MarineVERSE – The Marine Biodiversity and Scaling Project

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Coral Reefs as a Model Ecosystem (But also an Imperiled One)

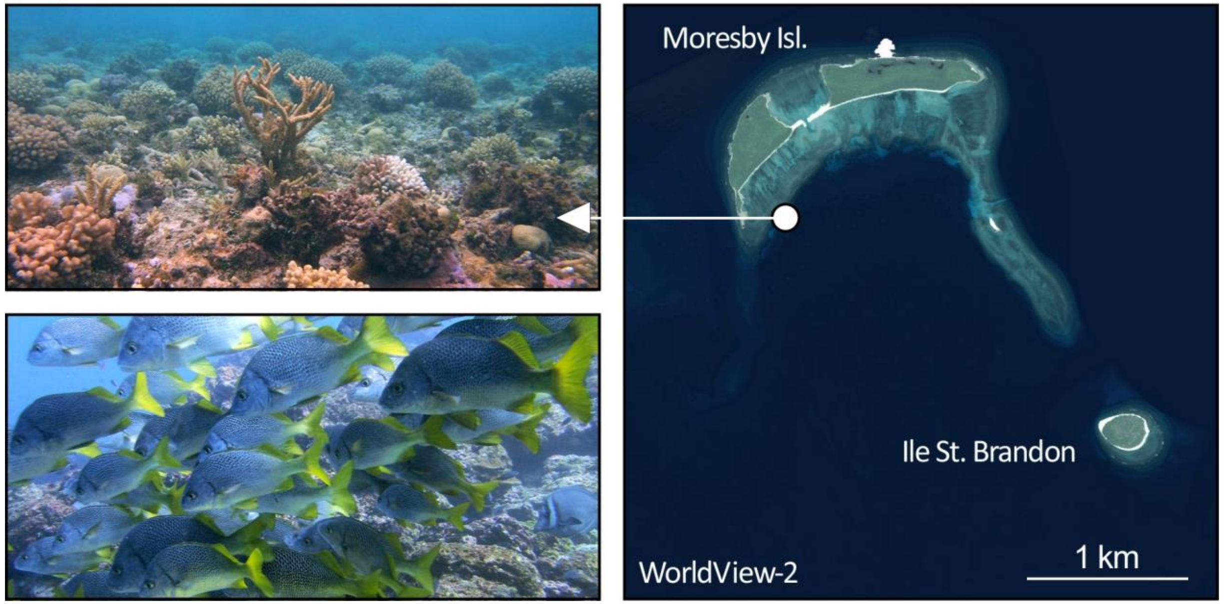
3-Yr. project – Kick-off May 2022

MarineVERSE Considers Three Remote Sensing Questions

1. α-to-Spectral Diversity to Hypothesis
2. α-to-β Diversity Hypothesis
3. Detecting Ecosystem Transitions from Self-Organization

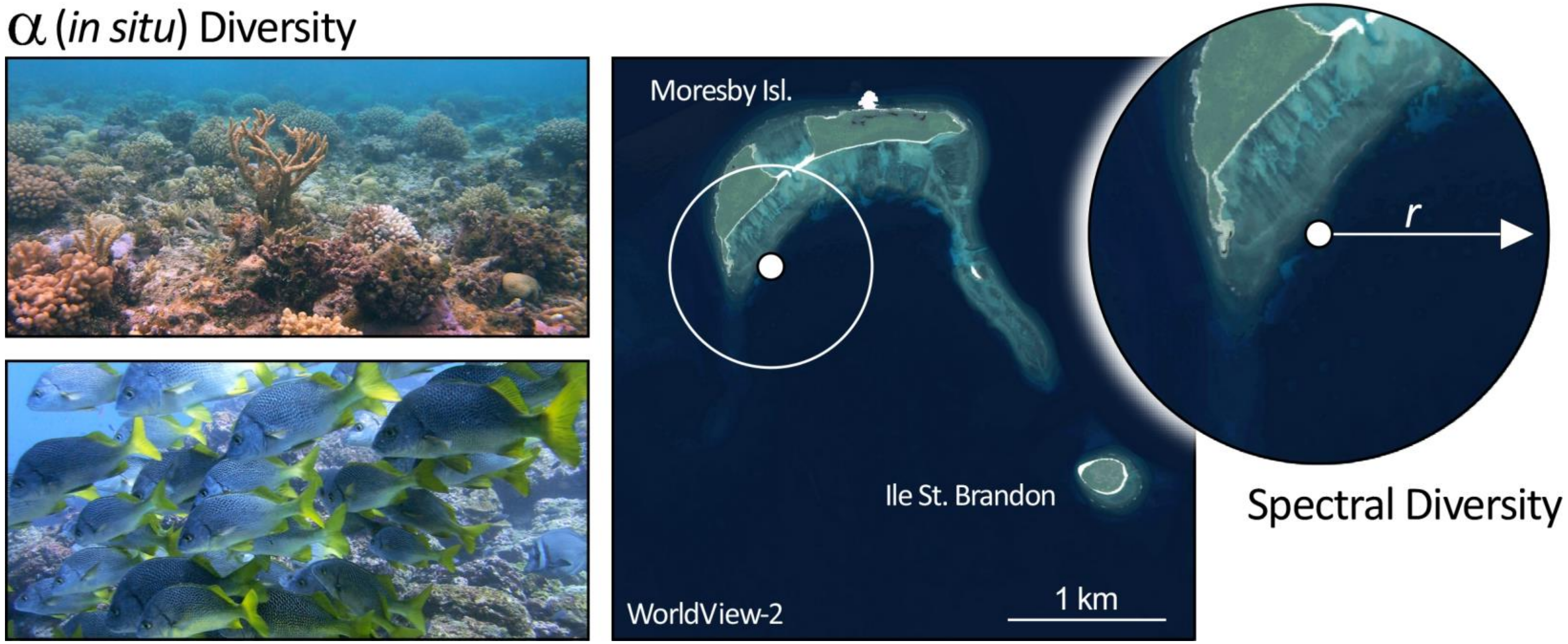
Key terms

α (*in situ*) Diversity

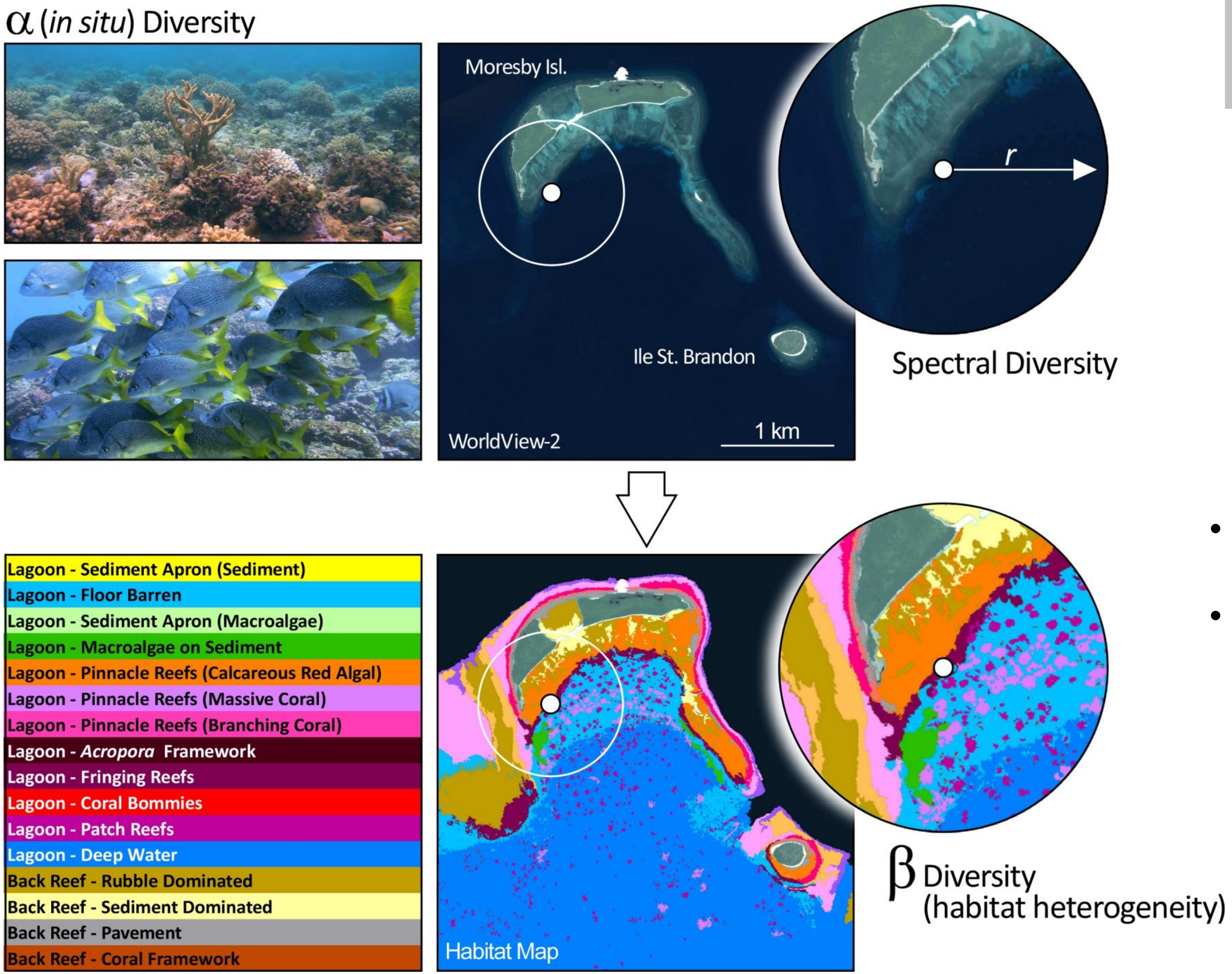


- Measured by divers
- α-diversity captures species diversity at a local scale
- Measured using a range of proxies including species-richness, species-variation, and species-evenness.
- Else metrics such as Shannon’s and Simpson’s Indices
- Typically applied to corals or reef fish

KEY TERMS



- Derived from remote sensing imagery
- Refers to variation in spectral intensity and/or reflectance, across sets of pixels
- Terrestrial studies posit that spectral variation is a surrogate for ecological niches, in turn predictive of biodiversity



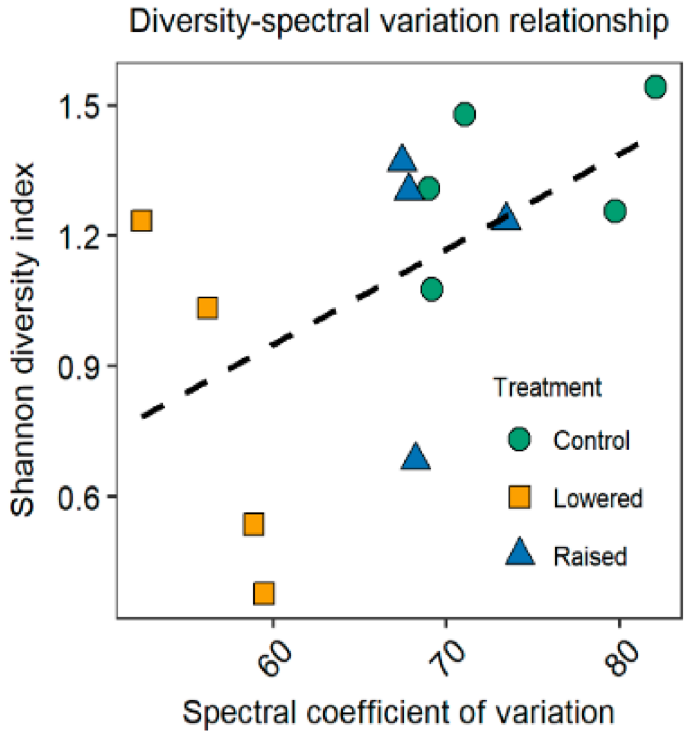
KEY TERMS

- A measure of spatial variation in benthic character
- Synonymous with 'habitat heterogeneity'

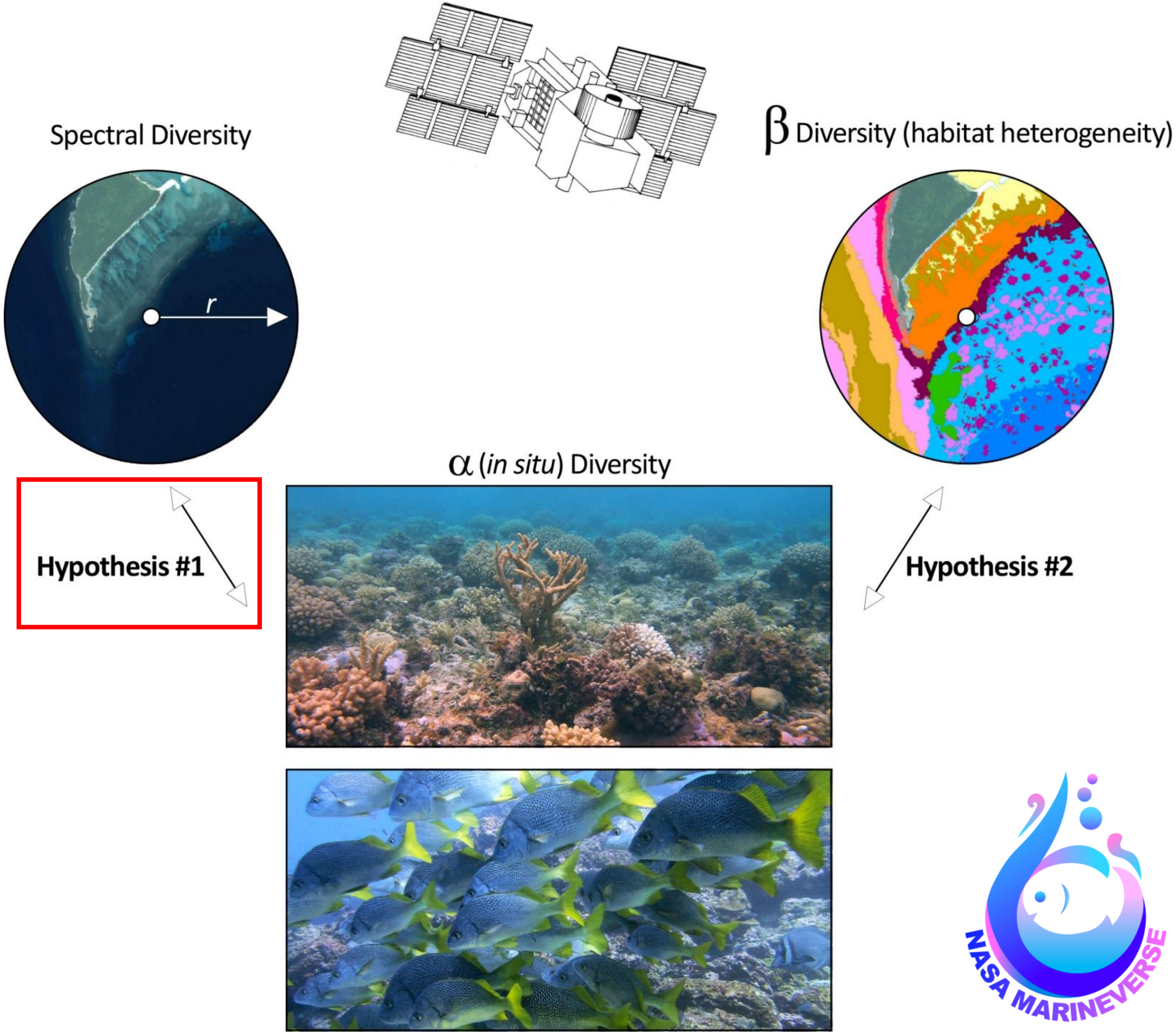
NASA MARINEVERSE

Spectral to α-Diversity

- Simple idea: Spectral variance indicates heterogeneous environment, which correlates with α-diversity
- Has been shown to work in certain terrestrial environments (one of many examples below)
- Does it hold over coral reefs?



Boreal peatland plants
McPartland, et al. (2019) *Remote Sens.* doi: 10.3390/rs11141685.



α-TO- β Diversity

- Convolves within-habitat α-diversity with spatial heterogeneity
- Patchiness is well-suited to remote sensing
- Now several global reef-mapping initiatives
- Can α-diversity be backed out of the signal?
- Many ways to compute β. Need to experiment with different approaches

Harborne, et al. (2006) *Ecology*. doi: 10.1890/0012-9658(2006)87

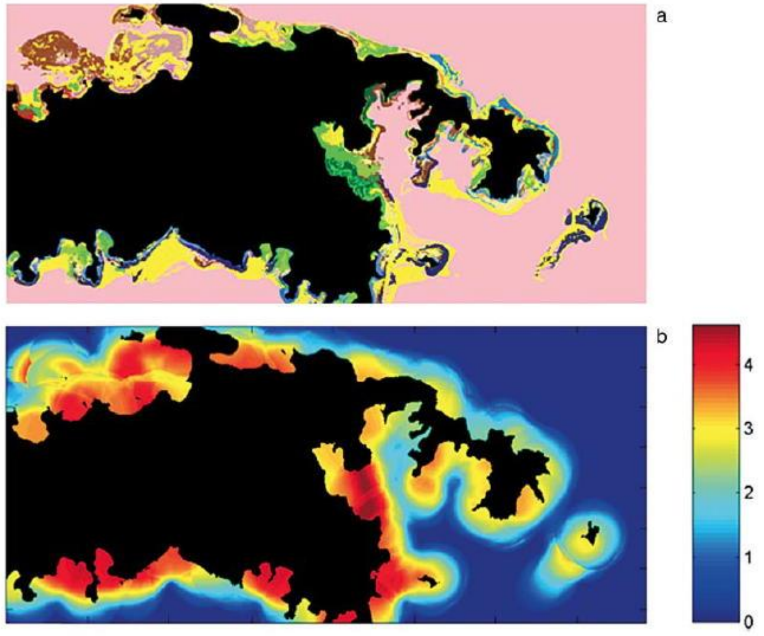
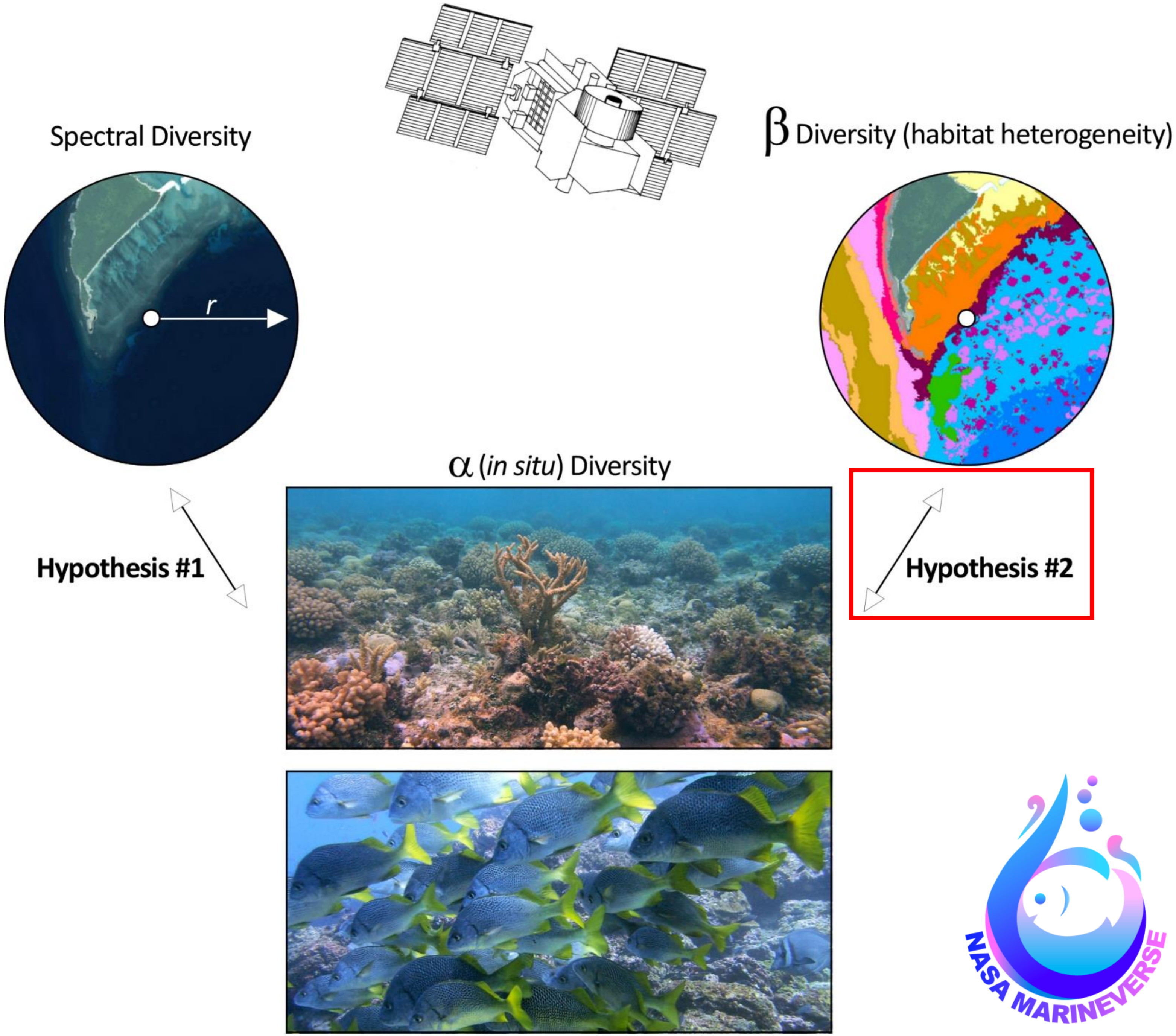


FIG. 2. A comparison of (a) habitat map and (b) map of beta diversity for St. John. (a) Coral-rich habitats are shown in blue, reef crest in red, hard-bottom habitats in brown, seagrass habitats in green, soft-bottom habitats in pink, and sand in yellow (maps with full legends are provided in Appendix A). (b) Beta diversity (key at right) was calculated using a window of 1 km^2. The area bounded by the map is 7.3 × 15.7 km.



Global-scale Data

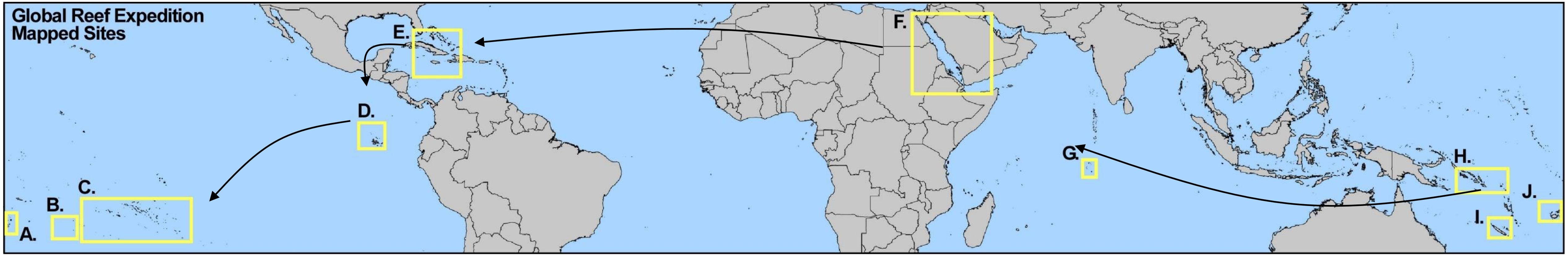
Living Oceans Foundation – Global Reef Expedition

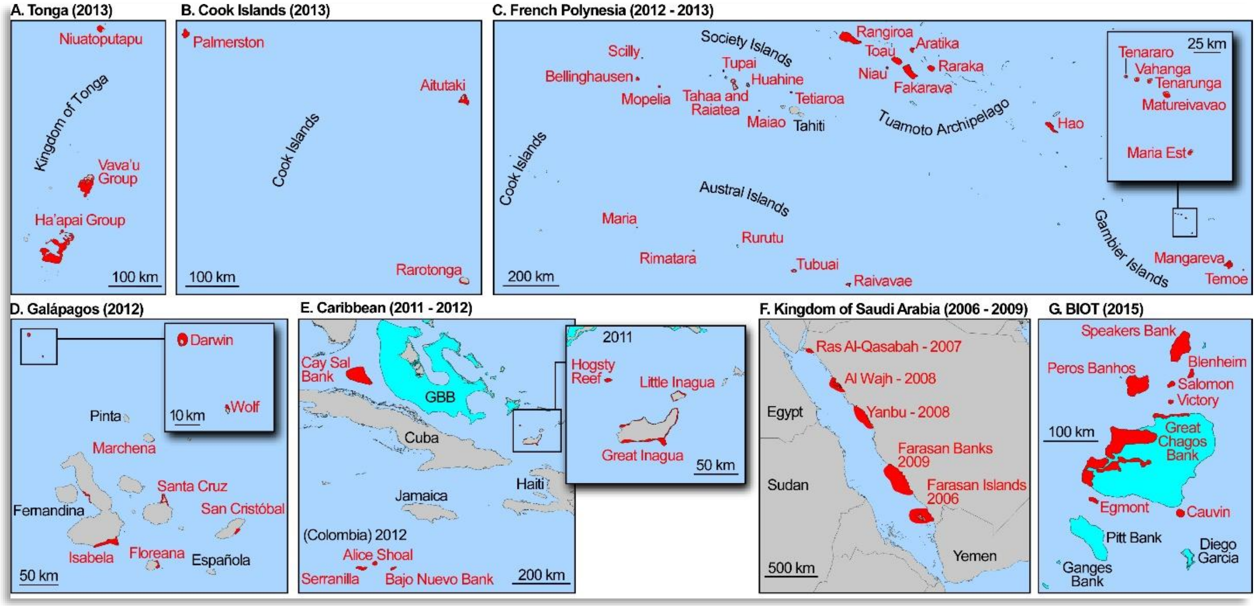
Khaled bin Sultan
Living Oceans
Foundation

Living Oceans Foundation – Global Reef Expedition

- **A global baseline of reef health**
- 2006 – 2015 (field) 2016 – 2020 (lab)
- 15 countries
- >1,000 reef sites
- >200 scientists
- 15,000 hrs. underwater
- 65,000 sq. km of m-res. seabed maps

LIVING OCEANS FOUNDATION – GLOBAL REEF EXPEDITION





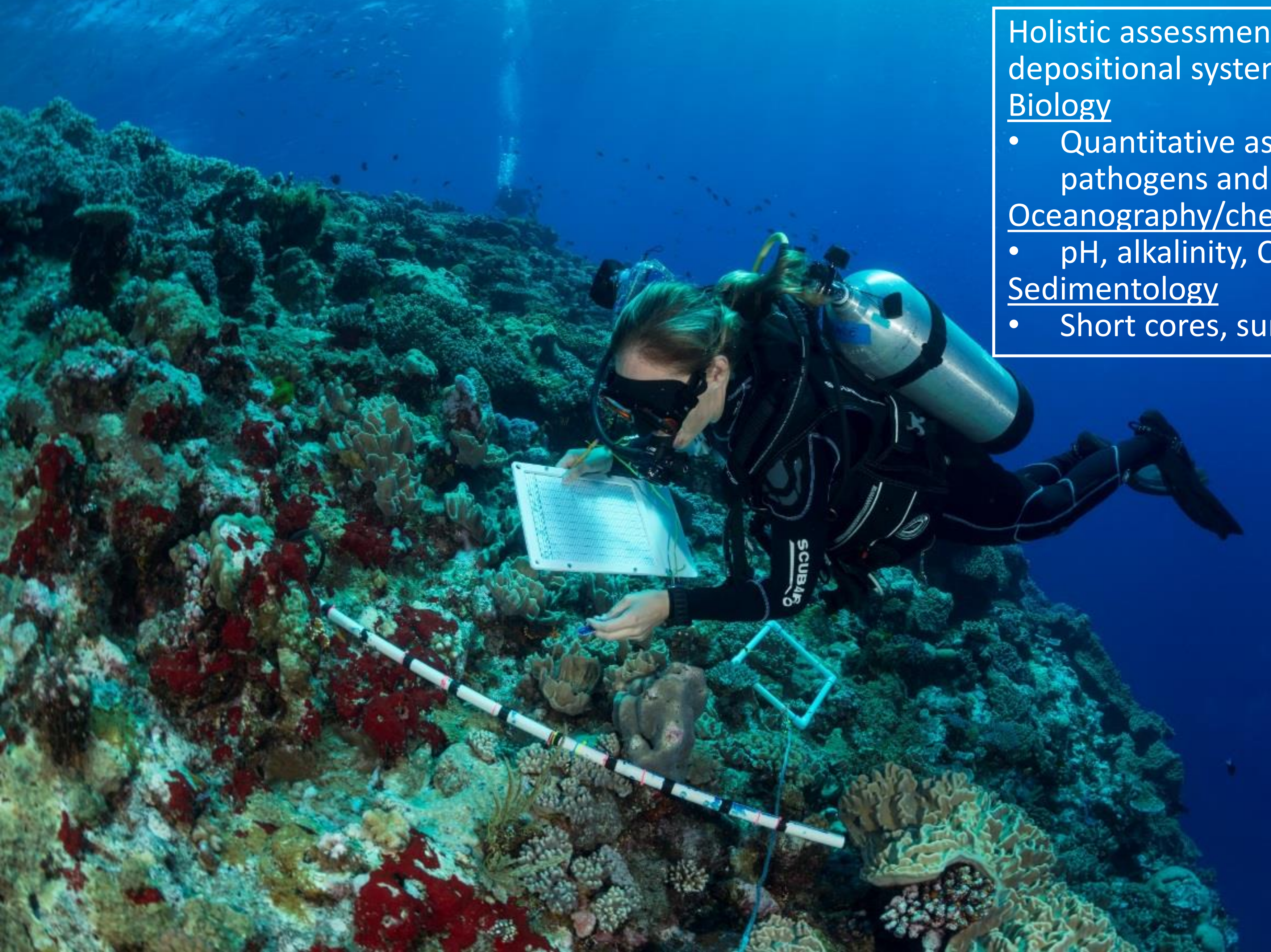
Coral Reefs (2019) 38:467–488

REPORT

High-resolution habitat and bathymetry maps for 65,000 sq. km of Earth's remotest coral reefs

Sam J. Purkis[1] · Arthur C. R. Gleason[1] · Charlotte R. Purkis[2] · Alexandra C. Dempsey[3] · Philip G. Renaud[3] · Mohamed Faisal[4] · Steven Saul[5] · Jeremy M. Kerr[6]

Rapid Reef Assessments and Surveys



Holistic assessments of the shallow-water carbonate depositional system, spanning:

Biology

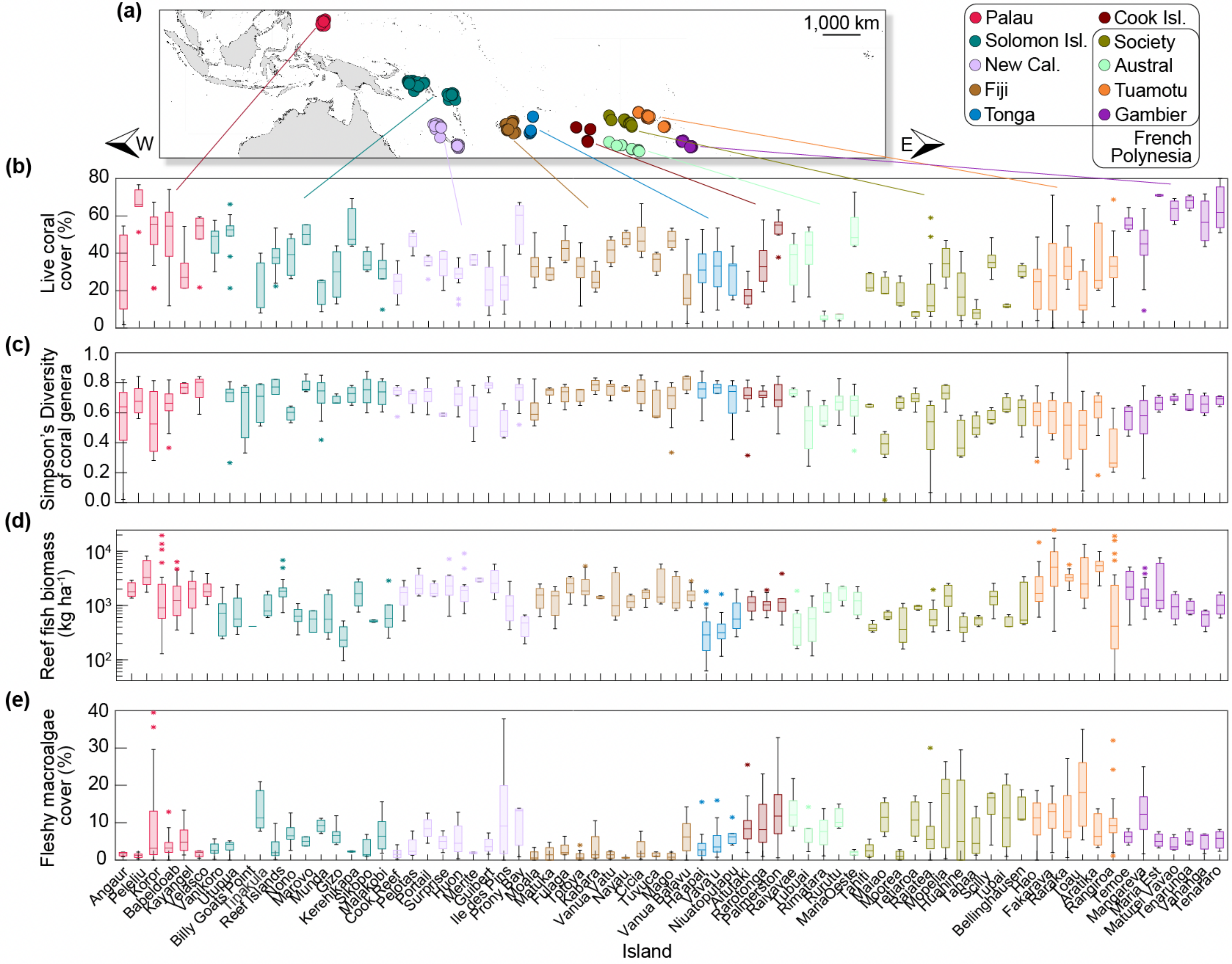
- Quantitative assessments of fish, corals (and their pathogens and predators), macroalgae, invertebrates

Oceanography/chemistry

- pH, alkalinity, CTD, ADCP, SST, etc

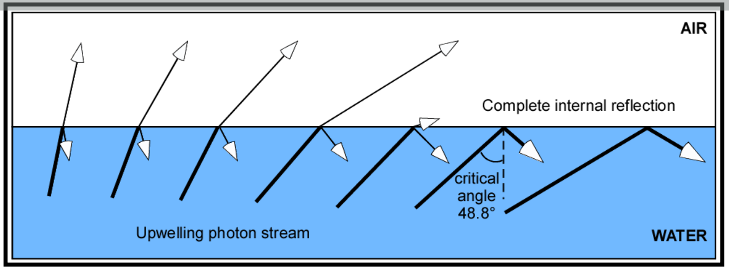
Sedimentology

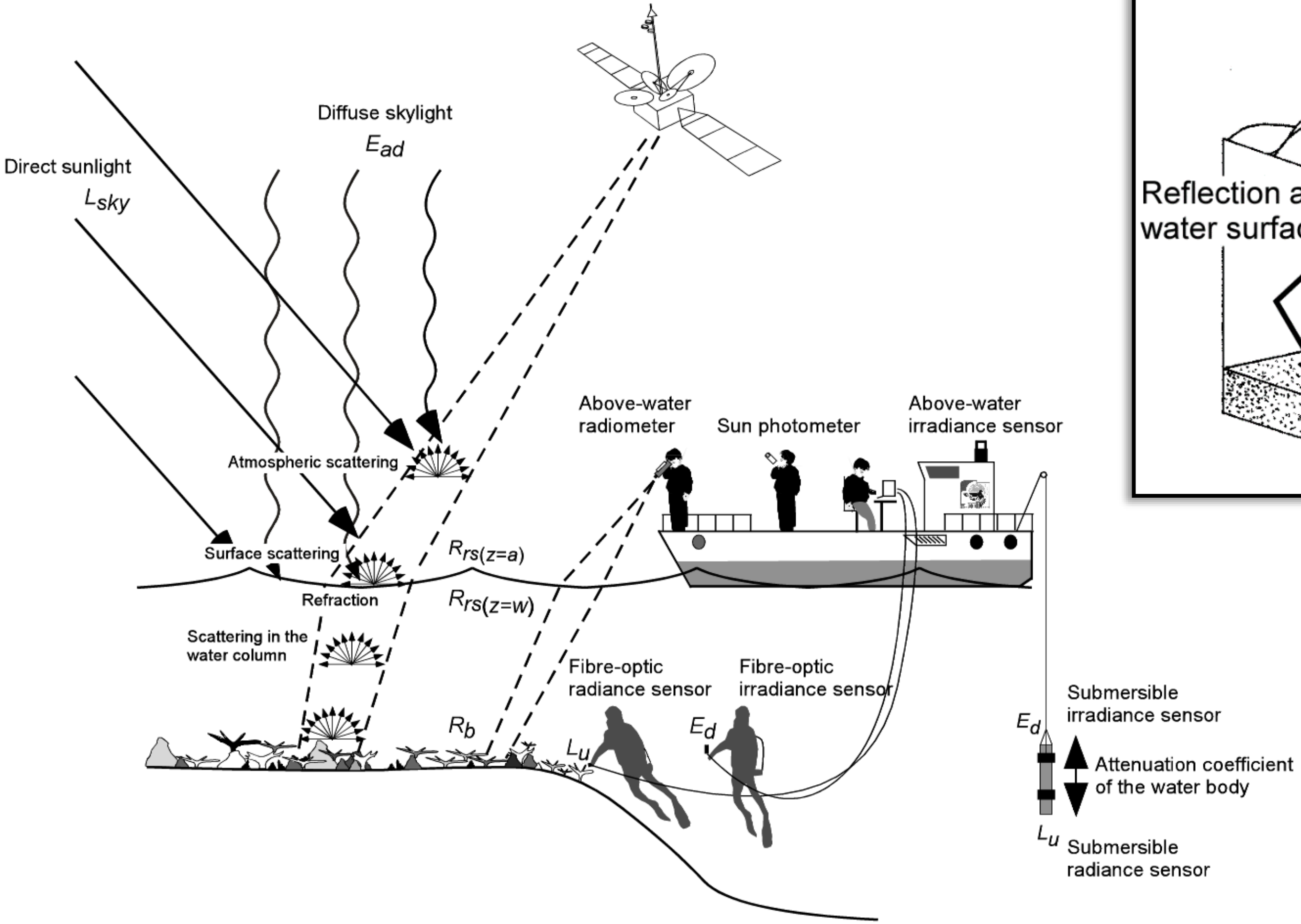
- Short cores, surficial sediment samples, sub-bottom

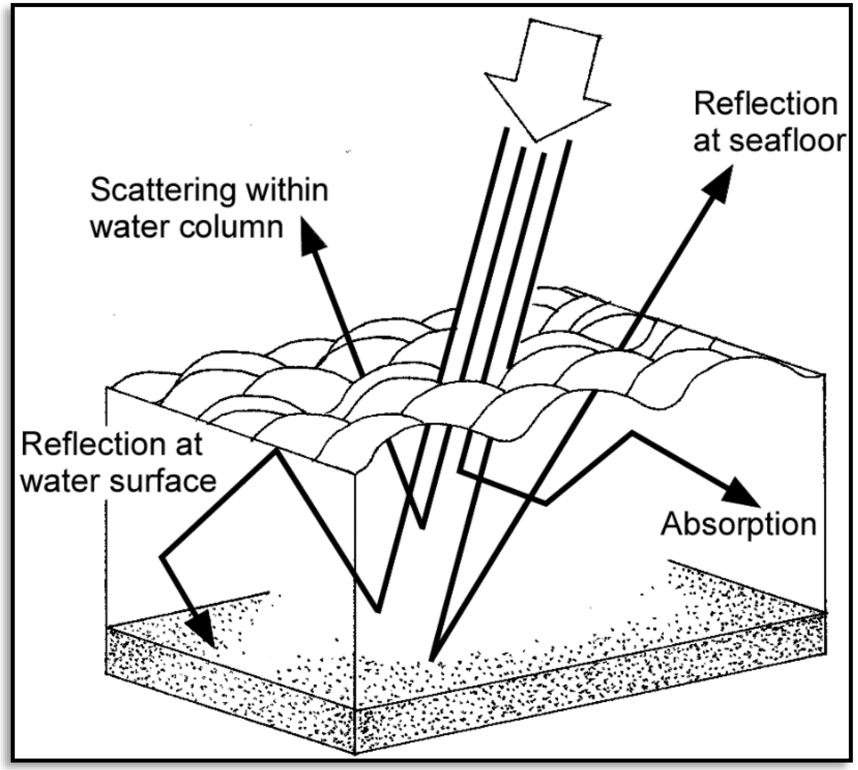

(a)
1,000 km
W
E
Palau
Solomon Isl.
New Cal.
Fiji
Tonga
Cook Isl.
Society
Austral
Tuamotu
Gambier
French Polynesia
(b)
Live coral cover (%)
(c)
Simpson's Diversity of coral genera
(d)
Reef fish biomass (kg ha⁻¹)
(e)
Fleshy macroalgae cover (%)
Angaur
Peleliu
Koror
Babeldoab
Kayangel
Velasco
Vanikoro
Utupua
Billy Goats Point
Tinakula
Reef Islands
Nono
Marovo
Munda
Gizo
Kerehikapa
Sikopo
Malakobi
Cook Reef
Pelotas
Portail
Surprise
Huon
Merite
Guilbert
Ile des Pins
Prony Bay
Moala
Matuka
Fulaga
Totoya
Kabara
Vanua Vatu
Nayau
Cicia
Tuvuca
Mago
Vanua Balavu
Ha'apai
Vava'u
Niuatoputapu
Aitutaki
Rarotonga
Palmerston
Raivavae
Tubuai
Rimatara
Rurutu
MariaOeste
Tahiti
Maiao
Moorea
Tetiaroa
Raiatea
Mopelia
Huahine
Tahaa
Scilly
Tupai
Bellinghausen
Hao
Fakarava
Raraka
Toau
Aratika
Rangiroa
Temoe
Mangareva
Maria Est
Maturei Vavao
Tenarunga
Vahanga
Tenararo
Island

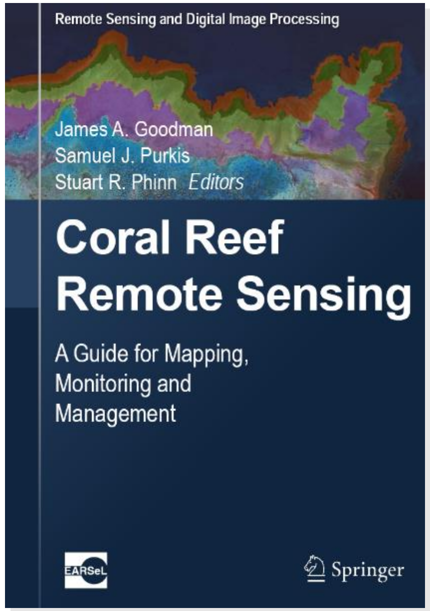

Remote Sensing

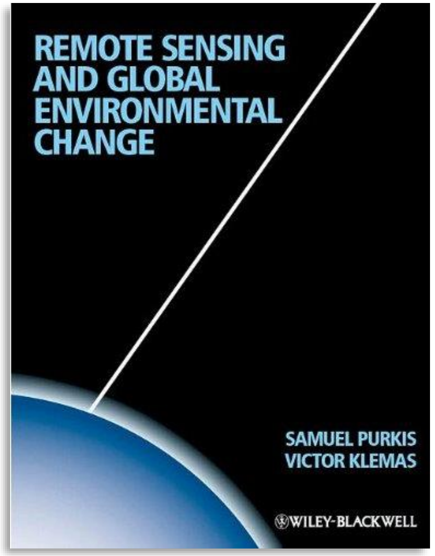
REMOTE SENSING - LIGHT AND WATER





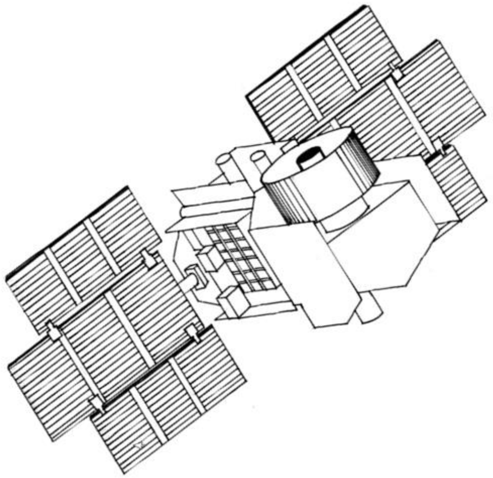


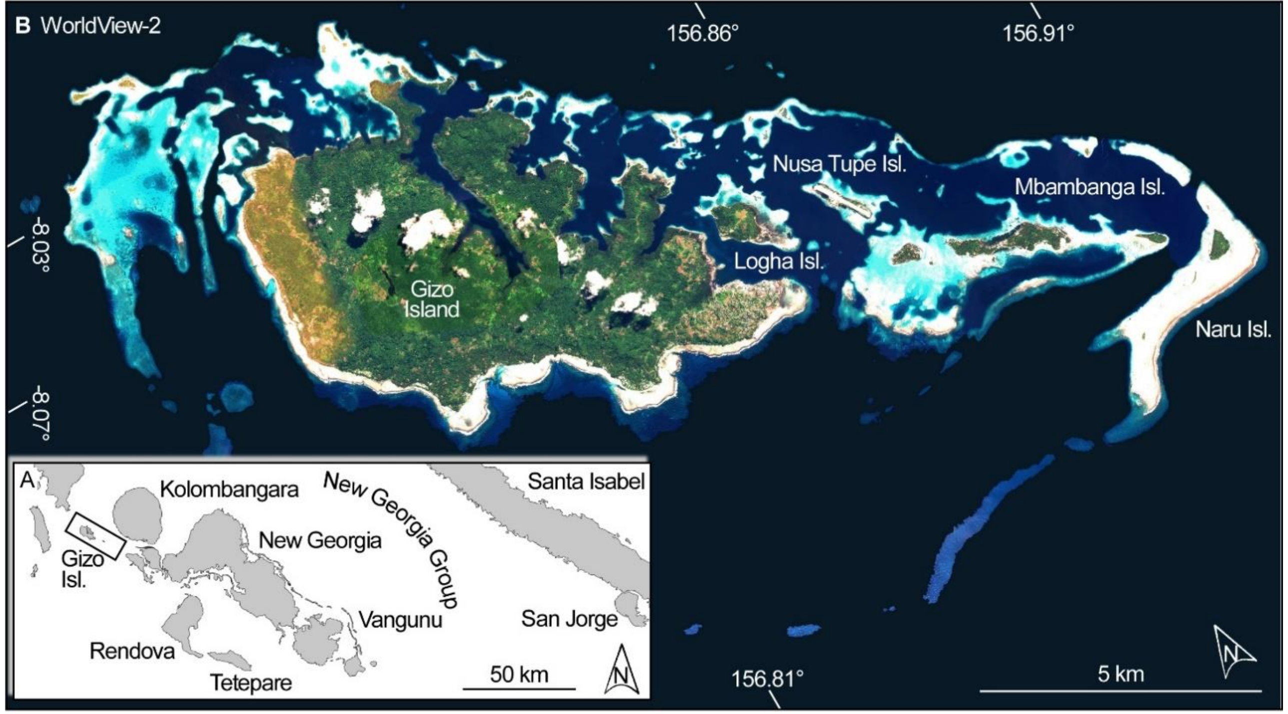


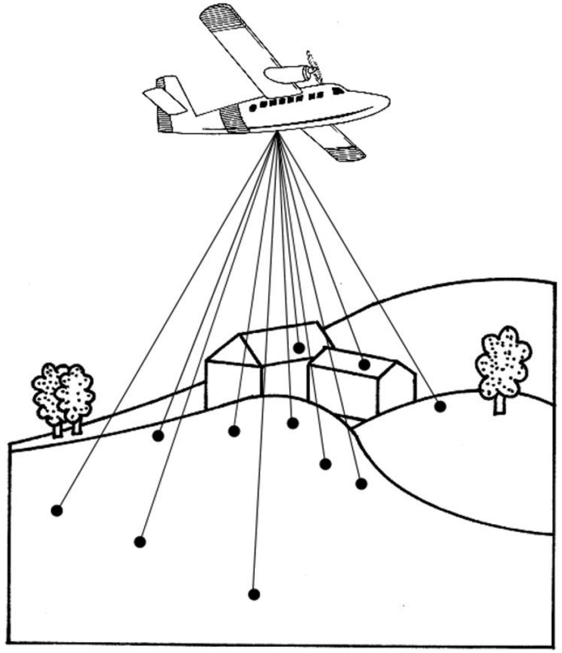


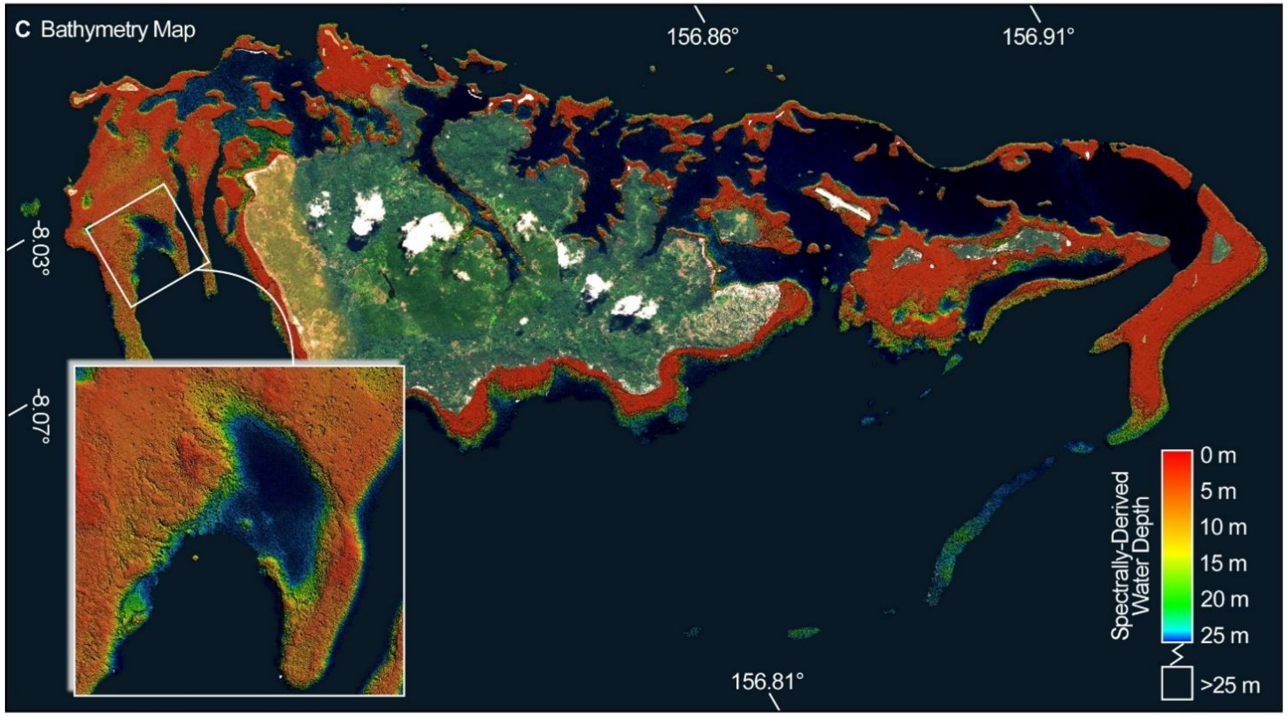
REMOTE SENSING

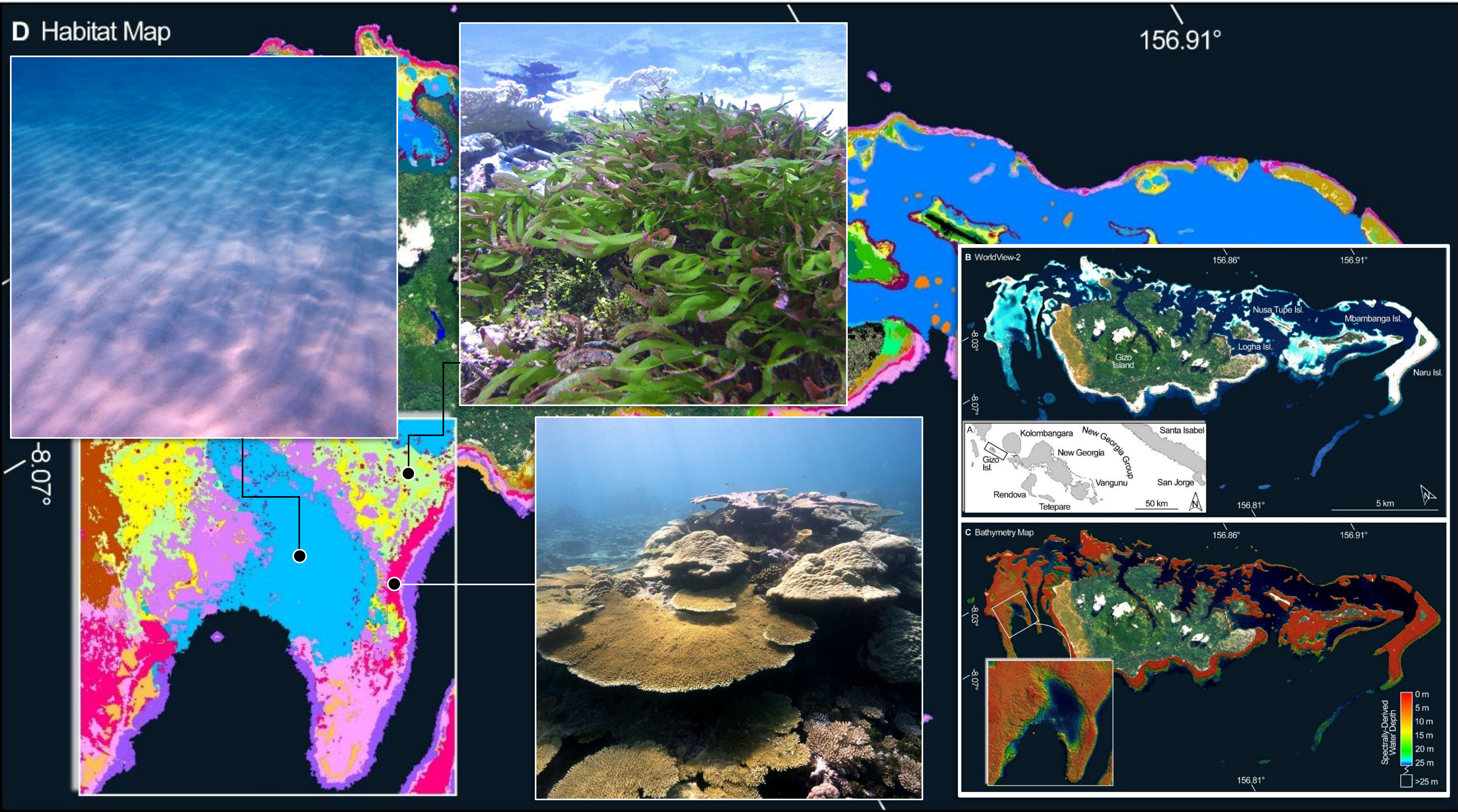
Solomon Isl.



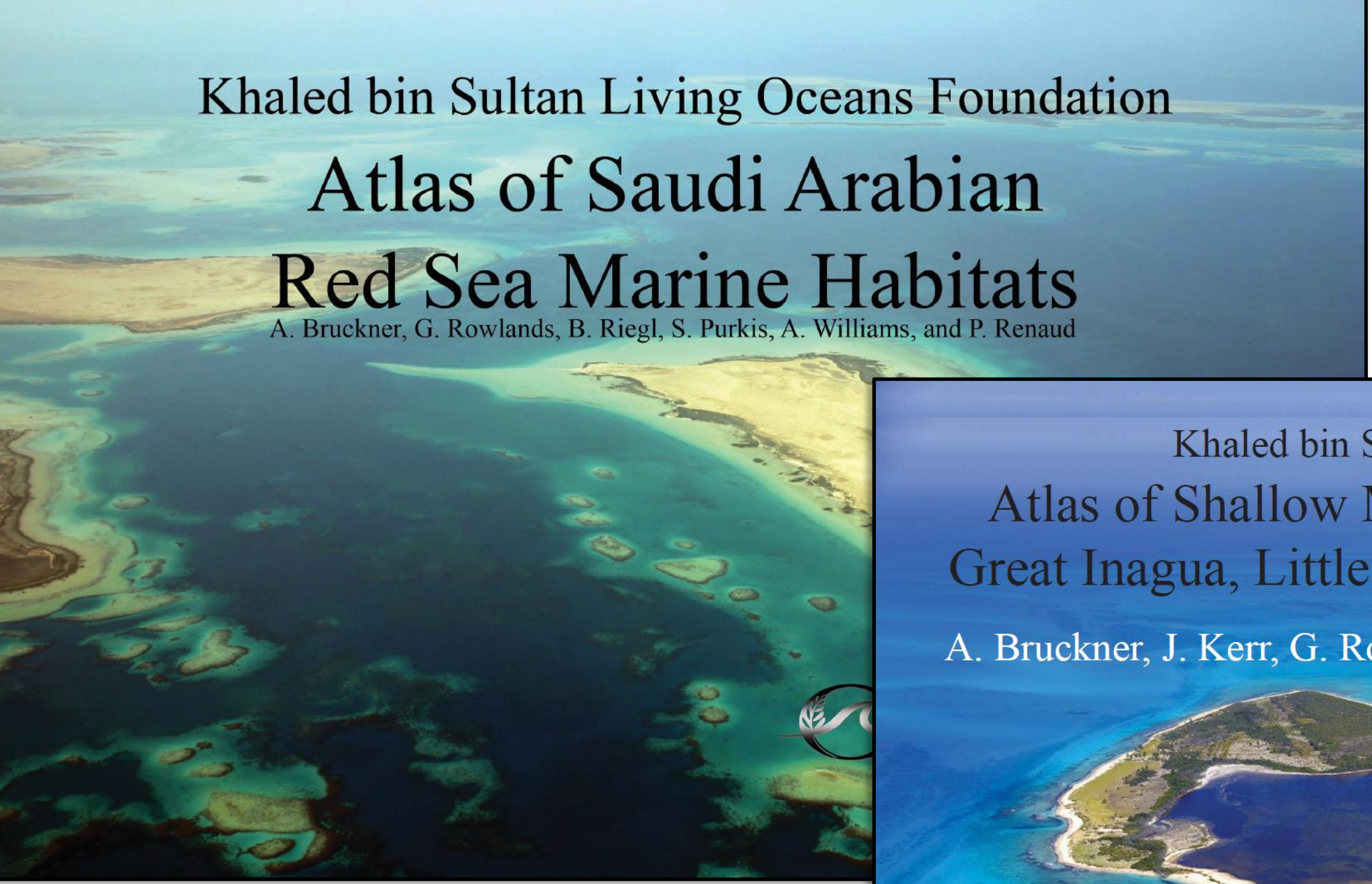


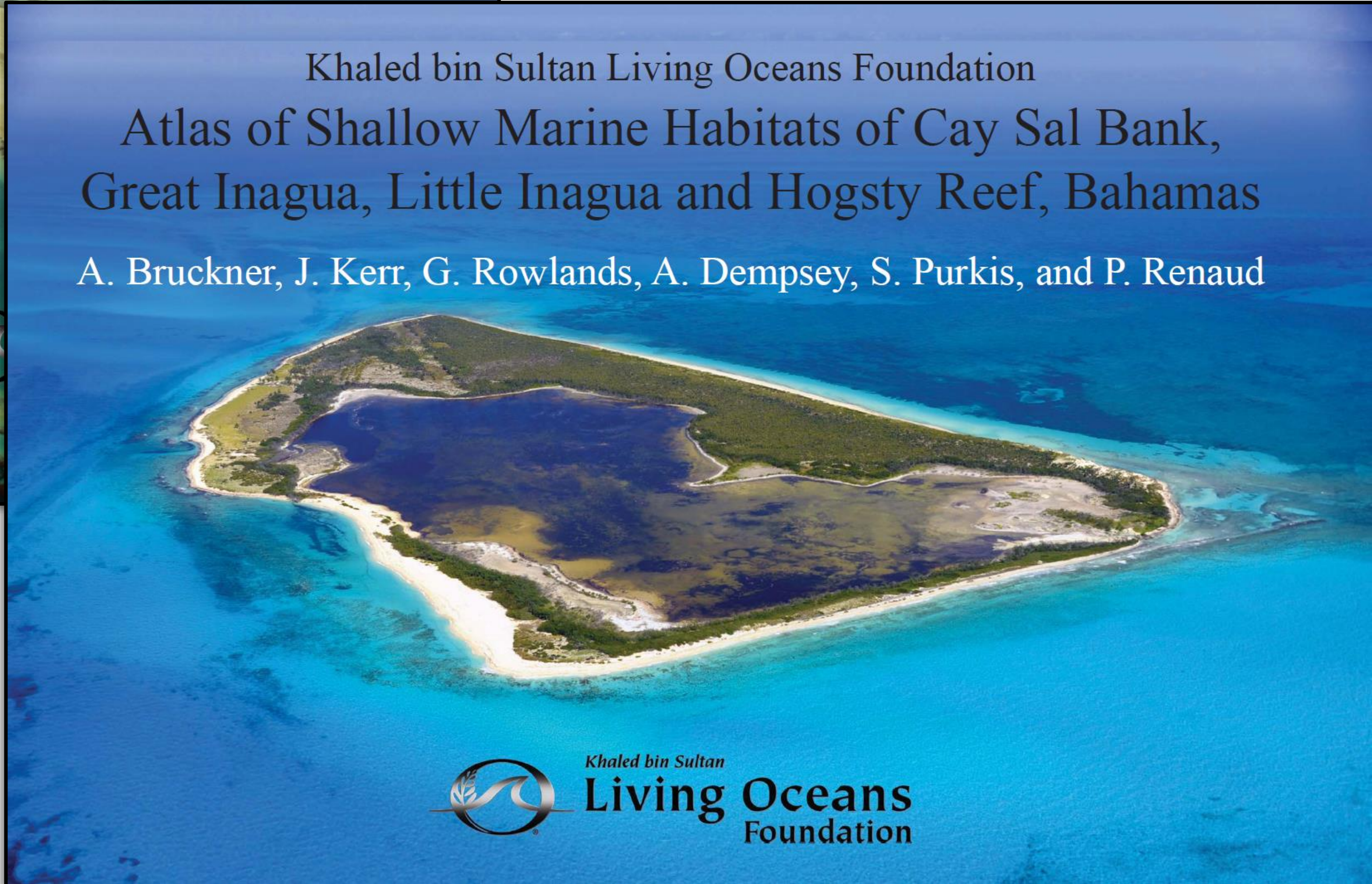






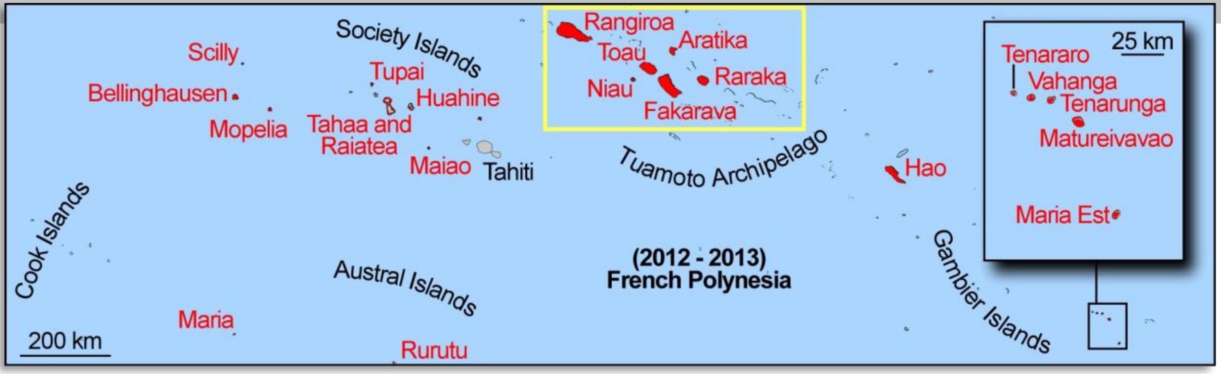
D Habitat Map
156.91°
-8.07°
B WorldView-2
156.86°
156.91°
Nusa Tupe Isl.
Mbambanga Isl.
Logha Isl.
Gizo Island
Naru Isl.
-8.03°
-8.07°
156.81°
5 km
A
Kolombangara
New Georgia Group
Santa Isabel
New Georgia
Gizo Isl.
Vangunu
San Jorge
Rendova
Tetepare
50 km
N
C Bathymetry Map
156.86°
156.91°
-8.03°
-8.07°
156.81°
Spectrally-Derived Water Depth
0 m
5 m
10 m
15 m
20 m
25 m
>25 m

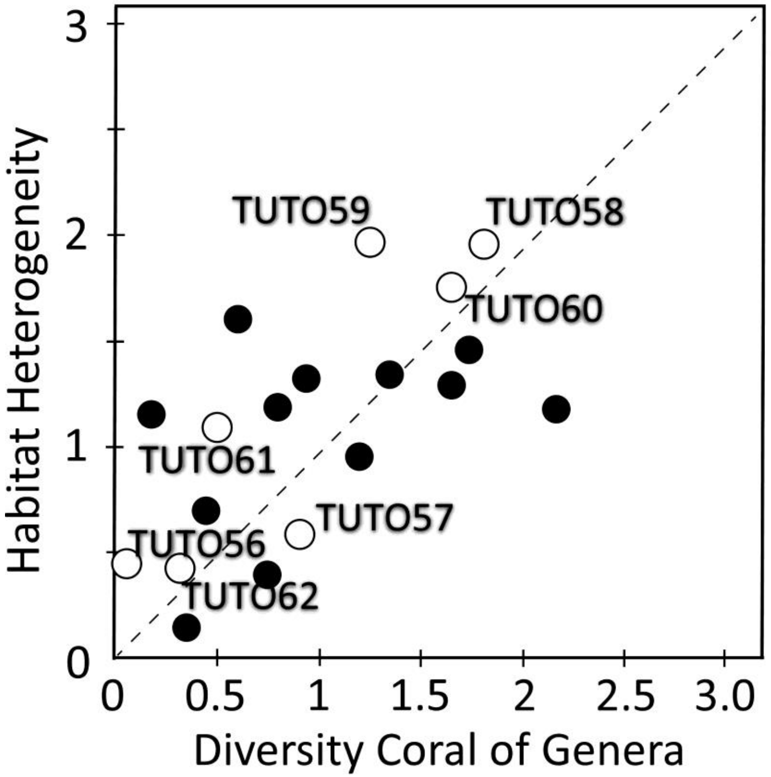

Khaled bin Sultan Living Oceans Foundation
Atlas of Saudi Arabian
Red Sea Marine Habitats
A. Bruckner, G. Rowlands, B. Riegl, S. Purkis, A. Williams, and P. Renaud

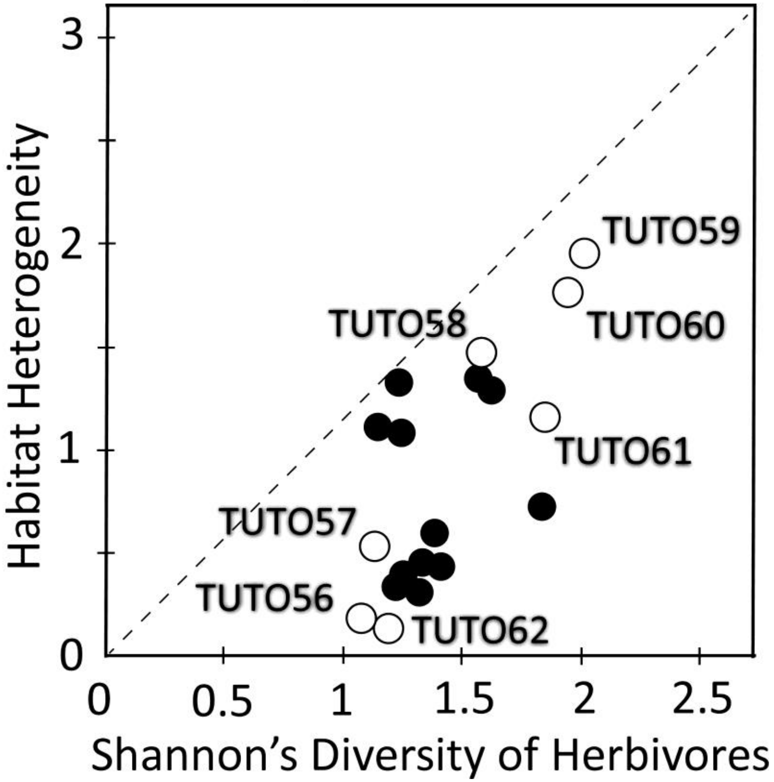

Khaled bin Sultan Living Oceans Foundation
Atlas of Shallow Marine Habitats of Cay Sal Bank,
Great Inagua, Little Inagua and Hogsty Reef, Bahamas
A. Bruckner, J. Kerr, G. Rowlands, A. Dempsey, S. Purkis, and P. Renaud
Khaled bin Sultan
Living Oceans
Foundation

α-TO- β Diversity – GRE Data – Tuamotu (French Polynesia)

Anna Bakker
(PhD student)







Local-scale Data

NASA AMES
LABORATORY FOR ADVANCED SENSING

FluidCam

A CubeSat-based Computational Imaging System

NASA NEMO NET

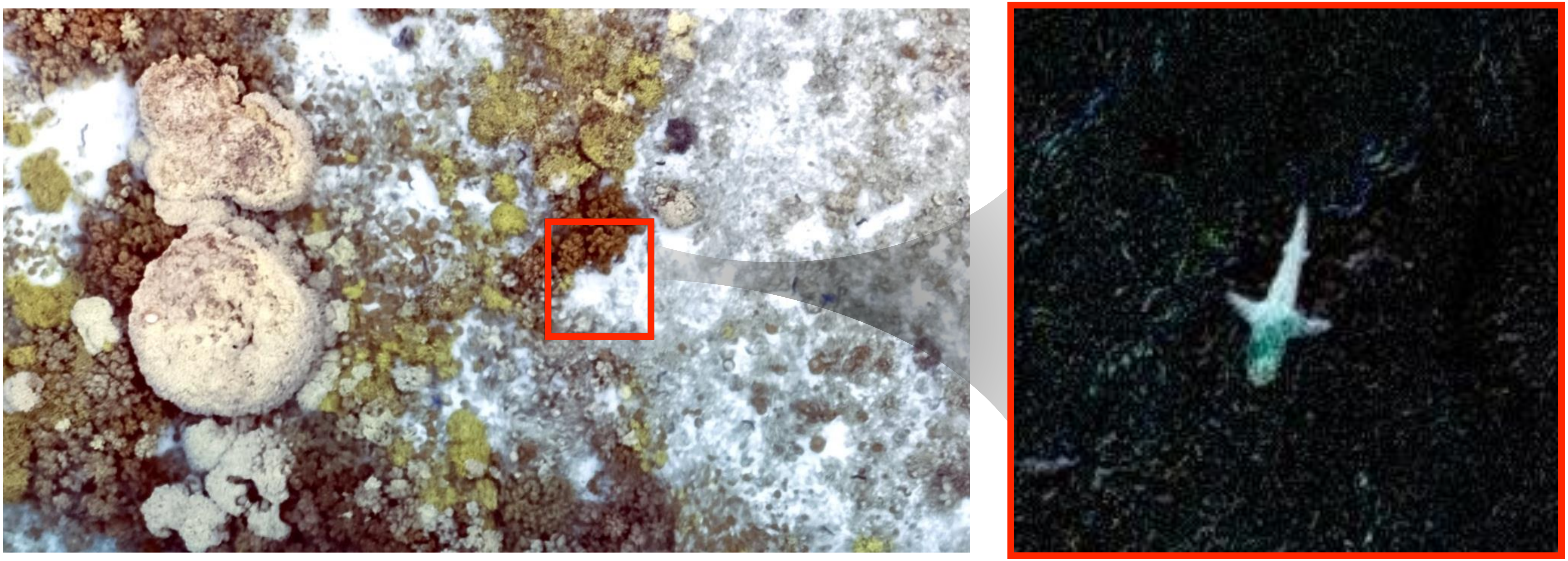
The Neural Multi-Modal Observation and Training Network for Global Coral Reef Assessment

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

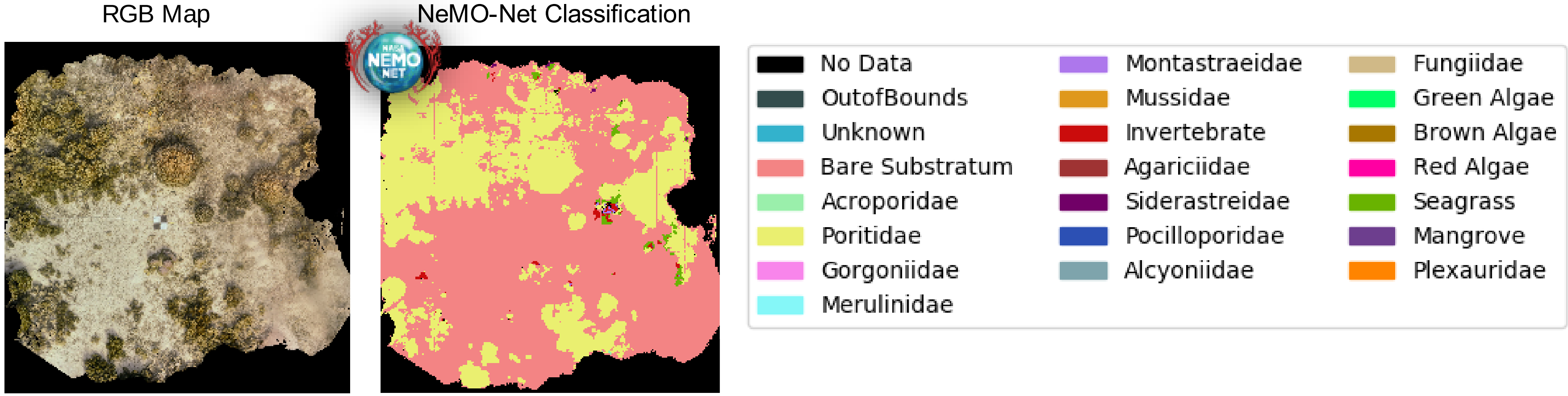

FluidCam
NASA

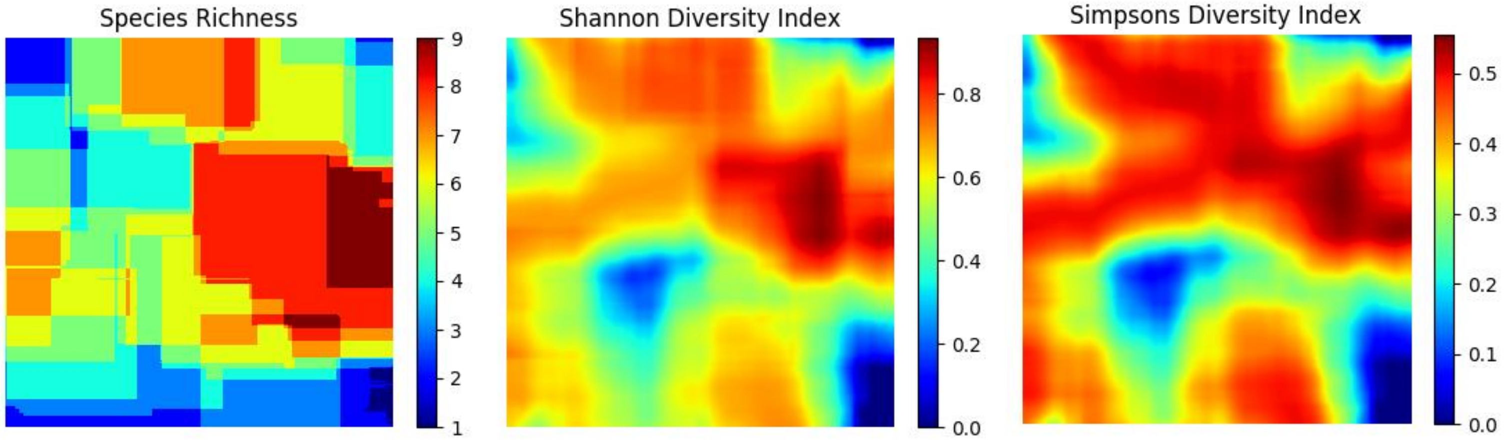
NEMO-NET PROTOTYPE DATA PRODUCTS

NEW FLUID AIRBORNE FLUID LENSING 2.0 RESULTS IN GUAM (2021)



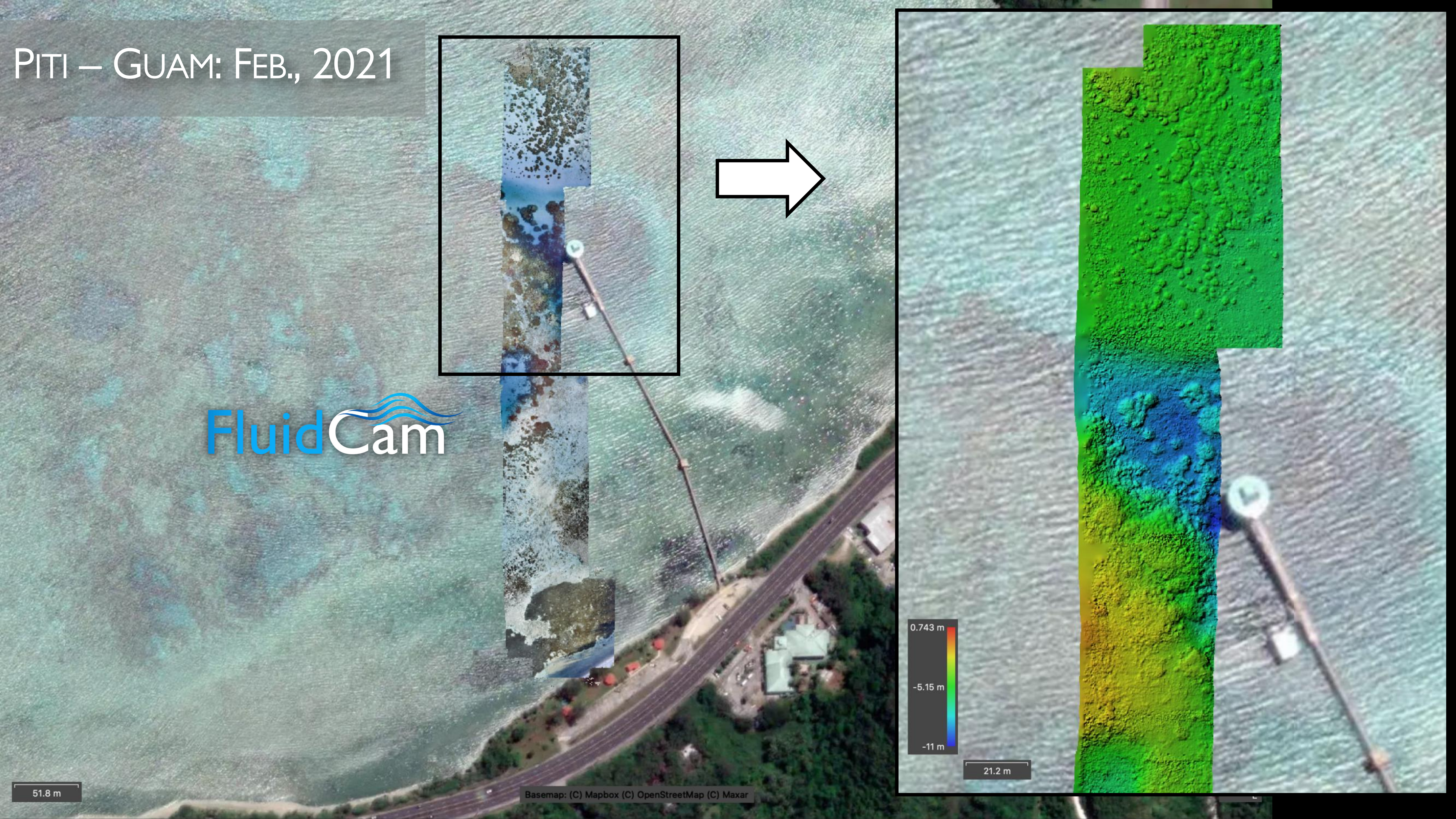
Prototype MarineVERSE Metrics from FluidCam





1. Cm-scale *in-situ* and airborne datasets are used to first produce habitat maps
2. Using fine-scale family-level mapping and sliding window implementation, higher-order metrics are calculated to create heatmaps of species richness, Simpson's index, and Shannon index for testing hypotheses on local and regional scales

Piti – Guam: Feb., 2021

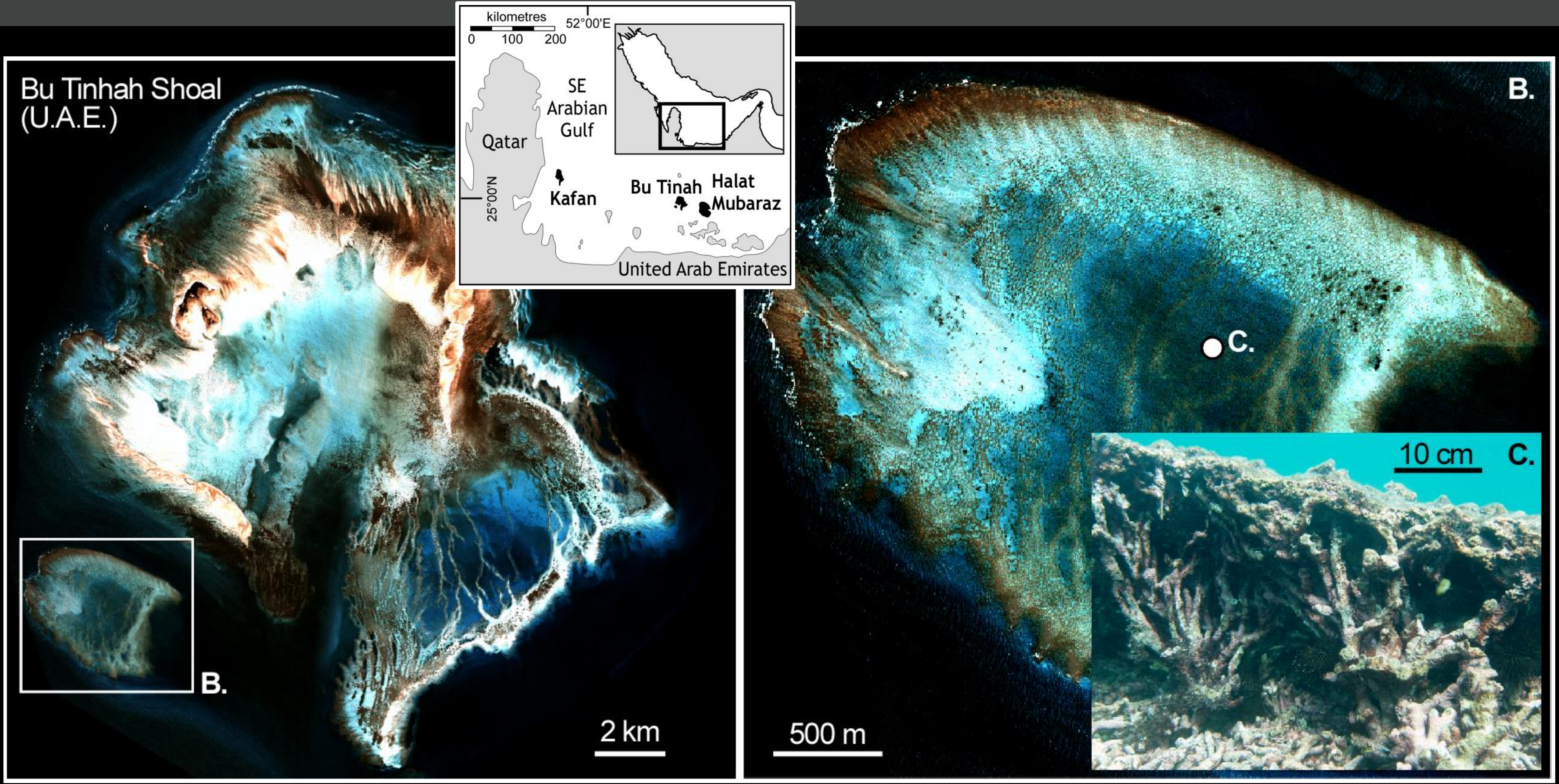


Detecting Ecosystem Transitions from Self-Organization

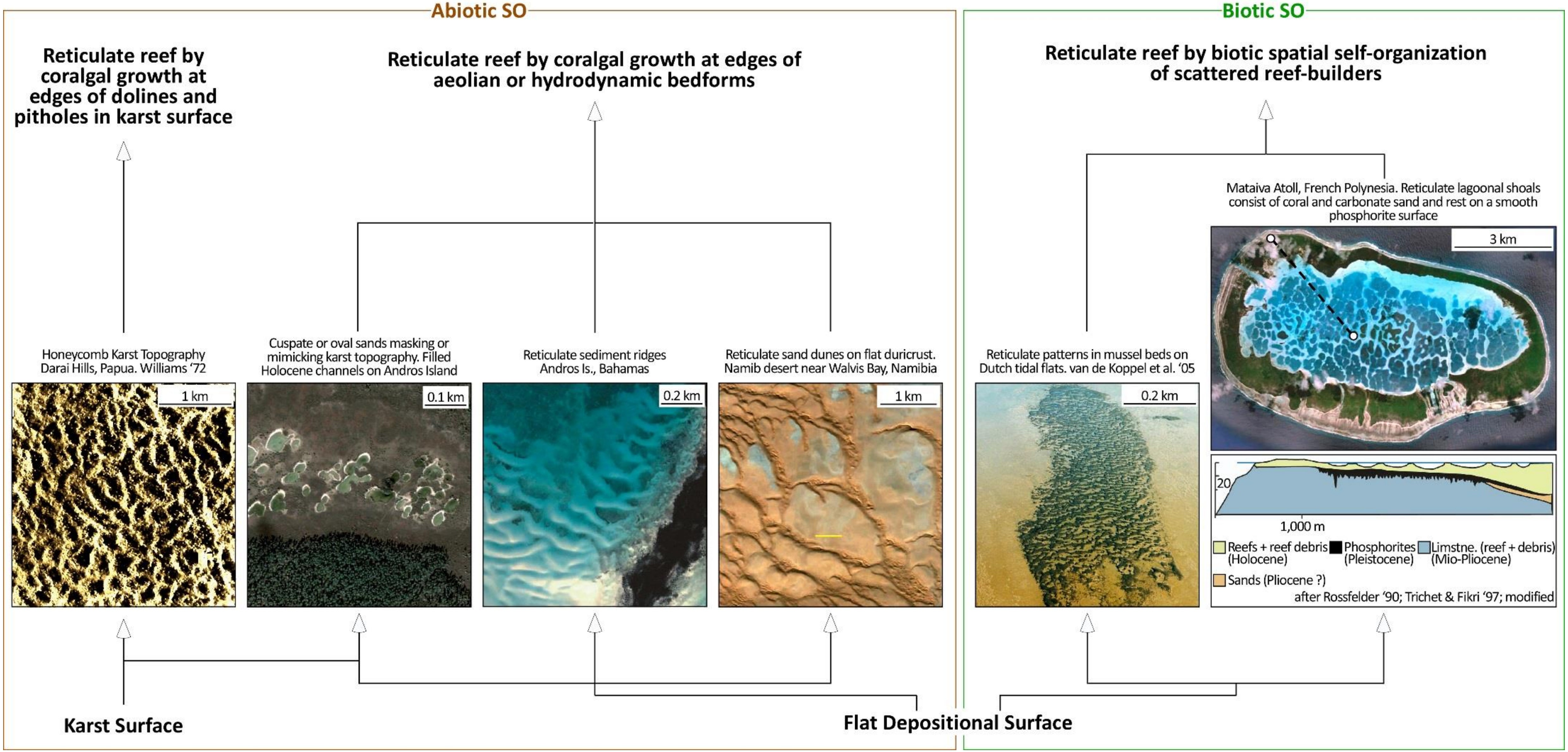
Detecting Ecosystem Transitions from Self-Organization

Pearl & Hermes Atoll, NW Hawaiian Isl.

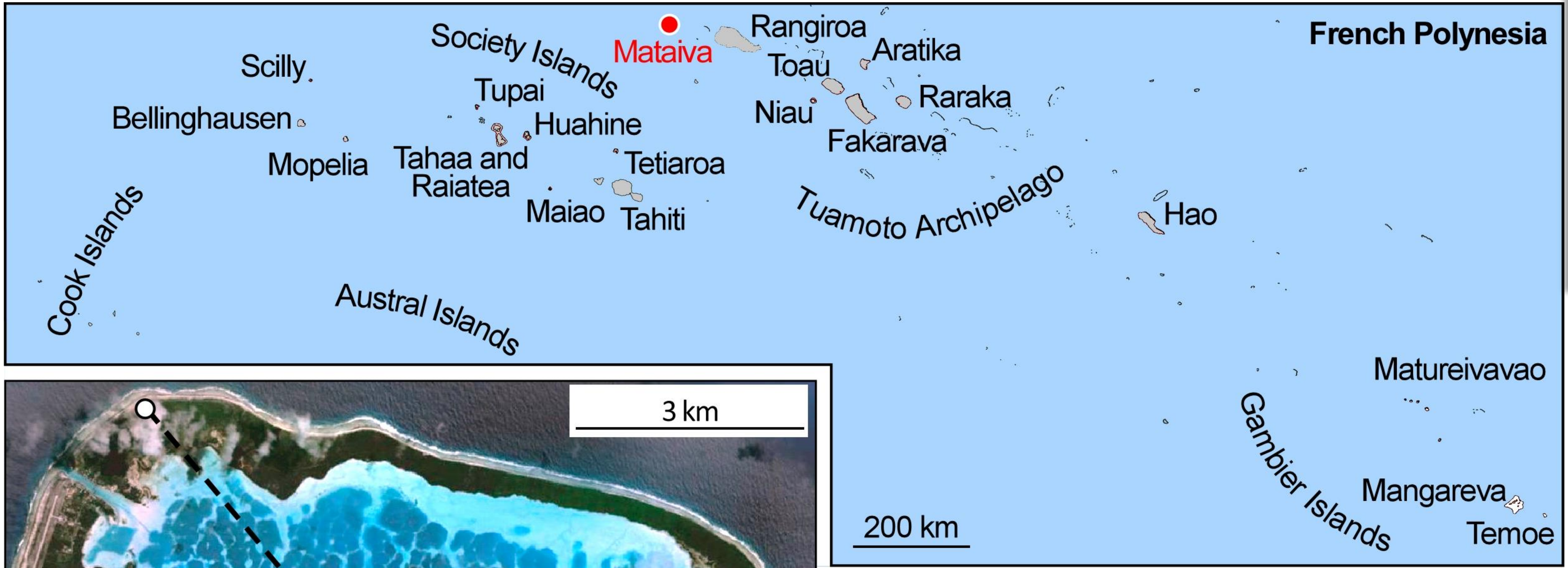
Coherent Patterning of Platform-Interior Reefs

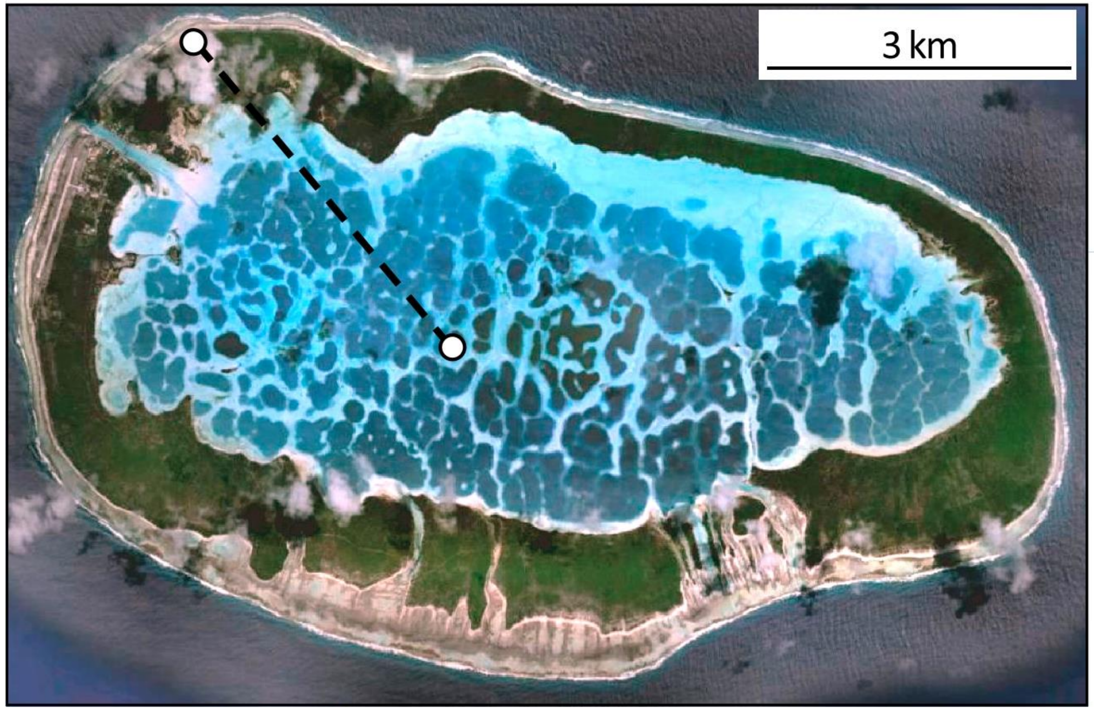


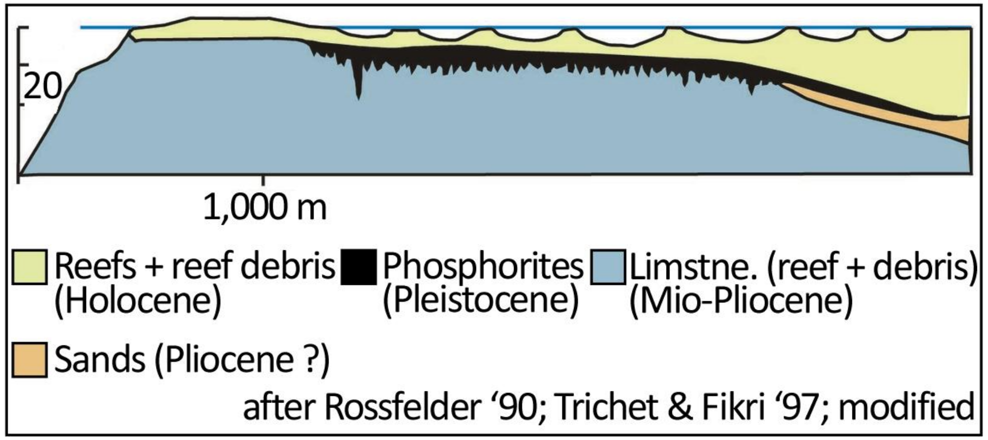
Why Coherent Patterning of Platform-Interior Reefs?



Coherent Patterning of Platform-Interior Reefs





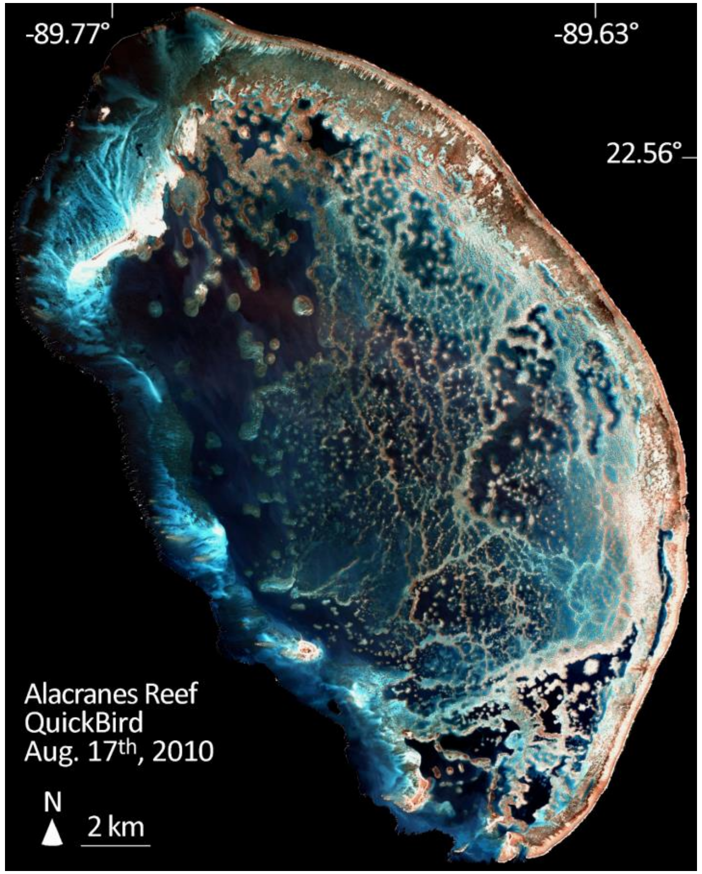


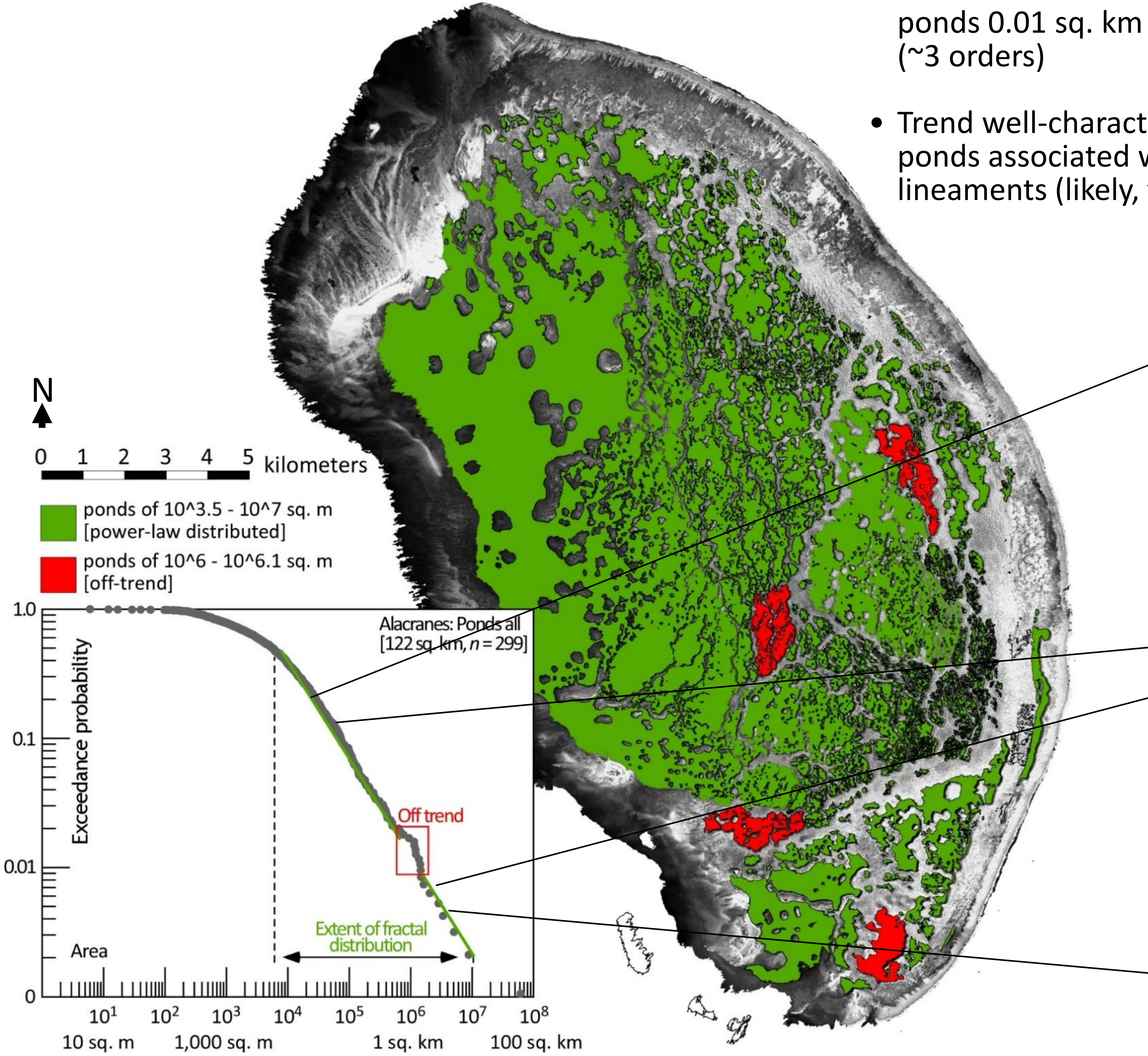
Reticulate lagoonal shoals consist of coral and carbonate sand and rest on a smooth phosphorite surface

Pleistocene mega kopara ponds – thick stromatolitic cyano mats:

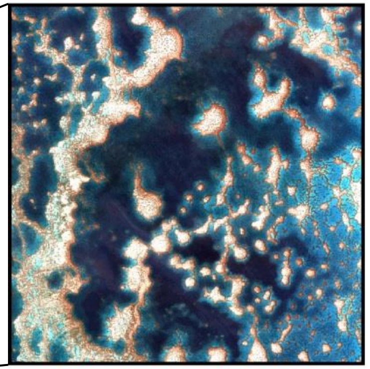
Phosphogenesis

- Power-law size-frequency dbn. of ponds 0.01 sq. km – 10 sq. km (~3 orders)
- Trend well-characterized apart from ponds associated with structural lineaments (likely, faults)

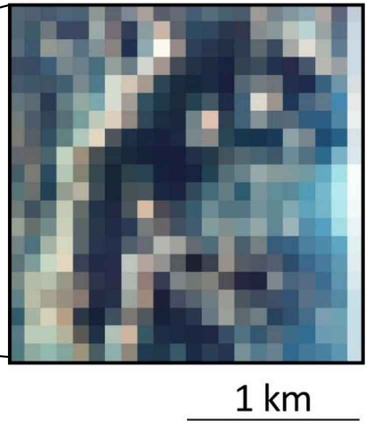


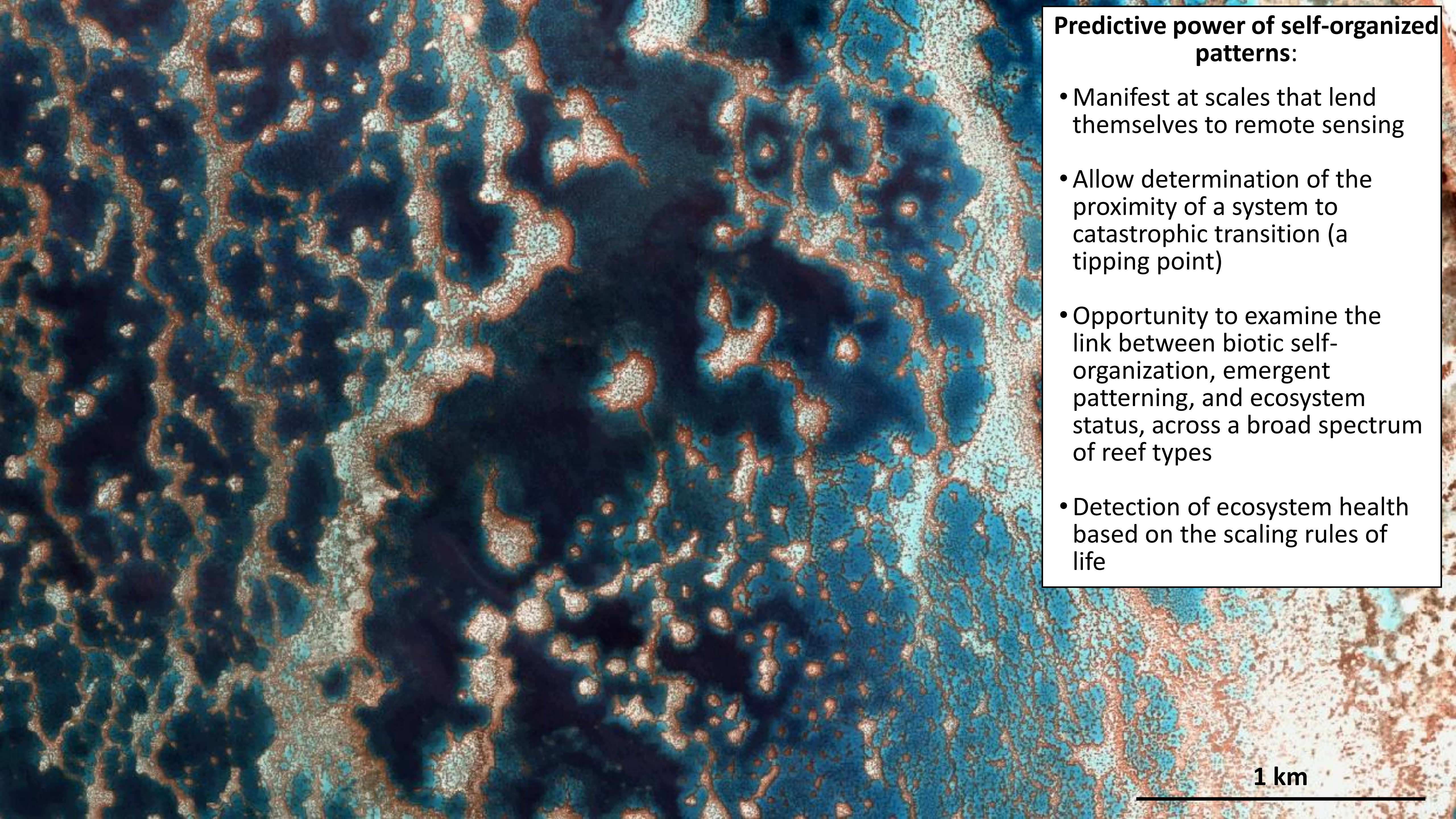


@ satellite resolution



@ seismic resolution

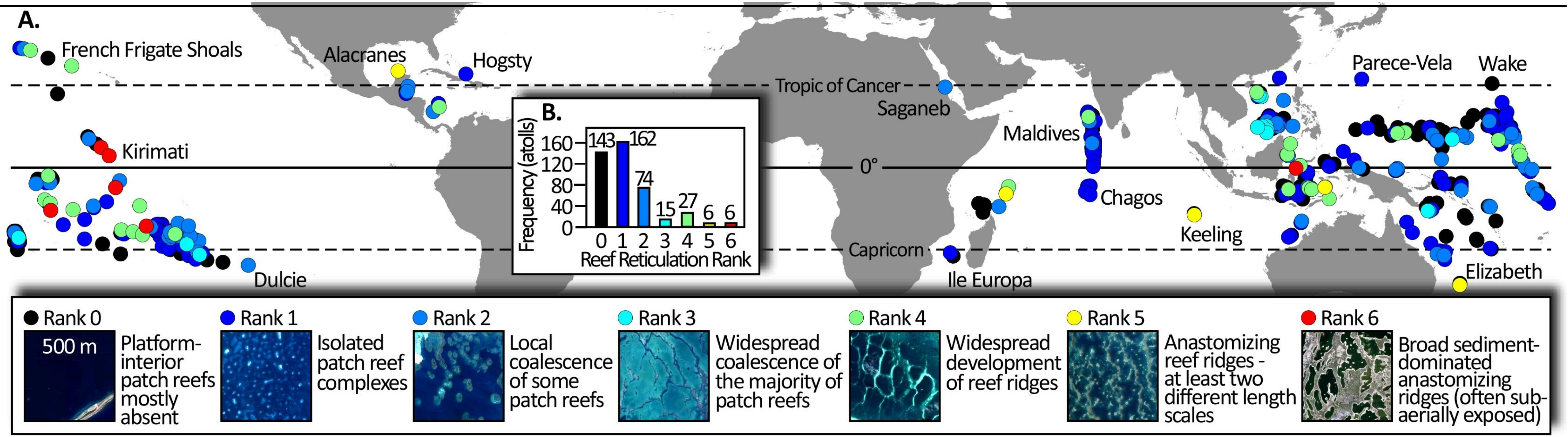




Predictive power of self-organized patterns:

- Manifest at scales that lend themselves to remote sensing
- Allow determination of the proximity of a system to catastrophic transition (a tipping point)
- Opportunity to examine the link between biotic self-organization, emergent patterning, and ecosystem status, across a broad spectrum of reef types
- Detection of ecosystem health based on the scaling rules of life

Widespread Reticulation

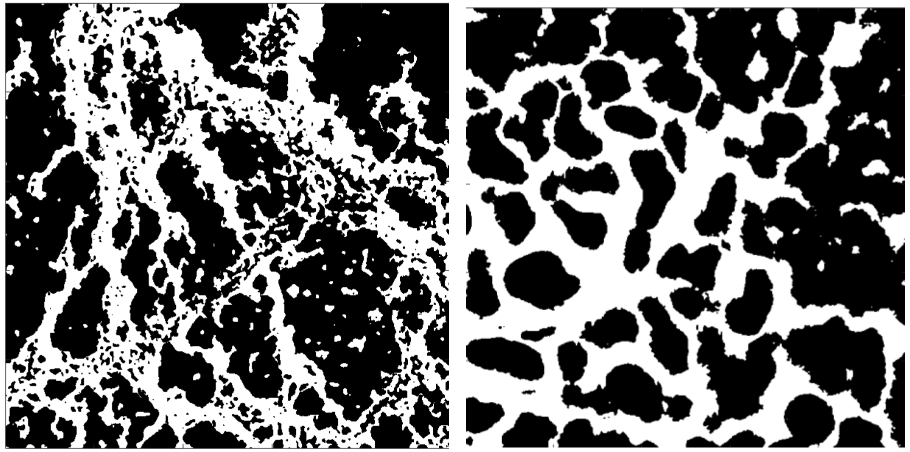


- Geographic and frequency distributions of reticulation ranks for †Goldberg's 433 'Atolls of the World'
- Globally, 30% of atoll lagoons contain reefs with some degree of reticulation
- Note that atolls with high degrees of reef reticulation are spatially clustered

†Goldberg, W.M., 2016. Atolls of the world: Revisiting the original checklist. Atoll Res Bull, 610, pp.543-544.

Mechanistic Insight of Pattern Formation in Reefs

1 km



Reaction-transport

Governing Equations for PDE model:

- (1) $\frac{\partial B}{\partial t} = g_{max} * \frac{v}{v+k_1} * B - \alpha * B * f_M(S) + D_B * (\frac{\partial^2 B}{\partial x^2} + \frac{\partial^2 B}{\partial y^2})$

  Growth controlled by flow velocity — Mortality due to sedimentation — Spatial expansion by diffusion

- (2) $\frac{\partial S}{\partial t} = s_{max} * \frac{k_2 - v}{k_2} + c_1 * B - v * (\frac{\partial^2 S}{\partial x^2} + \frac{\partial^2 S}{\partial y^2})$

  Settling from flow — Sediment debris produced by coral reef — Sediment removed by unidirectional flow

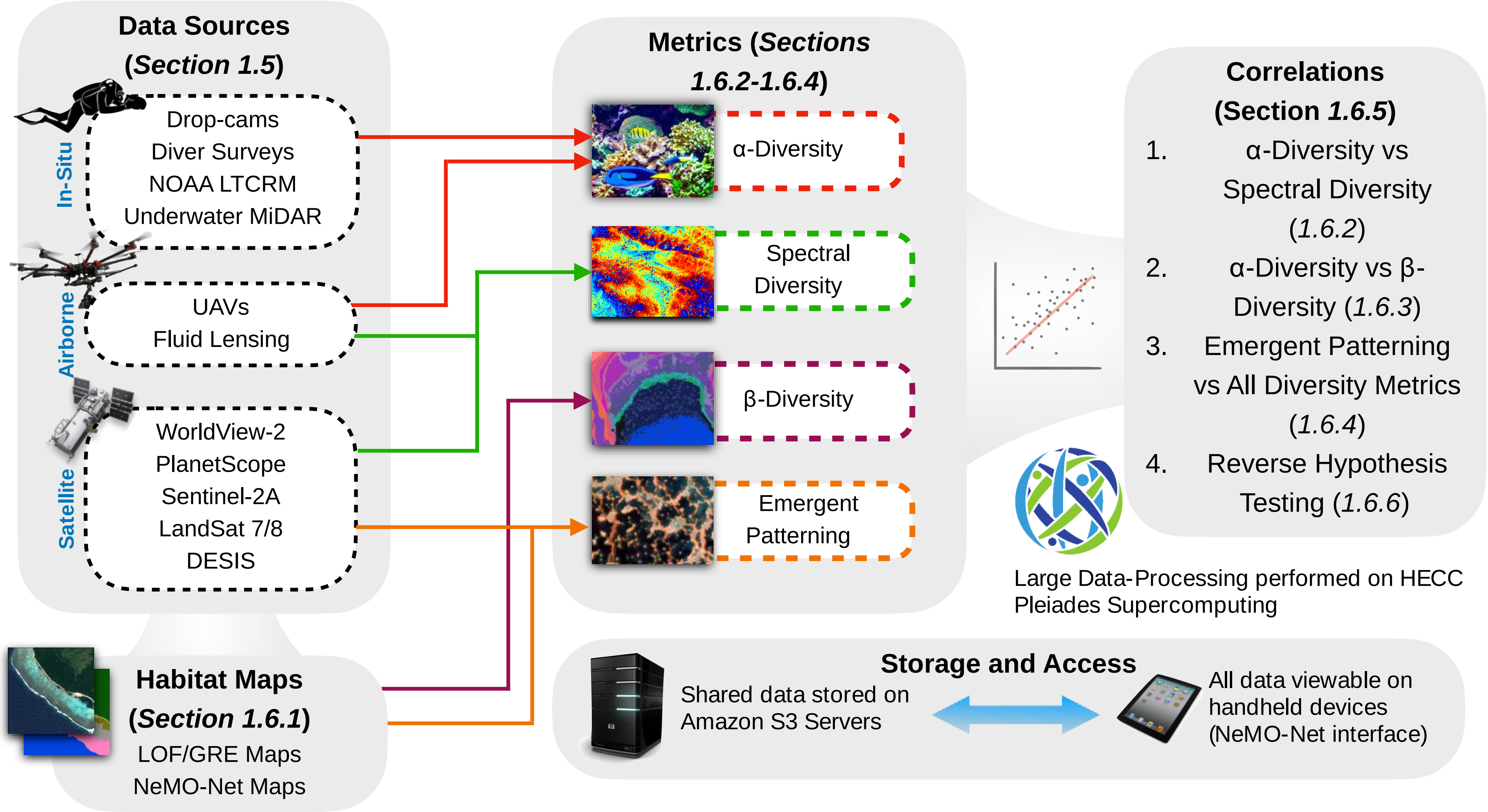
- (3) $\frac{\partial z}{\partial t} = \frac{\partial B}{\partial t} * c_2 + \frac{\partial S}{\partial t}$ Surface elevation changes due to a combination of both reef growth and sedimentation

- (4) $\frac{\partial v}{\partial t} = f(z)$ Flow movement is controlled by topography

Post-doc, Haiwei Xi

CONCLUSIONS:

- MarineVERSE takes coral reefs as a model ecosystem and takes four approaches to amplifying our ability to remotely sense ecosystem-scale biodiversity



QUESTIONS