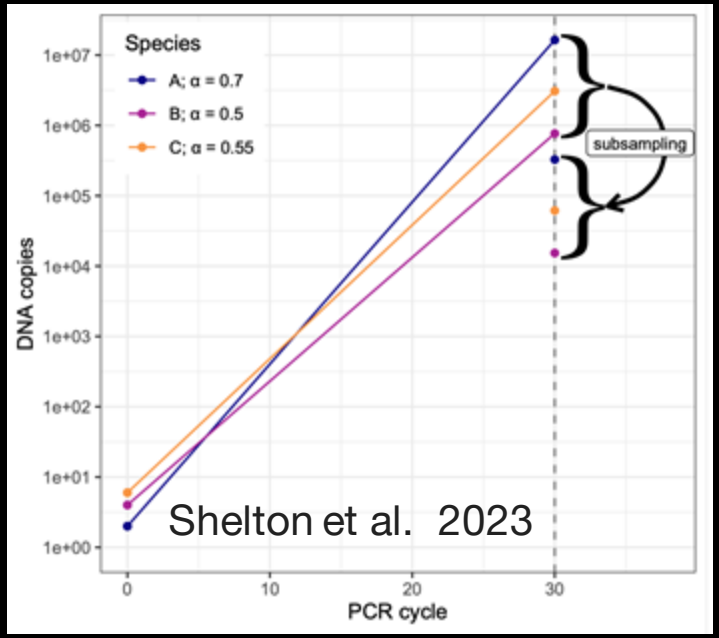
Abundance Matters



Developing Mechanistic Frameworks

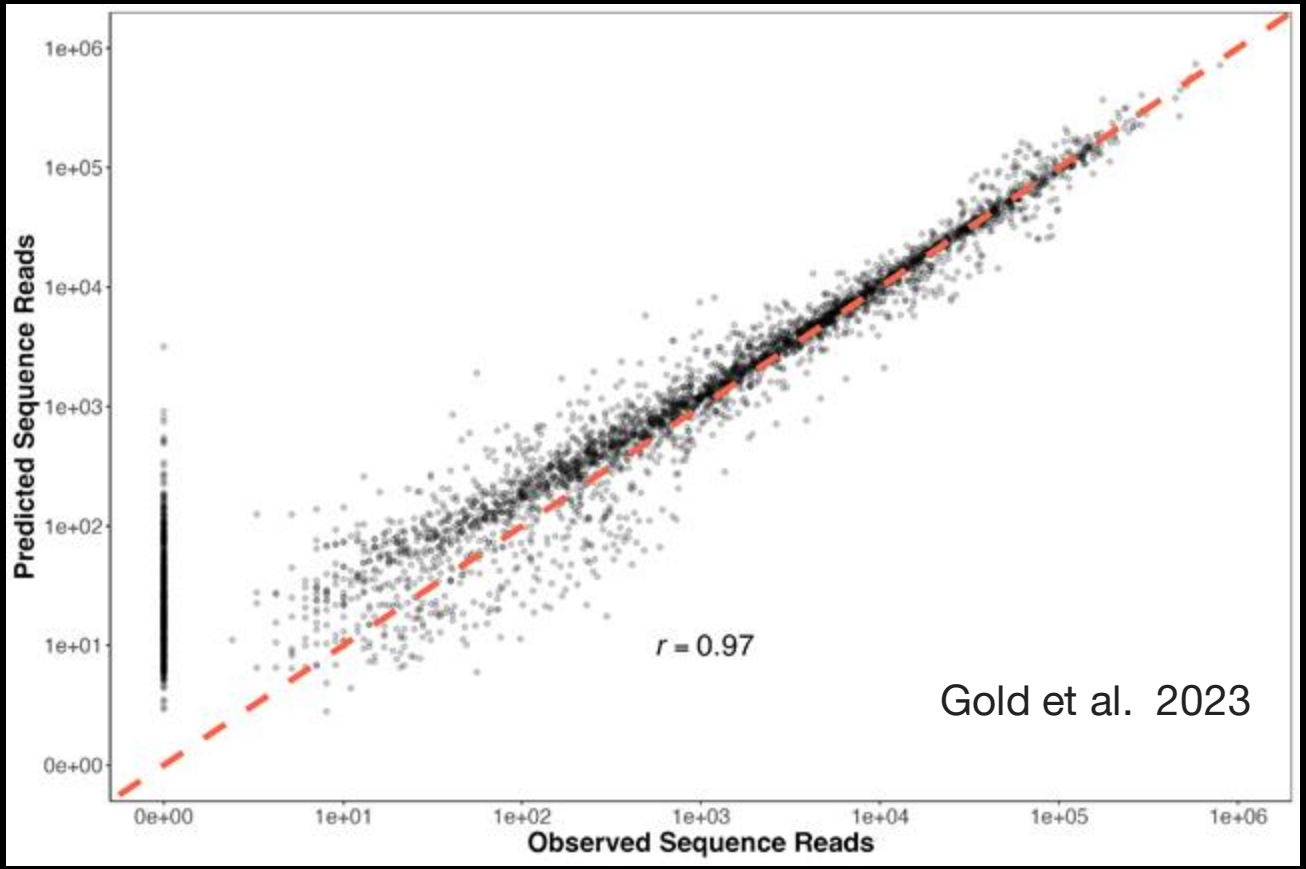
DNA Conc. = Poisson(DNA Molecules * Volume)





Reads = DNA Conc. (Amp. efficiency +1) $^{N_{pcr}}$ + η

Applying Mechanistic Frameworks



Gold et al. 2023

Critical Needs in Advancing Marine Biodiversity Monitoring

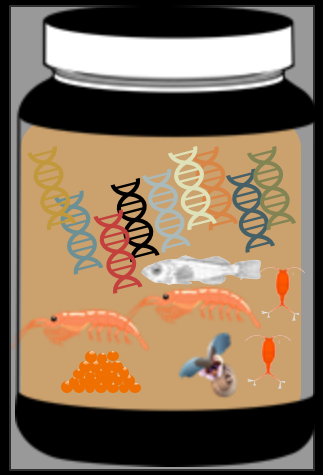
5: Leverage long-term observations

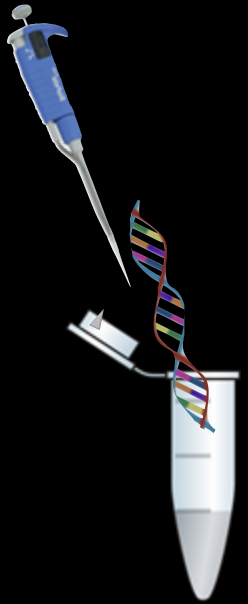
Metabarcoding can unlock information in historical collections providing insights into the future

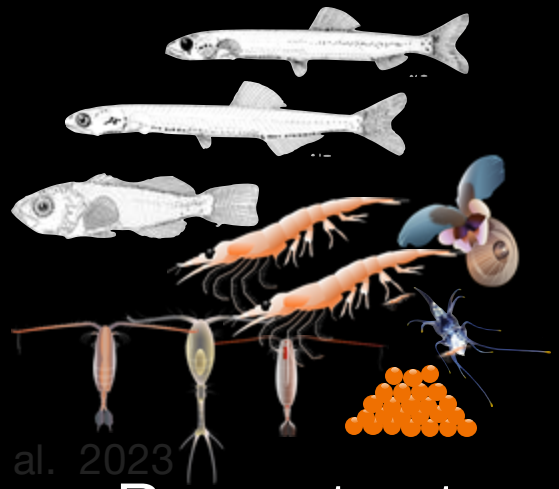
As we look to the future, we need to tap into collections from the past

CalCOFI
est. 1949

Applying Mechanistic Frameworks



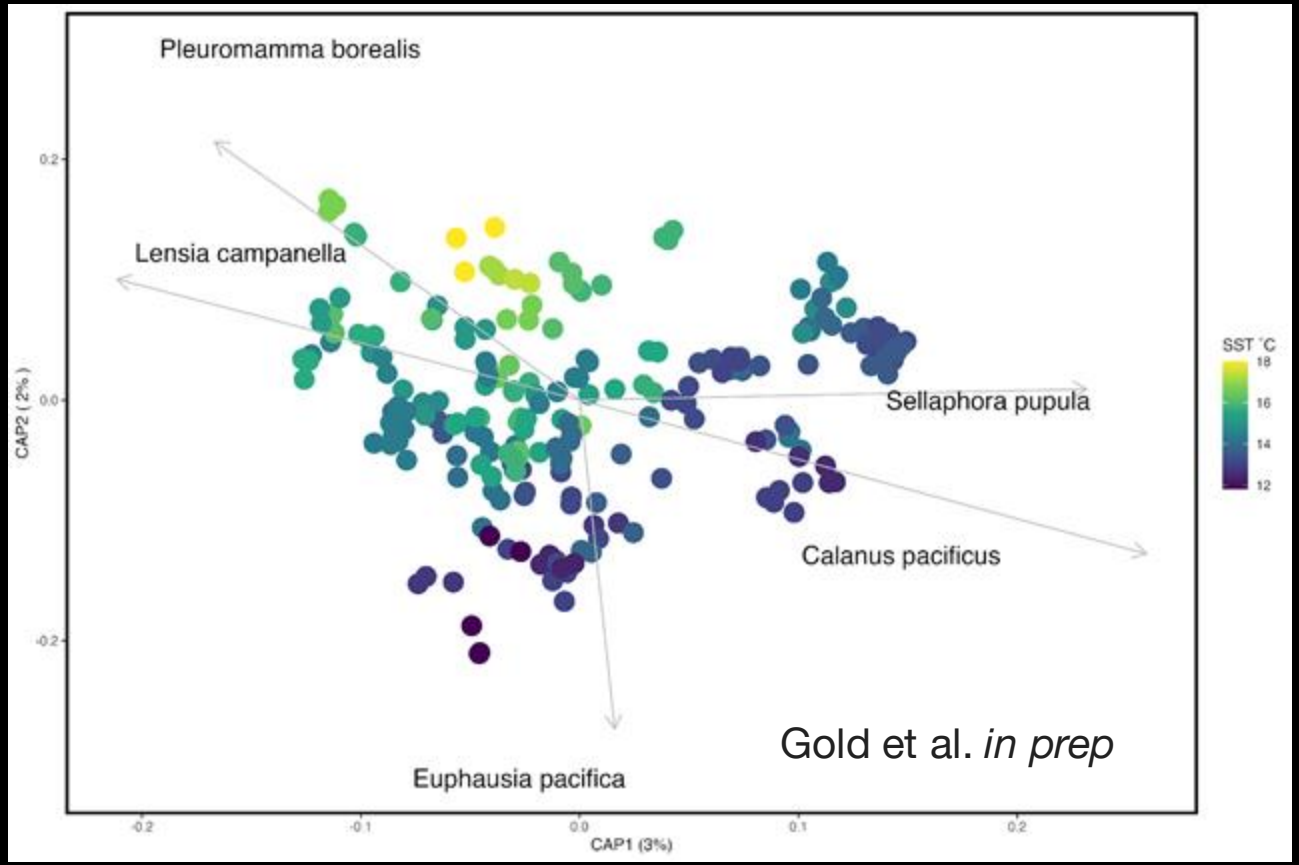




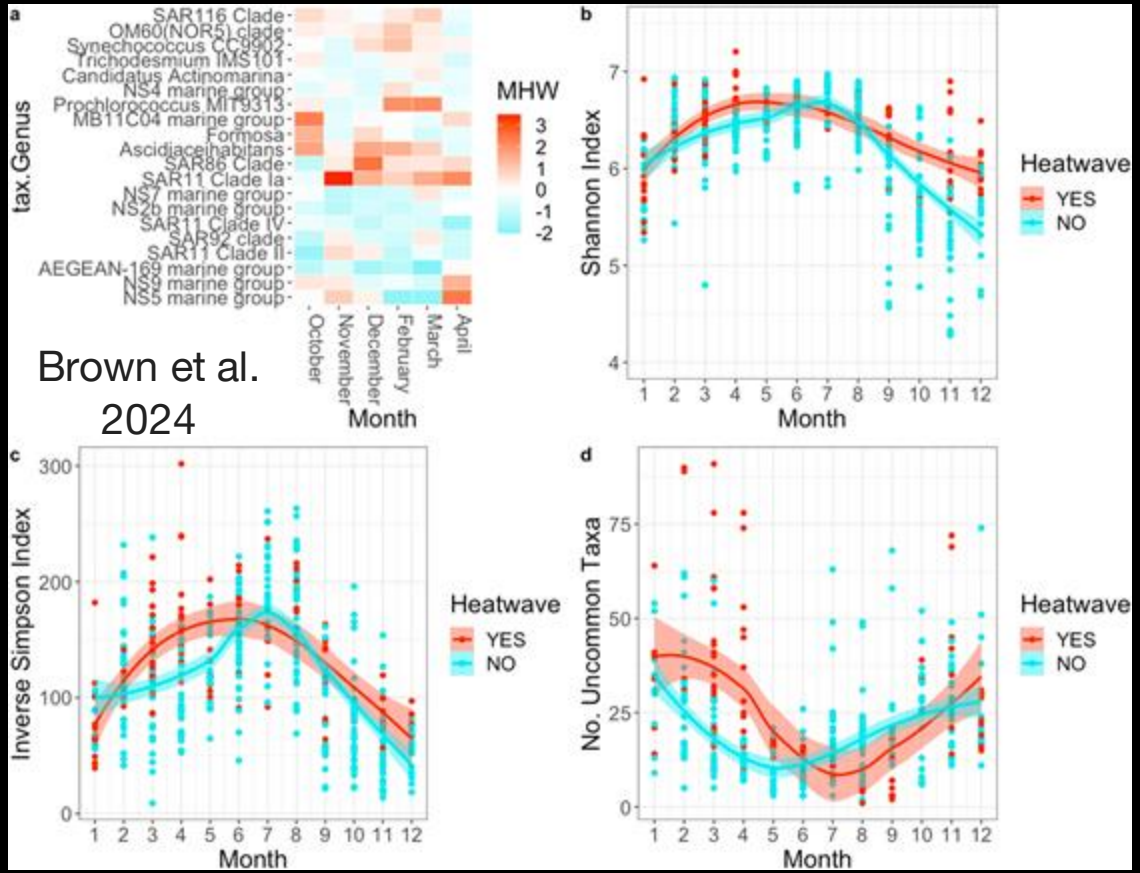
Gold et al. 2023

Sample → Process → Sequence → Reconstruct

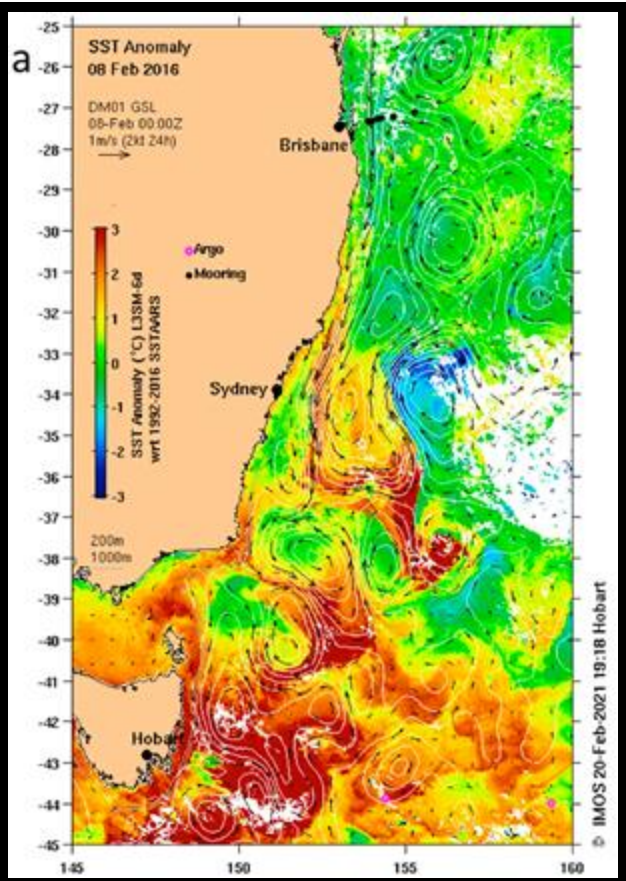
Climate Grade Zooplankton Time Series



Decadal Scale Microbial Responses



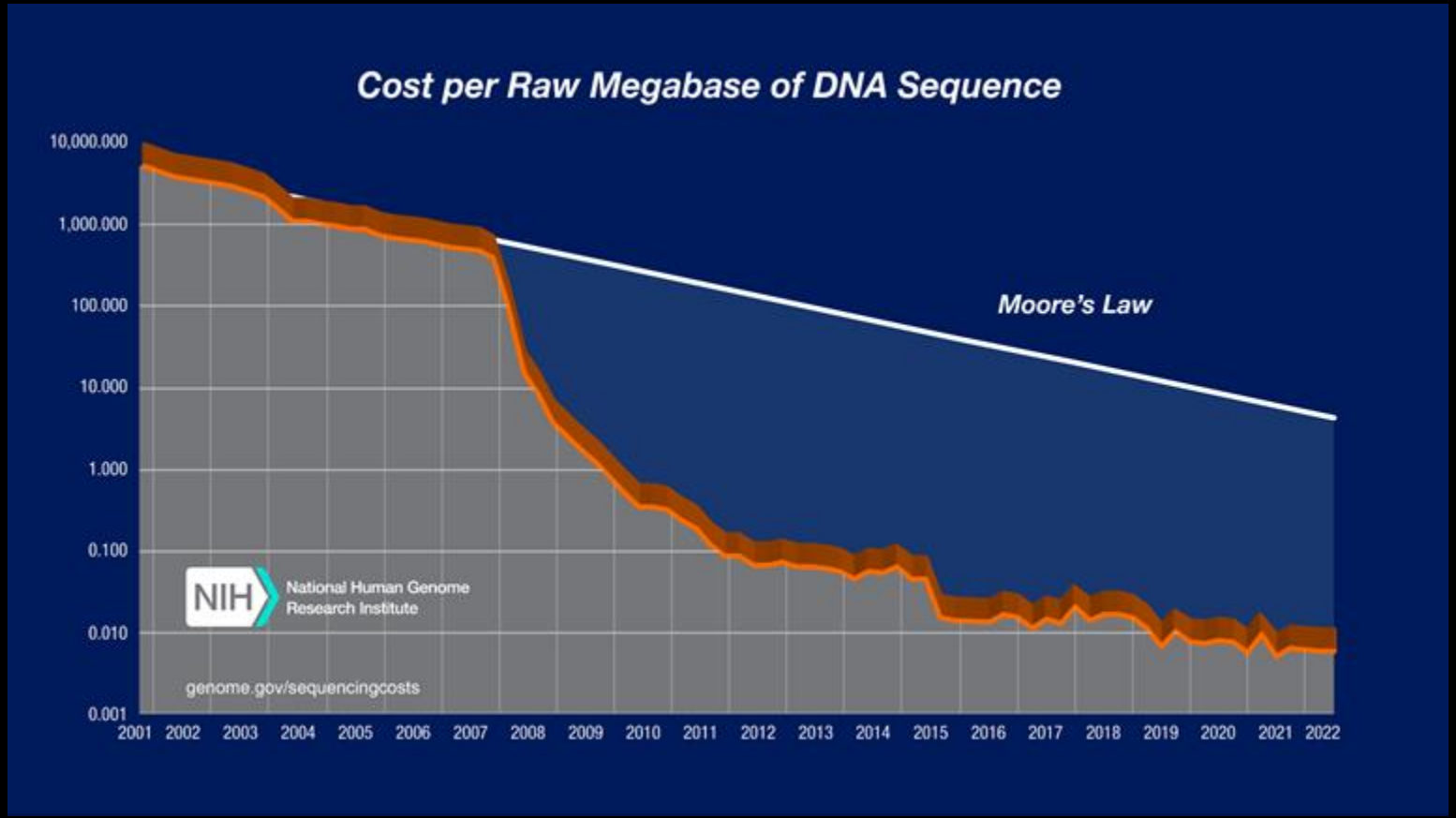
Brown et al. 2024



Why Metabarcoding Ocean Observation is a Key Investment

1: Declining Cost of Sequencing

Declining Cost of Sequencing



Why Metabarcoding Ocean Observation is a Key Investment

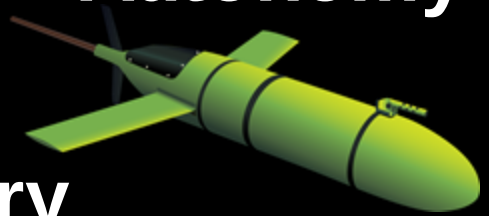
2: Highly complementary to advanced tools

Complementary Techniques

AI/ML

Acoustics

Autonomy



Imagery

‘Omics

Why Metabarcoding Ocean Observation is a Key Investment

3: Scalable

Automation to Scale Biodiversity Observations

Metabarcoding Can Maximize Ocean Biodiversity Observation

- Broader biodiversity, global scale
- Higher Sensitivity
- Quantitative estimates
- Scalable - Automation & Lower cost
- Access archived samples needed for baselines

Critical Needs in Ocean Biodiversity Observation

1: Think holistically about biodiversity monitoring

2: Think globally about biodiversity monitoring

3: Develop Resources and Capacity for Metabarcoding-based Monitoring of Marine Biodiversity

4: Overcome key technical challenges

5: Leverage long-term observations

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NSF

UCLA

UCLA La Kretz Center
California Conservation Science

SCCWRP
Established 1969

National Park Service

Natural History Museum
Los Angeles County

DISCO
Diversity Initiative for the Southern California Ocean

OBON
Ocean Biomolecular Observing Network

Scripps Institution of Oceanography
UCSD

National Geographic

BIONESIA
Biodiversitas Indonesia

Smithsonian

Los Angeles Waterkeeper®

California ScienCenter

The Bay Foundation

Resources Legacy Fund

The International SeaKeepers Society

Heal the Bay

Reef Check
California

USC Wrigley Institute for Environmental Studies

Critical Questions Facing This Decade

1: Who are the winners & losers of climate change?

2: How are these changes impacting ecosystem function?

3: How can we support ecosystem resilience to anthropogenic change?

Critical Needs in Advancing Marine Biodiversity Monitoring

1: Think holistically about biodiversity monitoring

Monitoring must extend beyond megafauna, commercial species, and foundational species

Critical Needs in Advancing Marine Biodiversity Monitoring

2: Think globally about biodiversity monitoring

Oceans are an interconnected global ecosystem. Monitoring must extend beyond U.S. borders, territories, and exclusive economic zones

Critical Needs in Advancing Marine Biodiversity Monitoring

3: Develop Resources and Capacity for Metabarcoding based Monitoring of Marine Biodiversity

Monitoring will only be as effective as our collective capacity to conduct monitoring

Critical Needs in Advancing Marine Biodiversity Monitoring

4: Overcome key technical challenges

Automation, and extracting information on abundance and biomass are essential

Critical Needs in Advancing Marine Biodiversity Monitoring

5: Leverage long-term observations

Metabarcoding can unlock information in historical collections providing insights into the future