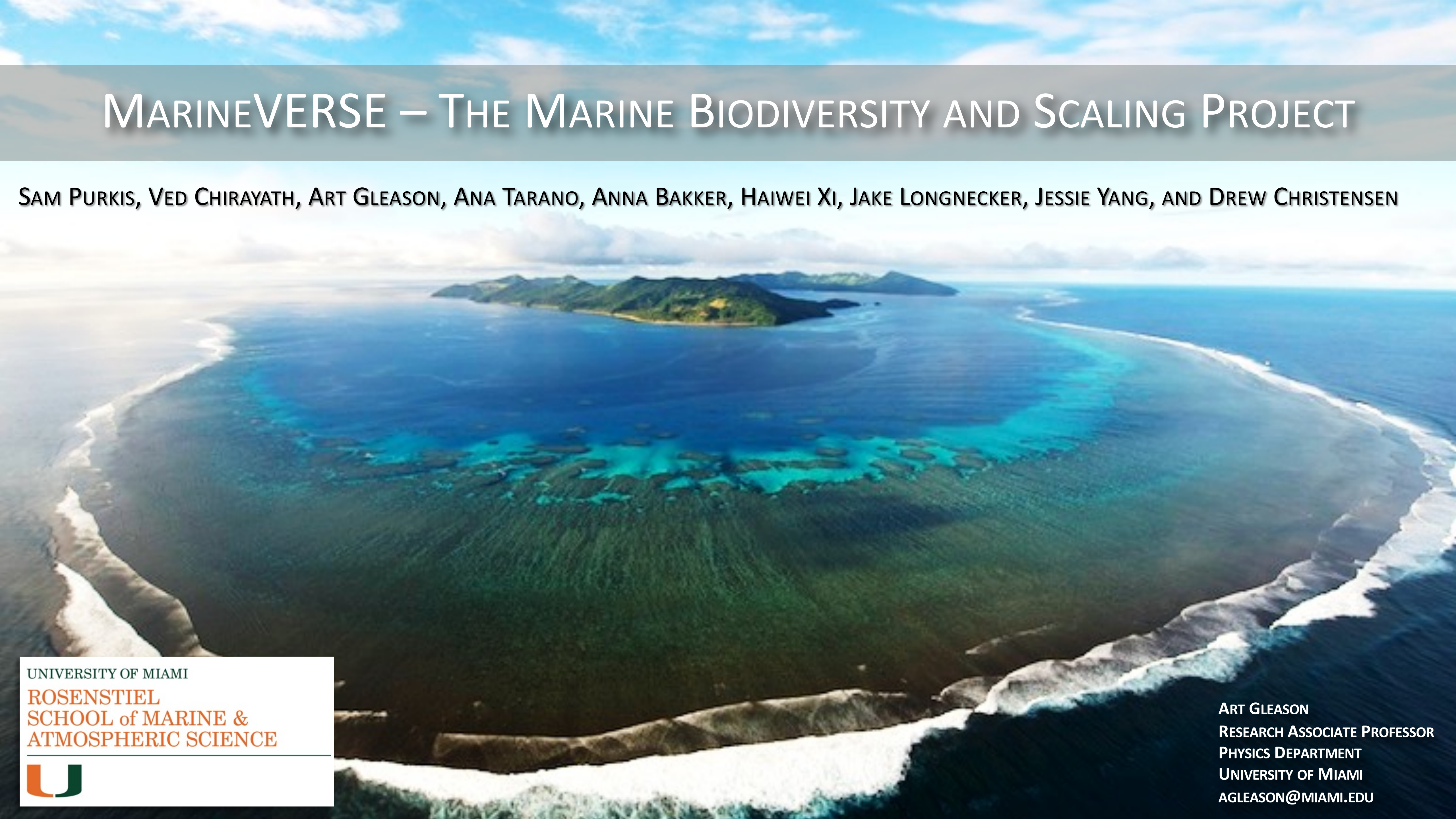
MarineVERSE – The Marine Biodiversity and Scaling Project

Sam Purkis, Ved Chirayath, Art Gleason, Ana Tarano, Anna Bakker, Haiwei Xi, Jake Longnecker, Jessie Yang, and Drew Christensen



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Physics Department
University of Miami
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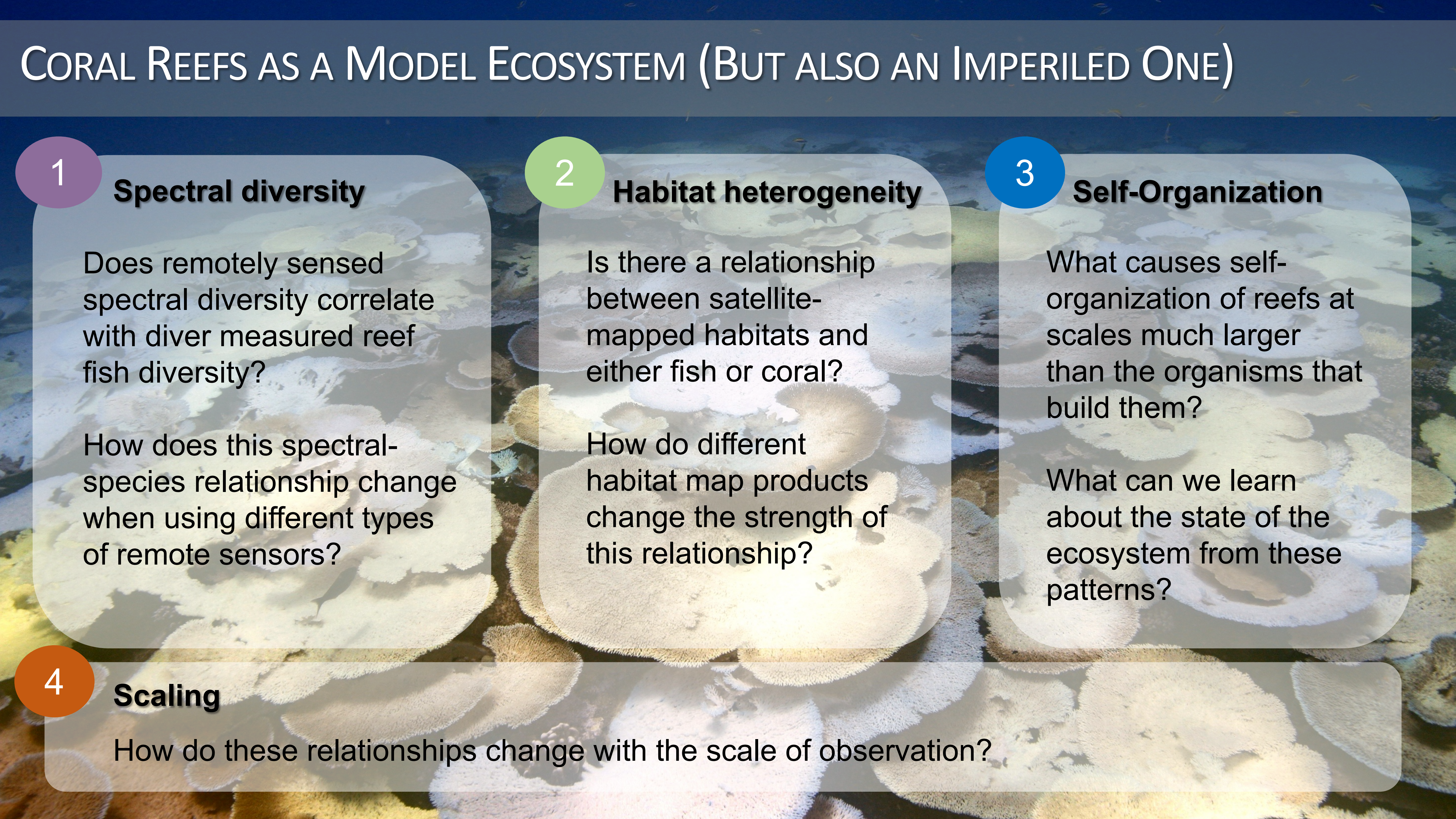
CORAL REEFS AS A MODEL ECOSYSTEM (BUT ALSO AN IMPERILED ONE)



1

Spectral diversity

Does remotely sensed spectral diversity correlate with diver measured reef fish diversity?

How does this spectral-species relationship change when using different types of remote sensors?

2

Habitat heterogeneity

Is there a relationship between satellite-mapped habitats and either fish or coral?

How do different habitat map products change the strength of this relationship?

3

Self-Organization

What causes self-organization of reefs at scales much larger than the organisms that build them?

What can we learn about the state of the ecosystem from these patterns?

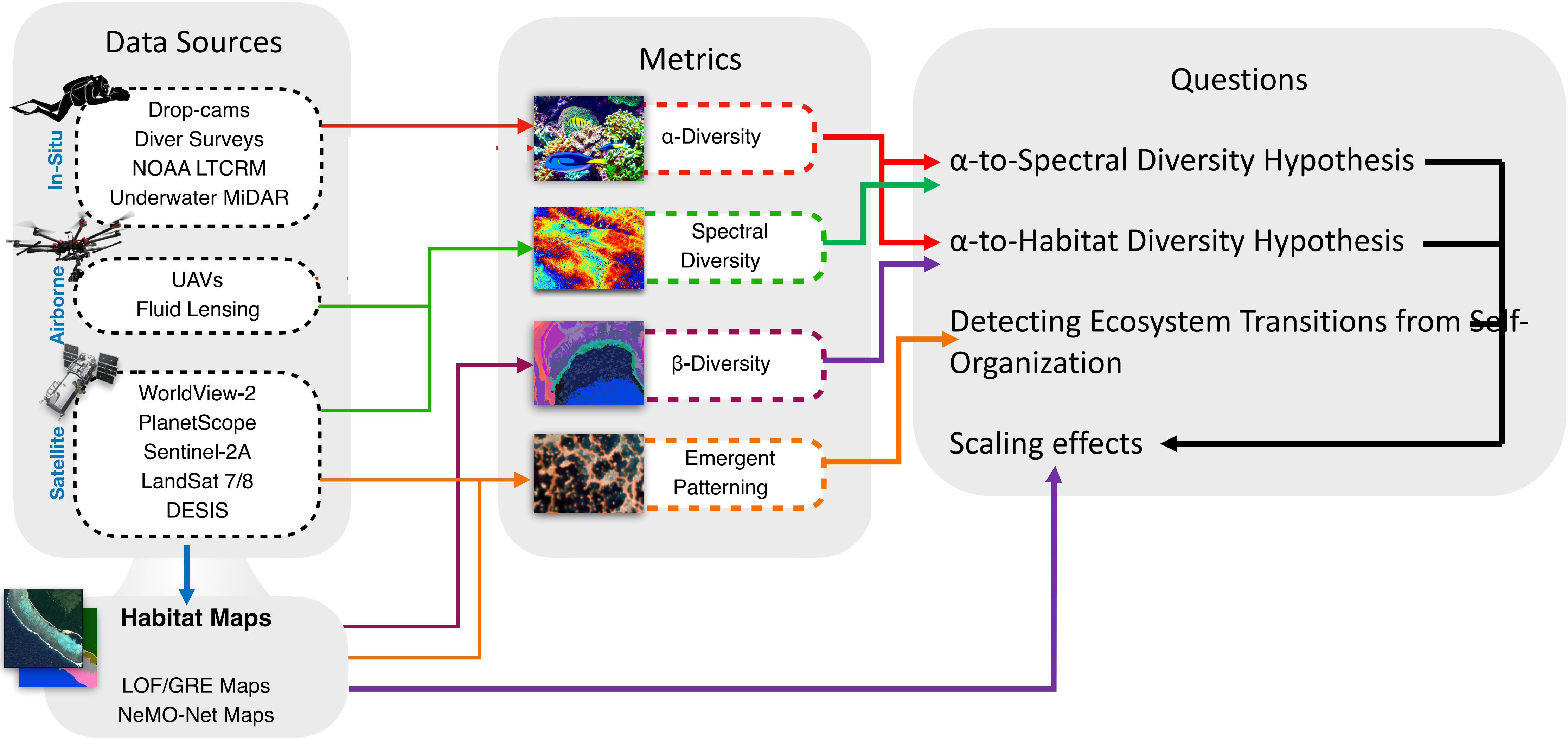
4

Scaling

How do these relationships change with the scale of observation?

The Marine Biodiversity and Scaling Project (NASA ROSES Biodiversity Award 20-BIODIV20-0108)

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



Data Sources

In-Situ
Drop-cams
Diver Surveys
NOAA LTCRM
Underwater MiDAR

Airborne
UAVs
Fluid Lensing

Satellite
WorldView-2
PlanetScope
Sentinel-2A
LandSat 7/8
DESIS

Habitat Maps
LOF/GRE Maps
NeMO-Net Maps

Metrics

α-Diversity

Spectral Diversity

β-Diversity

Emergent Patterning

Questions

α-to-Spectral Diversity Hypothesis

α-to-Habitat Diversity Hypothesis

Detecting Ecosystem Transitions from Self-Organization

Scaling effects

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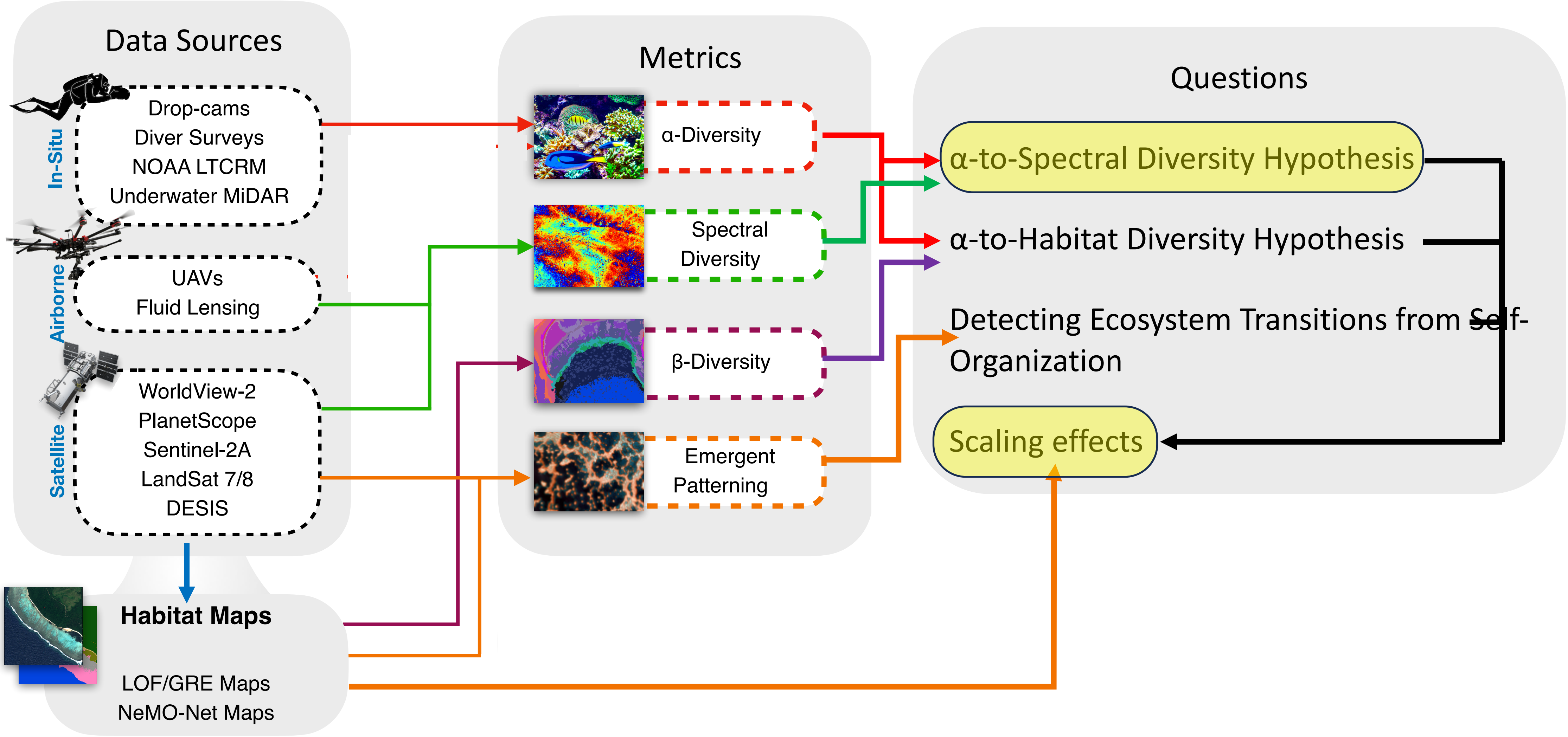

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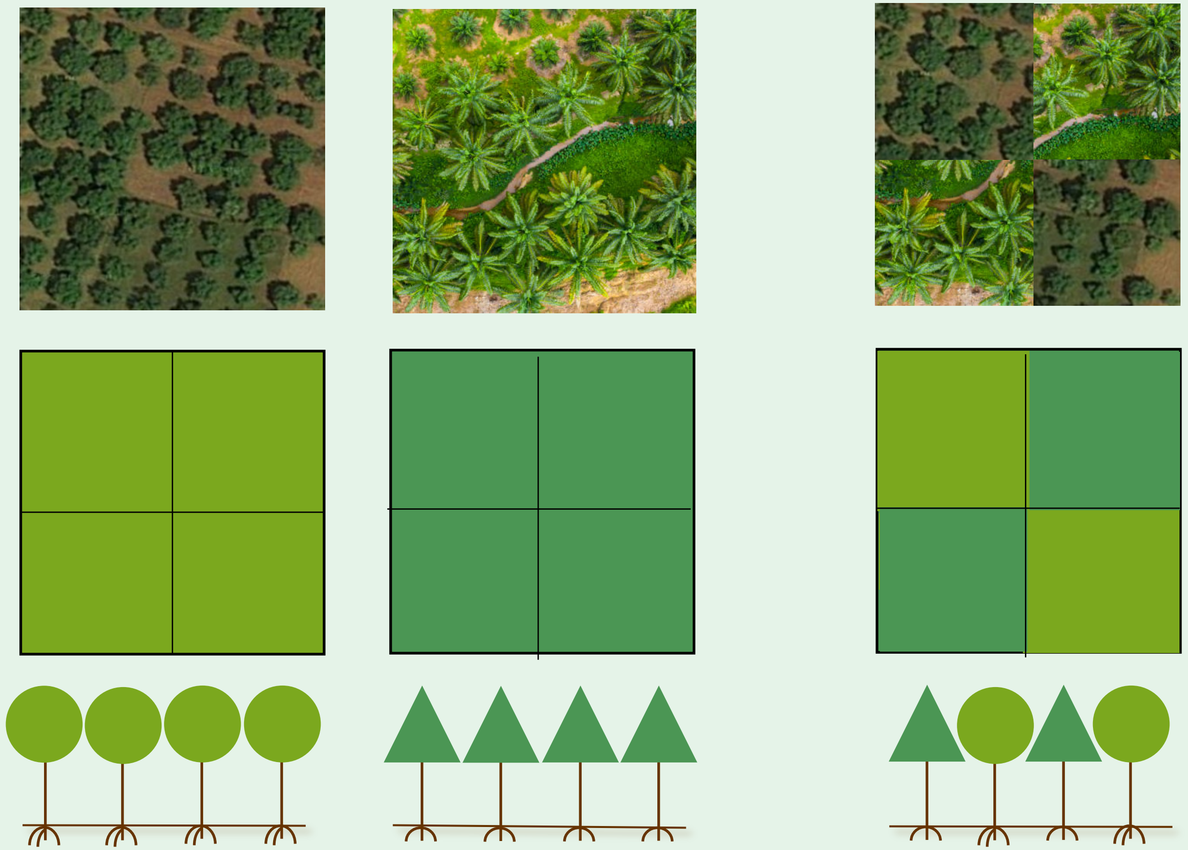
SPECTRAL VARIABILITY HYPOTHESIS

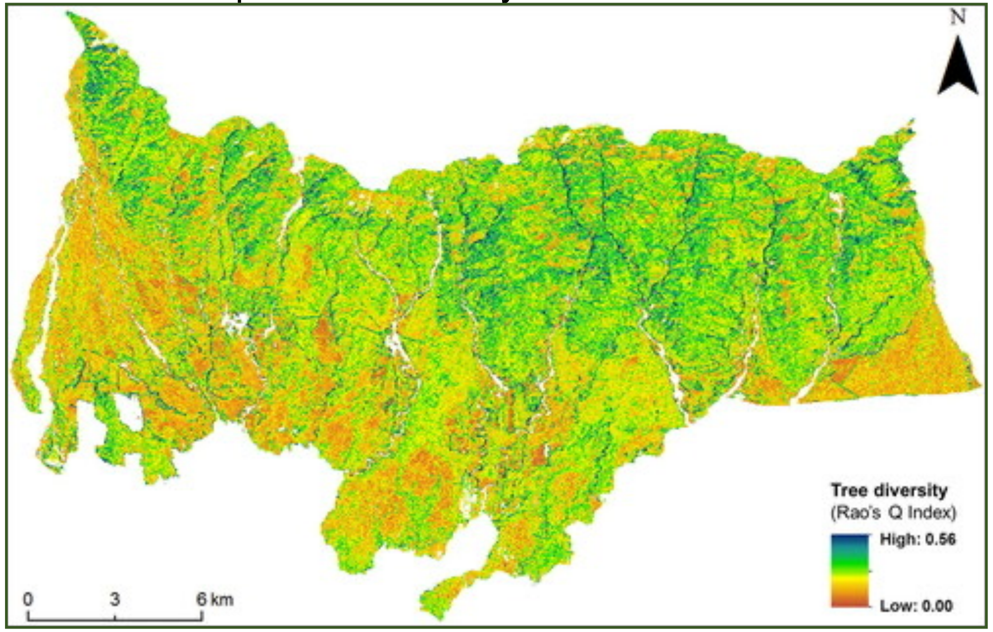
Simple idea:
Pixels over homogenous areas have lower spectral variance (within a moving window) than pixels over heterogeneous areas. Heterogeneous areas have more niches, so higher biodiversity.



adapted from
Cavender-Bares et al. (2021)

$$Q = \sum_i \sum_j \sum_\alpha \left[\left(\Phi_{i,\alpha} - \Phi_{j,\alpha}\right)^2\right]^{1/2}$$

Predicted map of tree diversity



Pangtey et al. (2022)

Φ = pixel value
i, j = spatial coordinates (pixels)
α = spectral coordinate (bands)

DATA FOR OUR STUDY

Reef fish surveys (2 sources):

Khaled bin Sultan Living Oceans Foundation Global Reef Expedition

- 2x 30 m transects at up to 5 depths per site
- A global transect
- Mostly forereef and lagoon settings

Guam Long-term Coral Reef Monitoring Program

- 2x stationary 15 min surveys per site at one depth
- Guam only
- Hardbottom reef terrace

Imagery (4 sources):

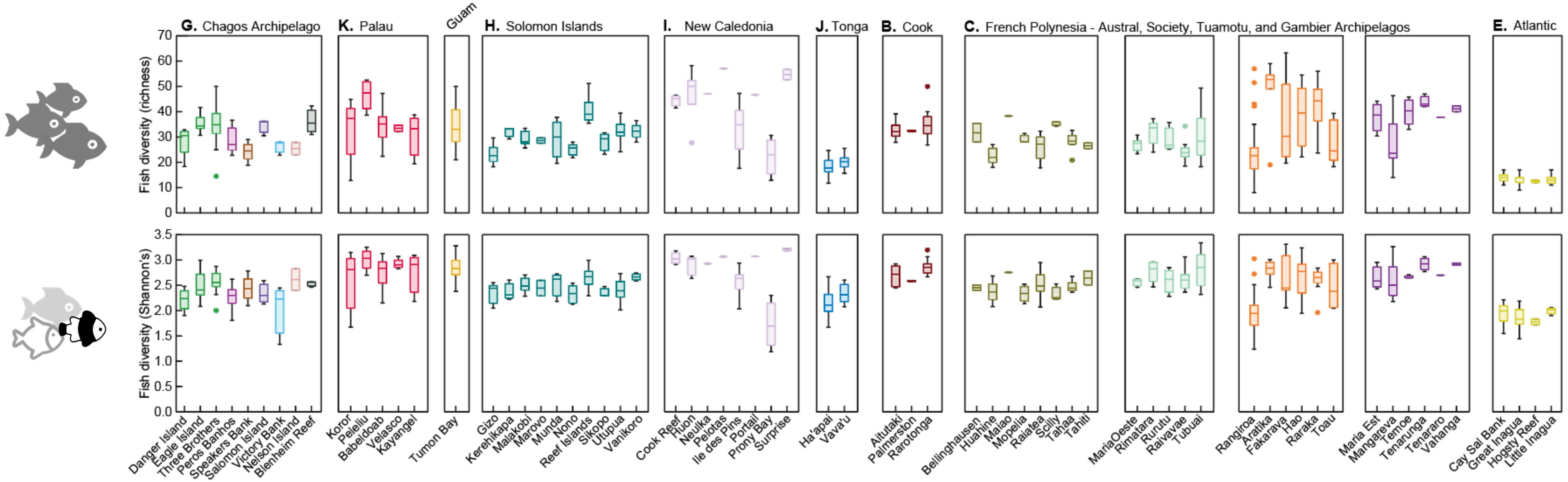
WorldView-2 (WV-2)

- Multispectral 2.5 m resolution
- Panchromatic 0.5 m resolution
- Atmospherically corrected reflectance (level 2A)

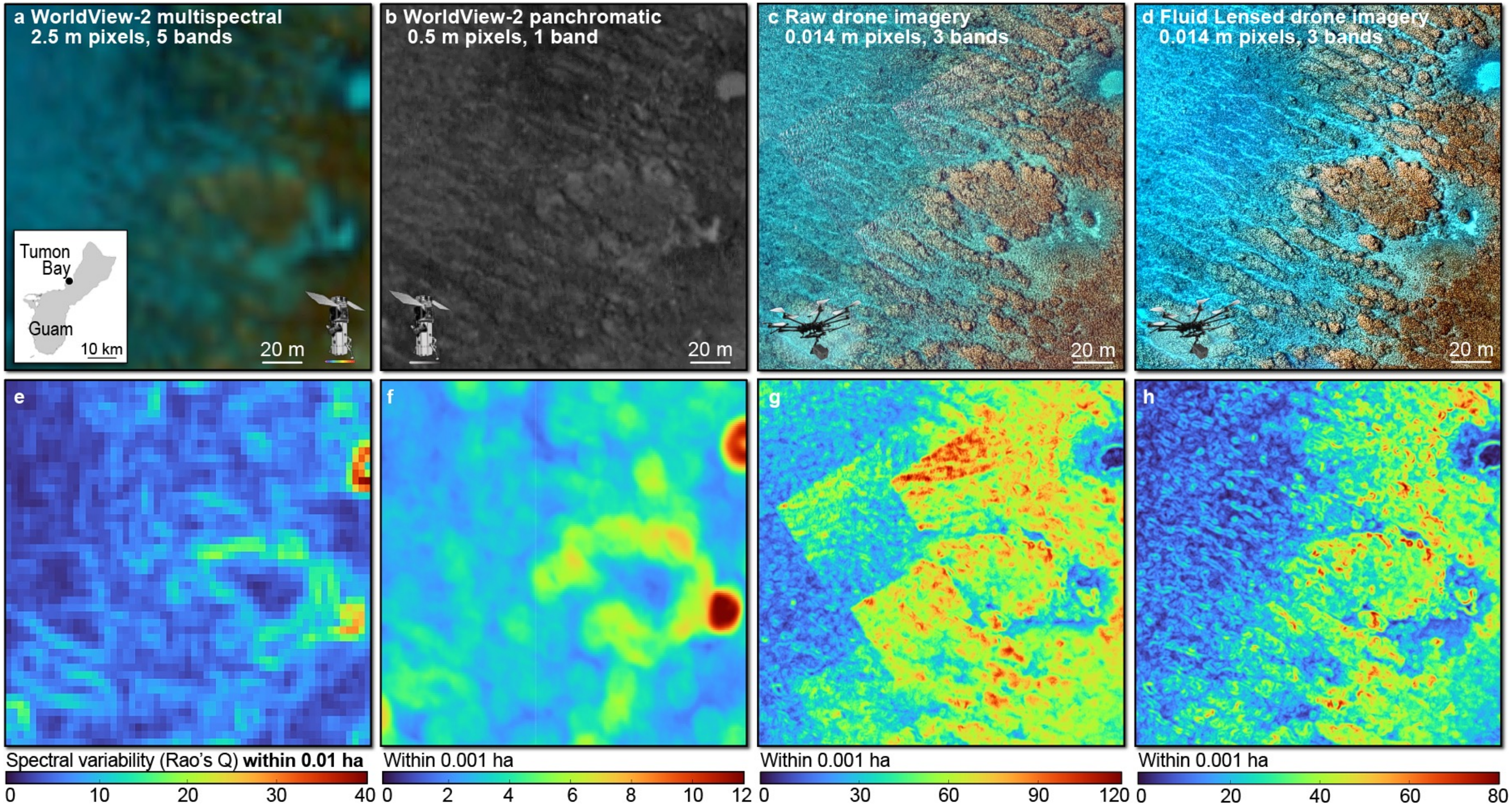
Drone-based

- RGB visible bands at 0.014 m resolution
- Raw imagery
- Fluid lens-corrected imagery

FISH SPECIES RICHNESS AND SHANNON'S DIVERSITY



EXAMPLE OF THE FOUR IMAGE SOURCES AND RAO'S Q



6 Window sizes for Q calculation in each case

WV-2: 0.5, 1, 5, 10, 25, 50 ha

Drone: 0.1, 0.5, 1, 5, 10, 50 m^2

About the same number of pixels but different spatial scales

WHAT IS FLUID LENSING?

V. Chirayath and R. Instrella *Remote Sensing of Environment 235 (2019) 111475*

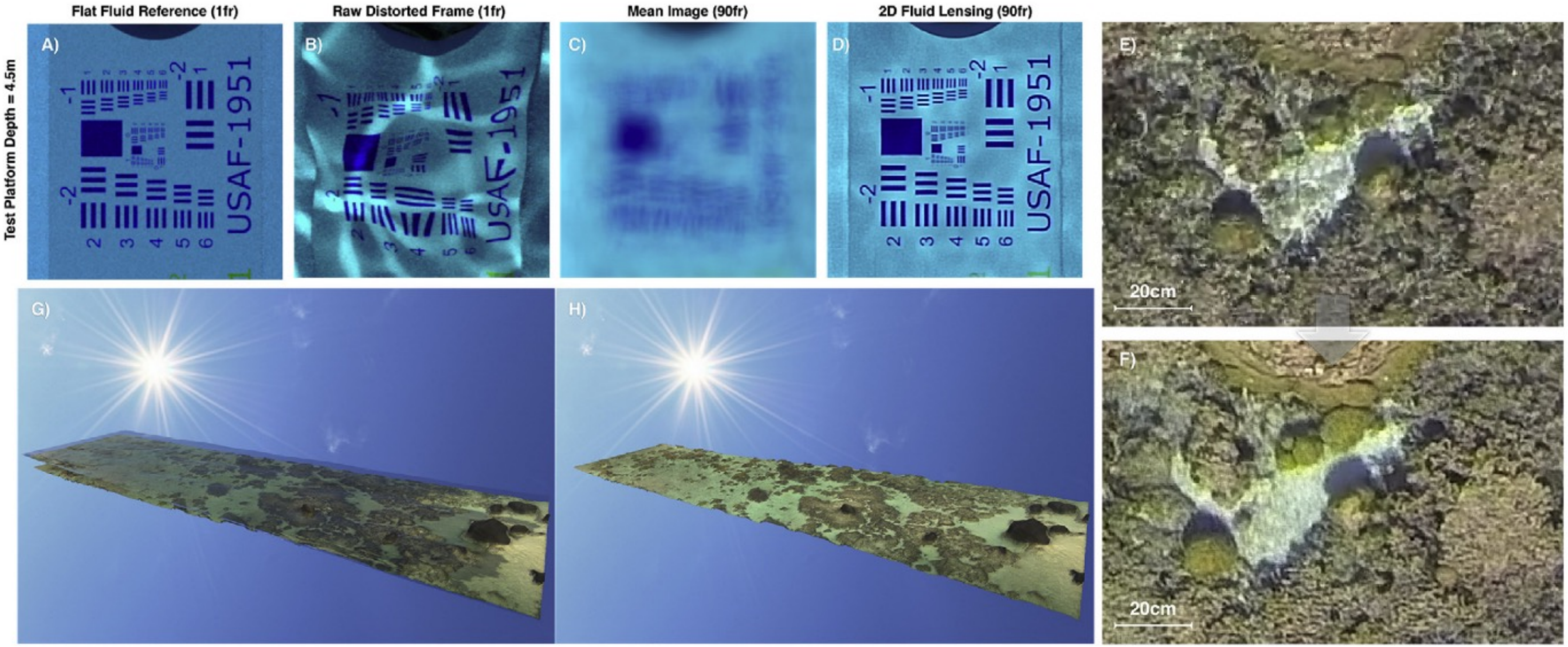
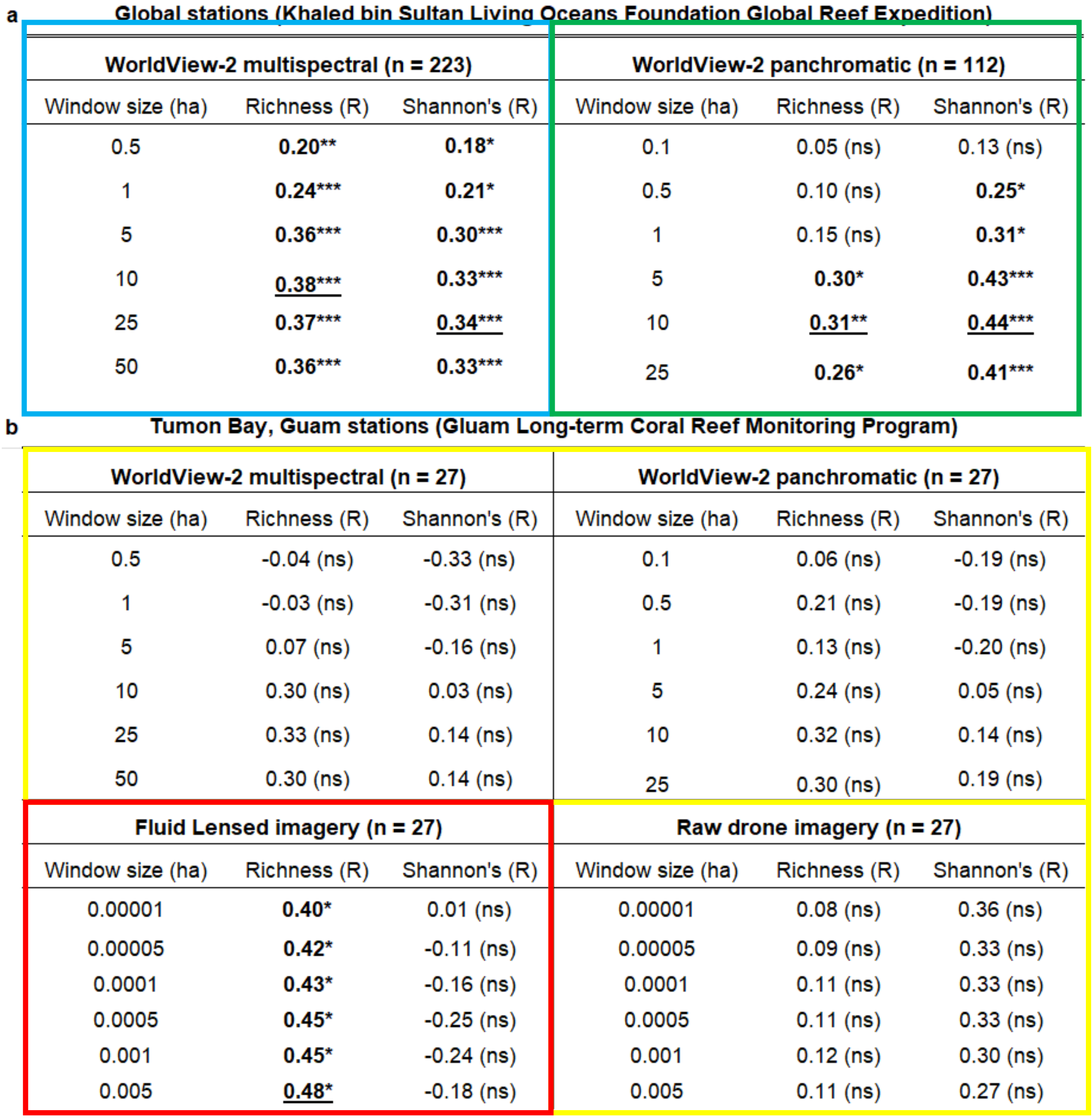


Fig. 1. - Fluid Lensing Algorithm Results. The general fluid lensing algorithm is used to process high frame rate multispectral imagery to remove refractive distortions from ocean waves and enhance the signal to noise ratio (SNR) of benthic images. (A–D) present imagery from the fluid lensing test pool showing removal of ocean wave related refractive distortion and signal enhancement of a USAF test target at a depth of 4.5 m. The flat fluid reference (A) shows target under flat fluid conditions over a 1 s integration time. The raw distorted frame (B) shows target under typical ocean wave conditions for shallow marine systems. Mean image (C) is the 90 frame average of raw frames over 1 s of integration time. The 2D fluid lensing result (D) uses these same 90 frames to successfully recover the test target with an effective 0.25 cm spatial resolution and uses caustics to enhance SNR. Airborne fluid lensing is used to survey aquatic system with UAVs. Raw airborne imagery from a 2013 airborne field test in American Samoa is shown in (E), with the 2D fluid lensing result from 90 frames in (F). Cm-scale 3D remote sensing of coral reef in American Samoa with fluid distortion (G), and without fluid distortion as processed using the 3D airborne fluid lensing algorithm (H). From PhD thesis, Chirayath

CORRELATIONS BETWEEN FISH DIVERSITY METRICS AND RAO'S Q



a Global stations (Khaled bin Sultan Living Oceans Foundation Global Reef Expedition)

WorldView-2 multispectral (n = 223)			WorldView-2 panchromatic (n = 112)		
Window size (ha)	Richness (R)	Shannon's (R)	Window size (ha)	Richness (R)	Shannon's (R)
0.5	**0.20****	**0.18***	0.1	0.05 (ns)	0.13 (ns)
1	**0.24*****	**0.21***	0.5	0.10 (ns)	**0.25***
5	**0.36*****	**0.30*****	1	0.15 (ns)	**0.31***
10	**0.38*****	**0.33*****	5	**0.30***	**0.43*****
25	**0.37*****	**0.34*****	10	**0.31****	**0.44*****
50	**0.36*****	**0.33*****	25	**0.26***	**0.41*****

b Tumon Bay, Guam stations (Gluam Long-term Coral Reef Monitoring Program)

WorldView-2 multispectral (n = 27)			WorldView-2 panchromatic (n = 27)		
Window size (ha)	Richness (R)	Shannon's (R)	Window size (ha)	Richness (R)	Shannon's (R)
0.5	-0.04 (ns)	-0.33 (ns)	0.1	0.06 (ns)	-0.19 (ns)
1	-0.03 (ns)	-0.31 (ns)	0.5	0.21 (ns)	-0.19 (ns)
5	0.07 (ns)	-0.16 (ns)	1	0.13 (ns)	-0.20 (ns)
10	0.30 (ns)	0.03 (ns)	5	0.24 (ns)	0.05 (ns)
25	0.33 (ns)	0.14 (ns)	10	0.32 (ns)	0.14 (ns)
50	0.30 (ns)	0.14 (ns)	25	0.30 (ns)	0.19 (ns)

Fluid Lensed imagery (n = 27)			Raw drone imagery (n = 27)		
Window size (ha)	Richness (R)	Shannon's (R)	Window size (ha)	Richness (R)	Shannon's (R)
0.00001	**0.40***	0.01 (ns)	0.00001	0.08 (ns)	0.36 (ns)
0.00005	**0.42***	-0.11 (ns)	0.00005	0.09 (ns)	0.33 (ns)
0.0001	**0.43***	-0.16 (ns)	0.0001	0.11 (ns)	0.33 (ns)
0.0005	**0.45***	-0.25 (ns)	0.0005	0.11 (ns)	0.33 (ns)
0.001	**0.45***	-0.24 (ns)	0.001	0.12 (ns)	0.30 (ns)
0.005	**0.48***	-0.18 (ns)	0.005	0.11 (ns)	0.27 (ns)

For the global transect

- 🟦 WV-2 MS significant positive correlations in all cases
- 🟩 WV-2 Pan significant positive correlations large windows

For the Guam site specifically

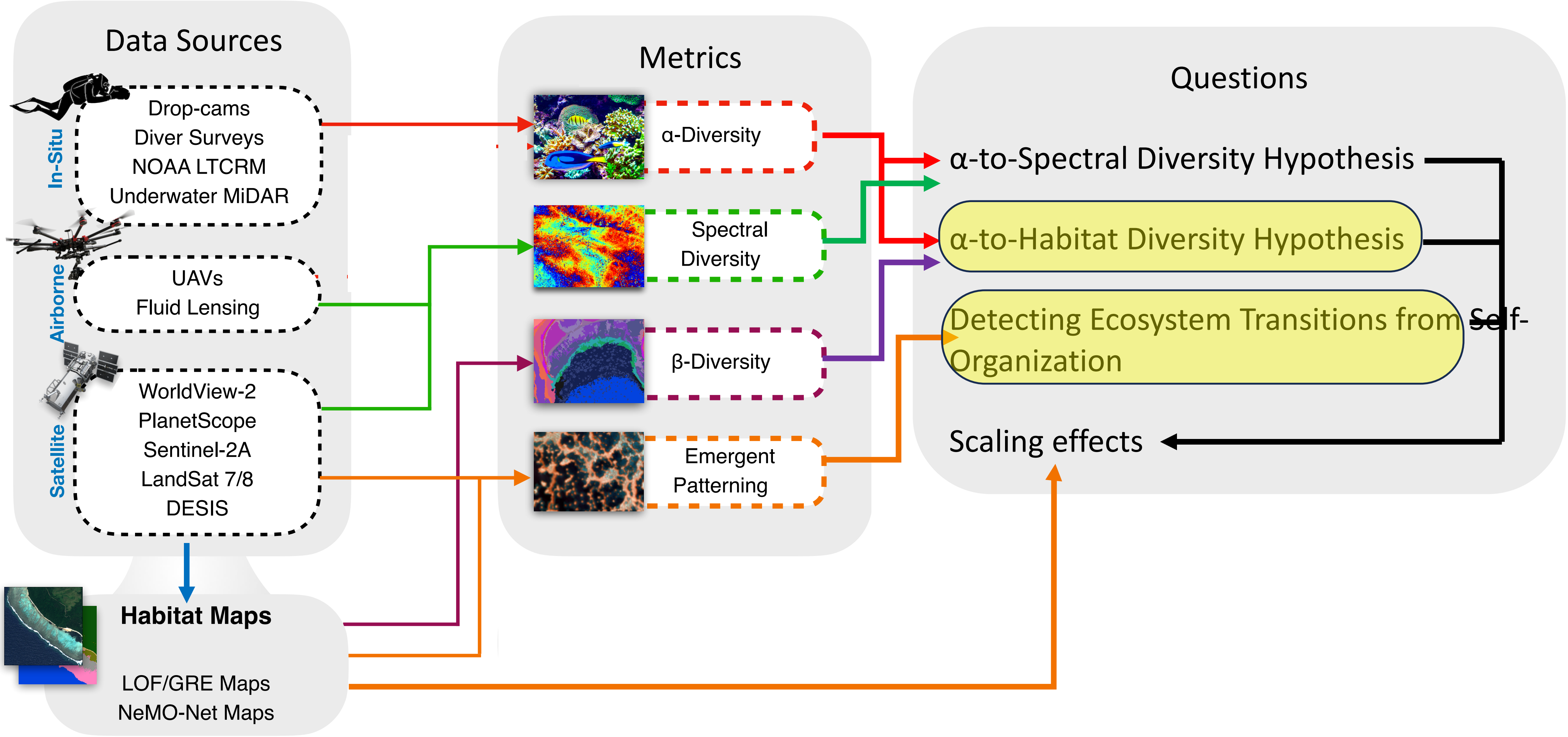
- 🟨 Neither WV-2 nor raw drone data correlated at all
- 🟥 Fluid lens-corrected imagery had highest correlations

Two most important conclusions:

- Scale matters: larger windows of WV-2 respond to habitat variance not local structure
- Fluid lensing corrections for caustics, glint, and depth make a huge difference for using drone imagery

THE MARINE BIODIVERSITY AND SCALING PROJECT (NASA ROSES BIODIVERSITY AWARD 20-BIODIV20-0108)

- Sam Purkis presented on these two topics at this meeting last year.
- I have some slides and happy to take questions but skipping for the moment due to time.



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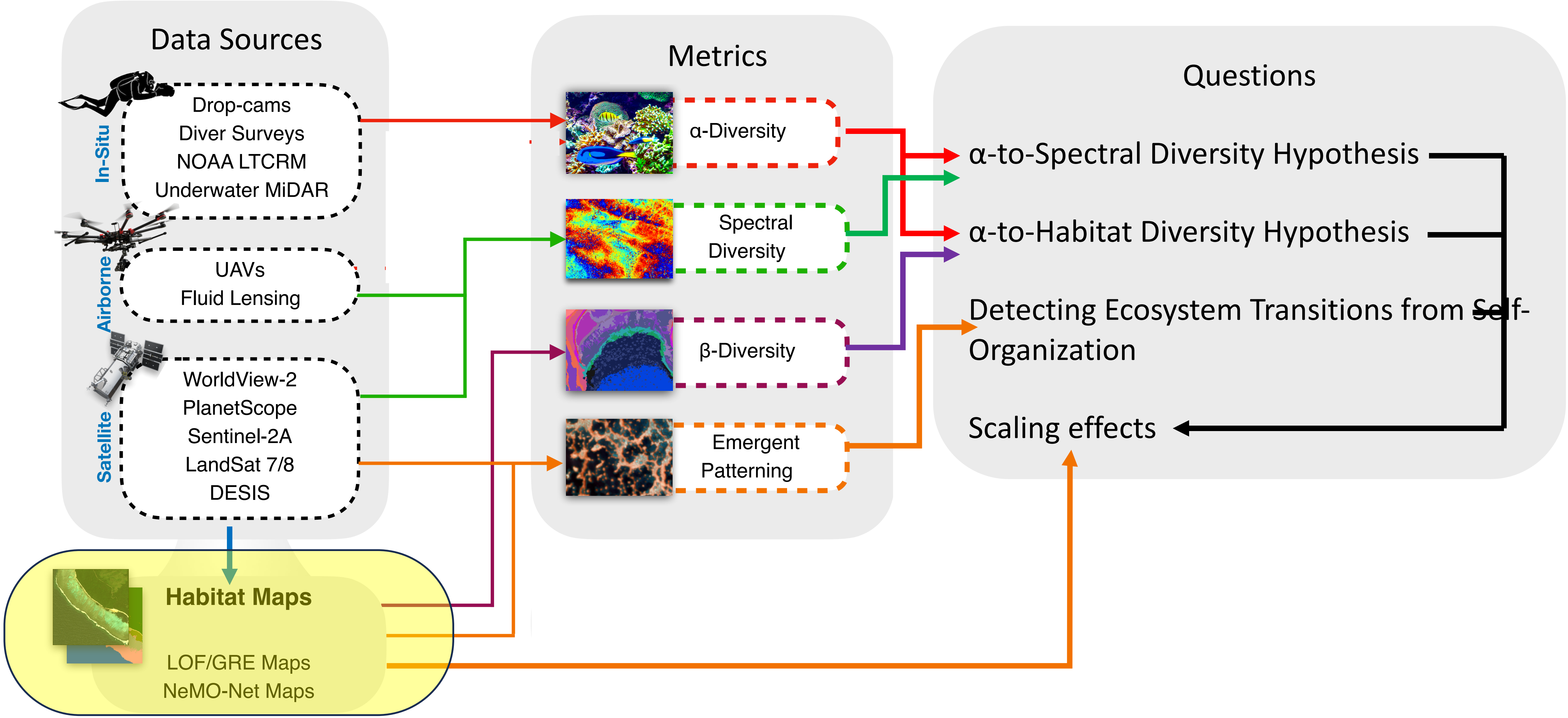
- Fluid-lensing imagery and habitat maps being produced as part of this and other projects: **http://nemonet.info/data-viewer**



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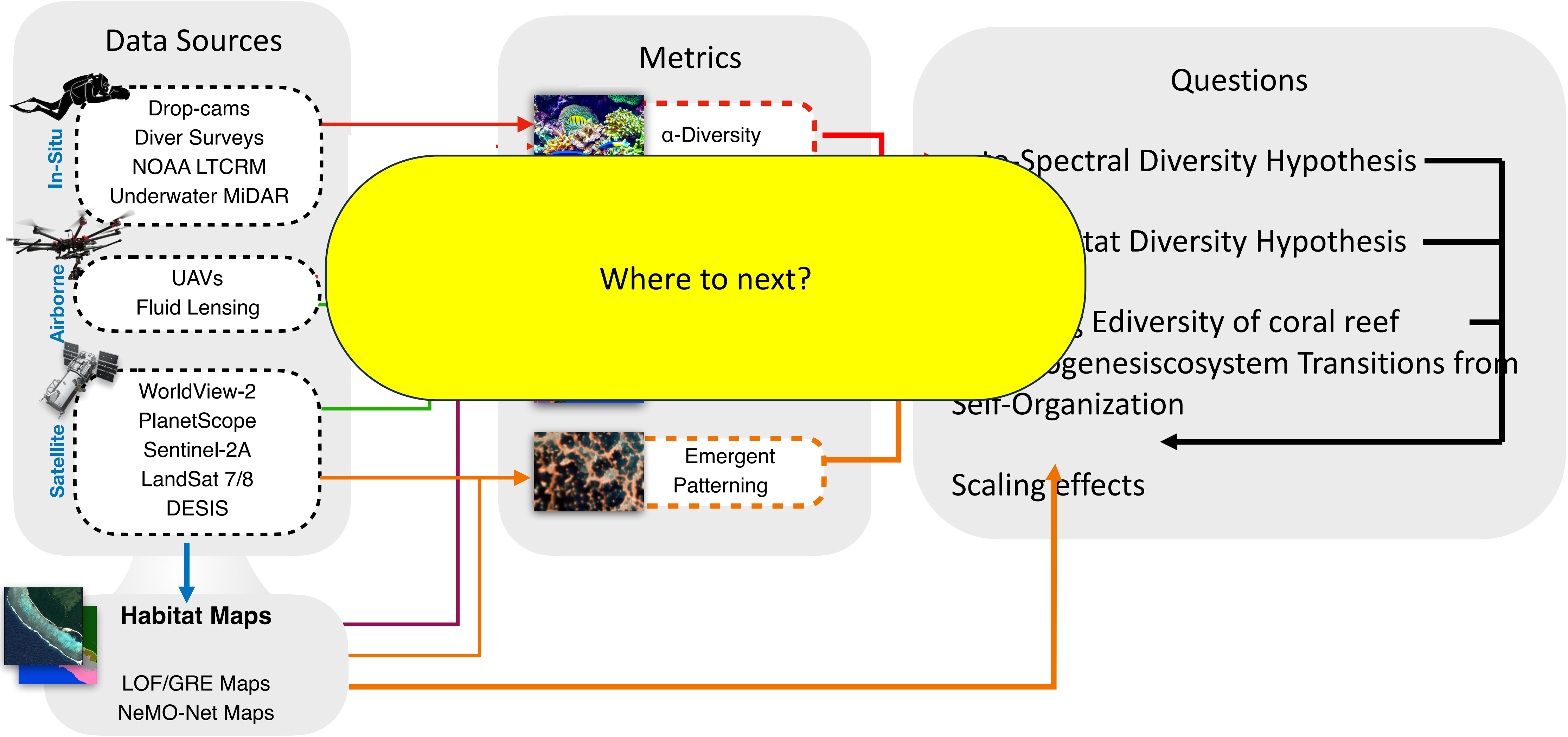

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Where to next?

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-Spectral Diversity Hypothesis

tat Diversity Hypothesis

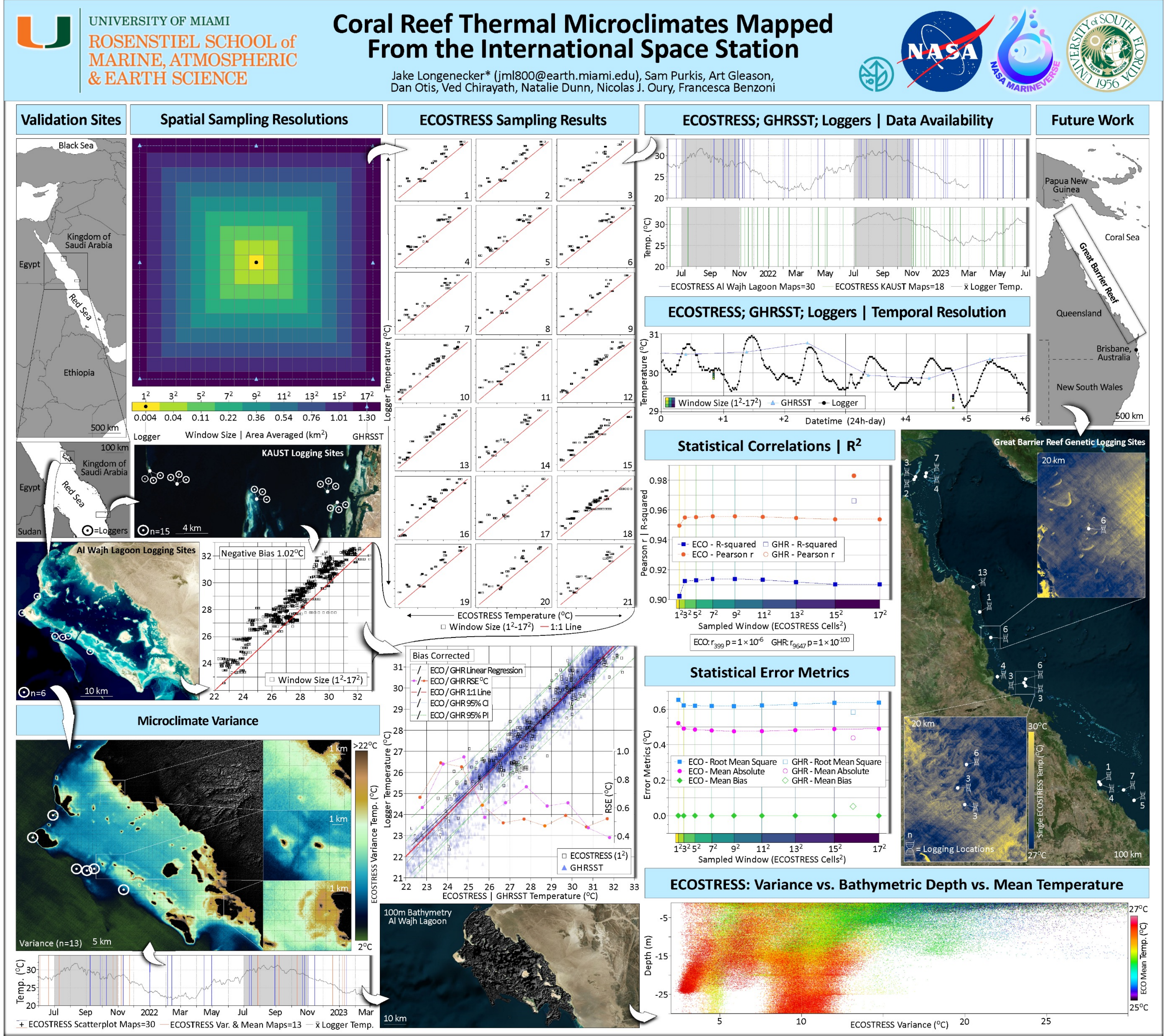
Ediversity of coral reef
ogenesiscosystem Transitions from
Self-Organization

Scaling effects

Jake Longnecker

Poster 5 PM Tonight!

- Idea is to expand the concept of habitat
- For most benthic remote sensing, habitat = benthos = relatively static
- Bring in the dynamics of the water column using new NASA sensors ECOSTRESS and PACE as well as historical record from Landsat and MODIS etc.



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Coral Reef Thermal Microclimates Mapped From the International Space Station

Jake Longenecker* (jml800@earth.miami.edu), Sam Purkis, Art Gleason,
Dan Otis, Ved Chirayath, Natalie Dunn, Nicolas J. Oury, Francesca Benzoni

Validation Sites

Spatial Sampling Resolutions

ECOSTRESS Sampling Results

ECOSTRESS; GHRSST; Loggers | Data Availability

ECOSTRESS; GHRSST; Loggers | Temporal Resolution

Statistical Correlations | R²

Statistical Error Metrics

Microclimate Variance

ECOSTRESS: Variance vs. Bathymetric Depth vs. Mean Temperature

Future Work

QUESTIONS

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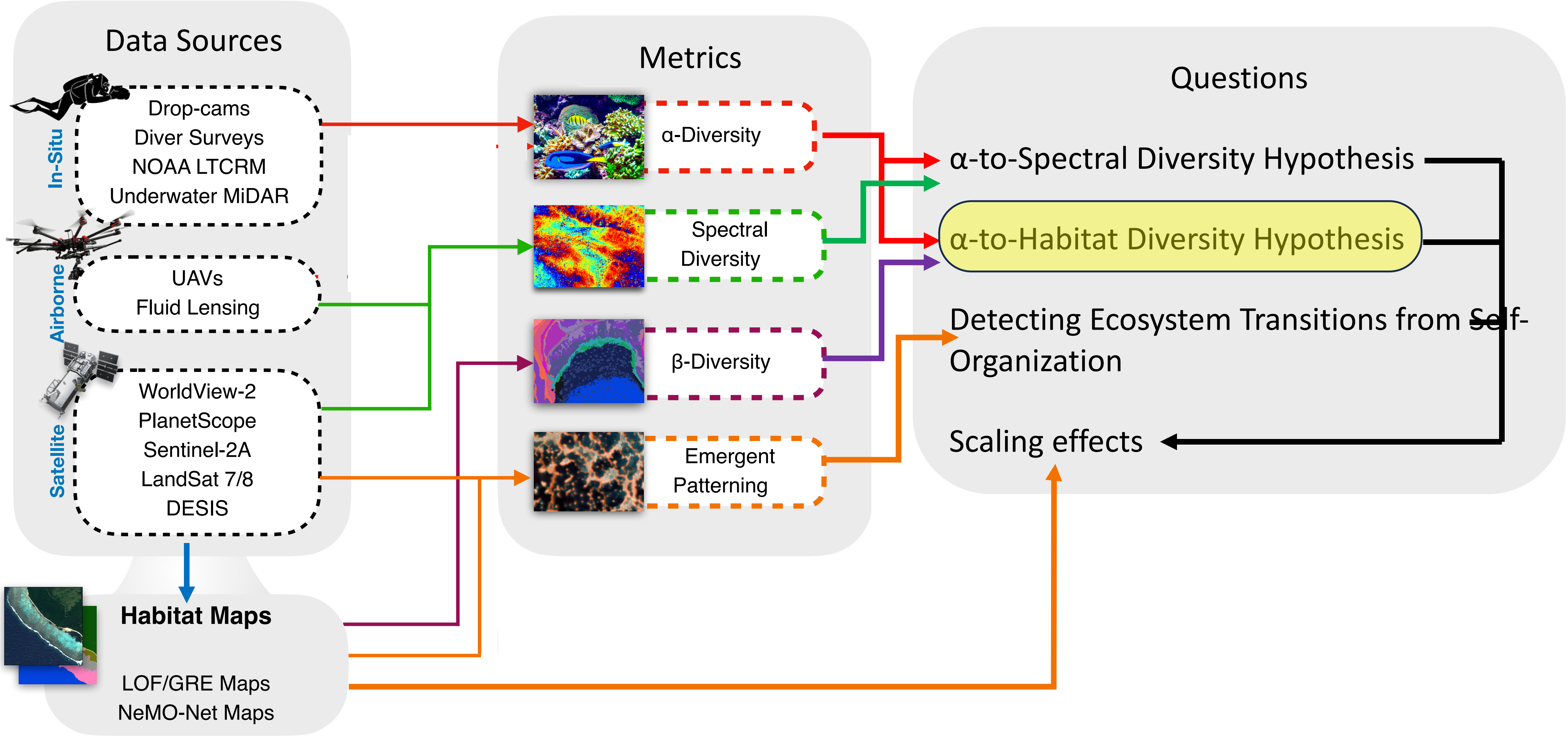

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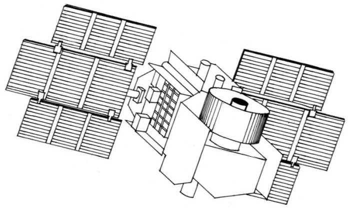
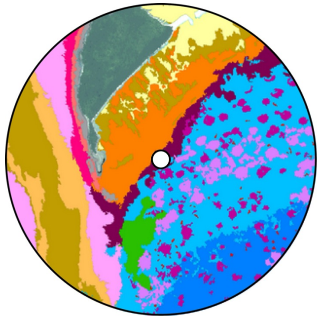
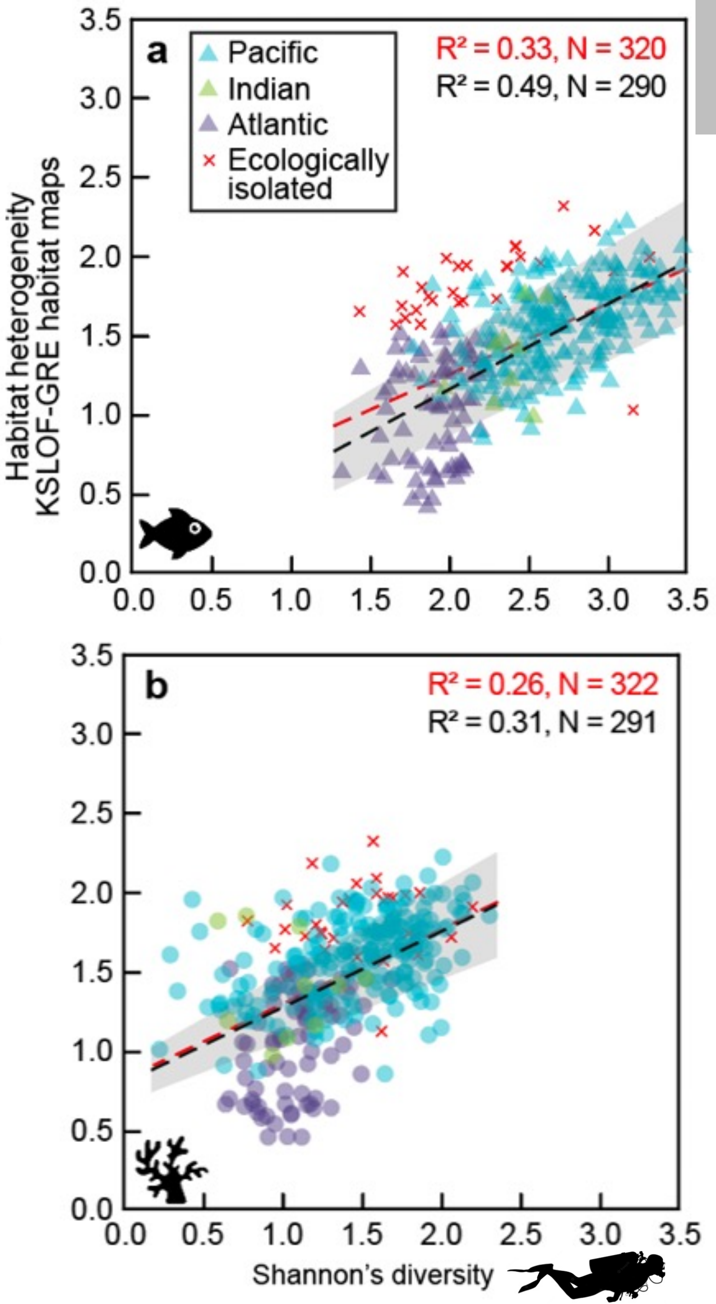
HABITAT DIVERSITY PREDICTS SPECIES DIVERSITY ON CORAL REEFS

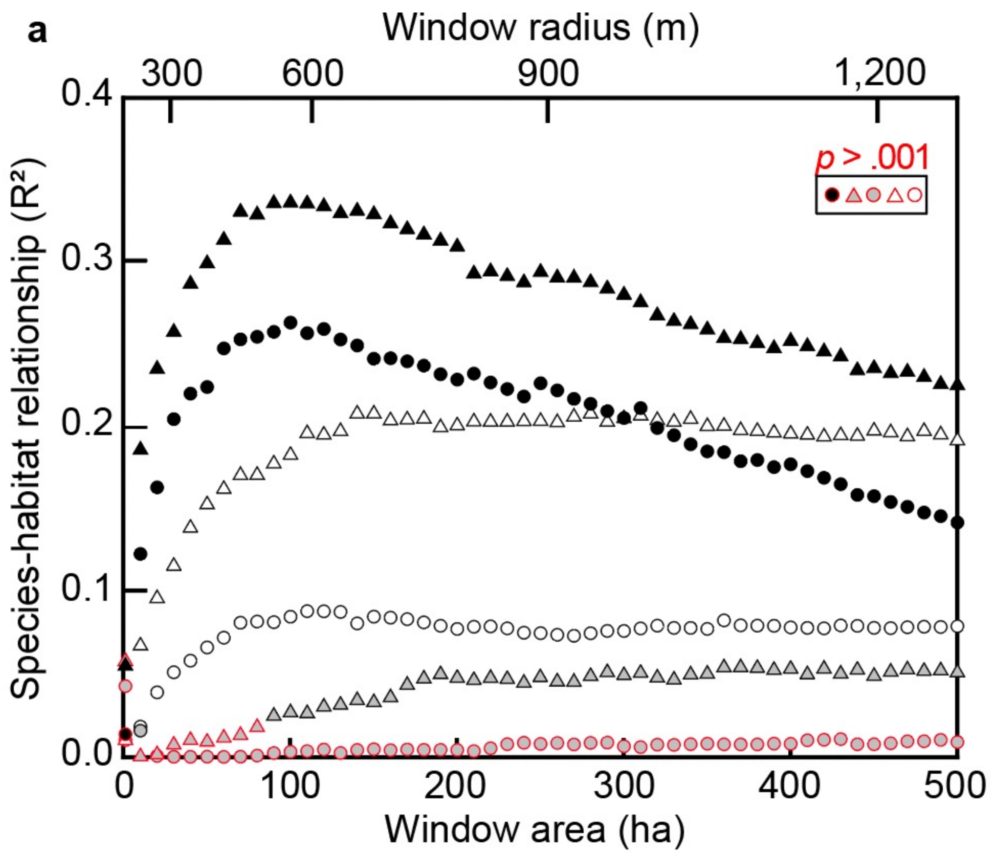
Dr. Anna Bakker

Bakker, et al, (2024). Remotely sensed habitat diversity predicts species diversity on coral reefs. *Remote Sensing of Environment*, 302, p.113990









b

		Window	Max R^2
KSLOF-GRE habitat	▲	90 ha	0.33
ACA benthic	△	190 ha	0.06
ACA geomorphic	△	140 ha	0.21

KSLOF-GRE habitat	●	100 ha	0.26
ACA benthic	●	1 ha	ns
ACA geomorphic	○	110 ha	0.09

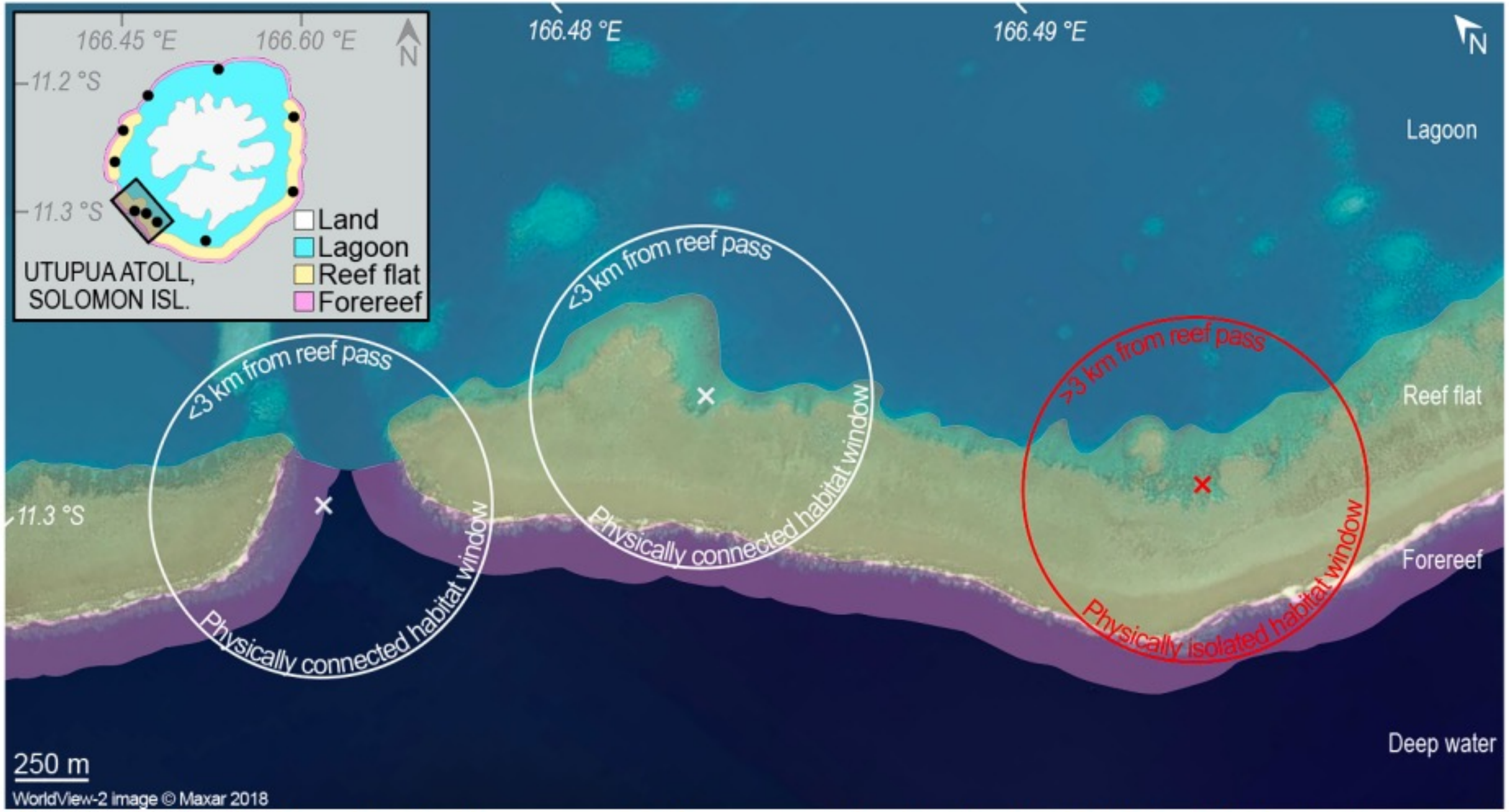
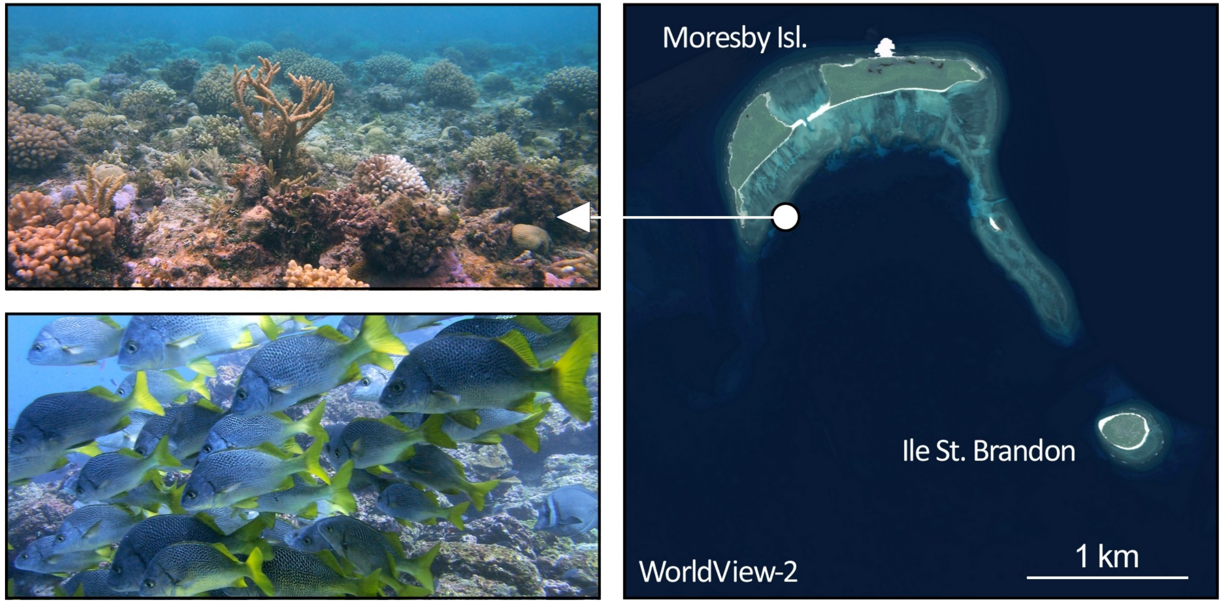


Fig 14 Criteria for physically connected versus physically isolated habitat windows in the Utupua Atoll (Solomon Islands). The atoll is colored by three distinct reef zones: lagoon (blue), reef flat (yellow), and forereef (pink). Three habitat windows are overlayed on the image. The two habitat windows in the west (white) are considered to straddle connected reef zones because they are positioned <3 km away from a reef pass which bisects the reef flat, thereby allowing faunal and hydrodynamic exchange between the lagoon and forereef. By contrast, the red habitat window is separated from the pass by >3 km and considered to be physically isolated.

KEY TERMS

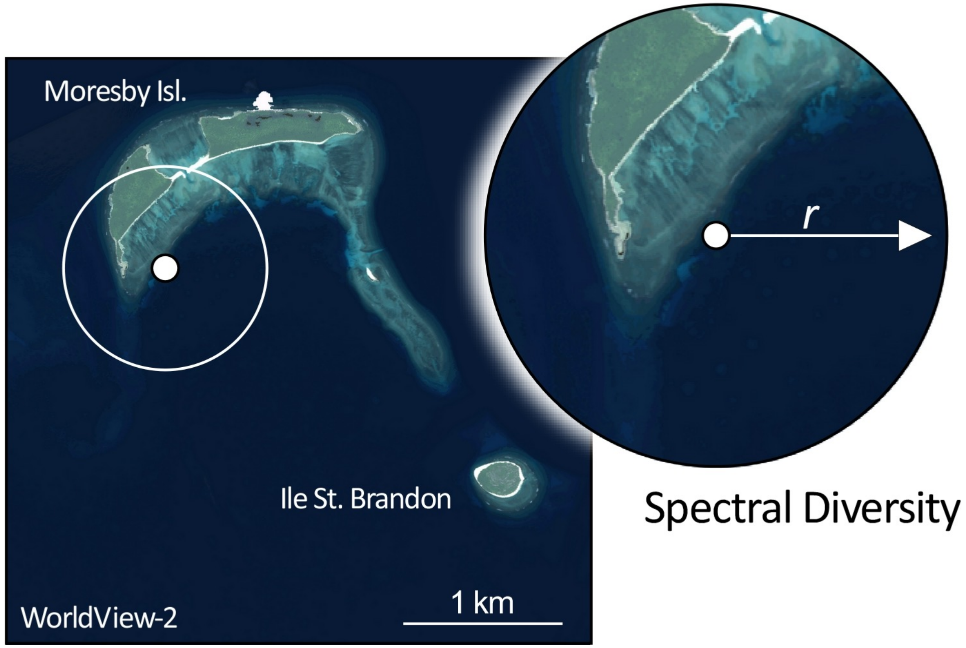


α (*in situ*) Diversity

- Measured by in situ, by divers in most of the data we have
- α-diversity captures species diversity at a local scale
- Parameterized using a range of indices including species-richness, species-variation, species-evenness or combinations:
- such as **<u>Shannon's</u>** and Simpson's Indices
- Typically applied to corals or reef fish

KEY TERMS

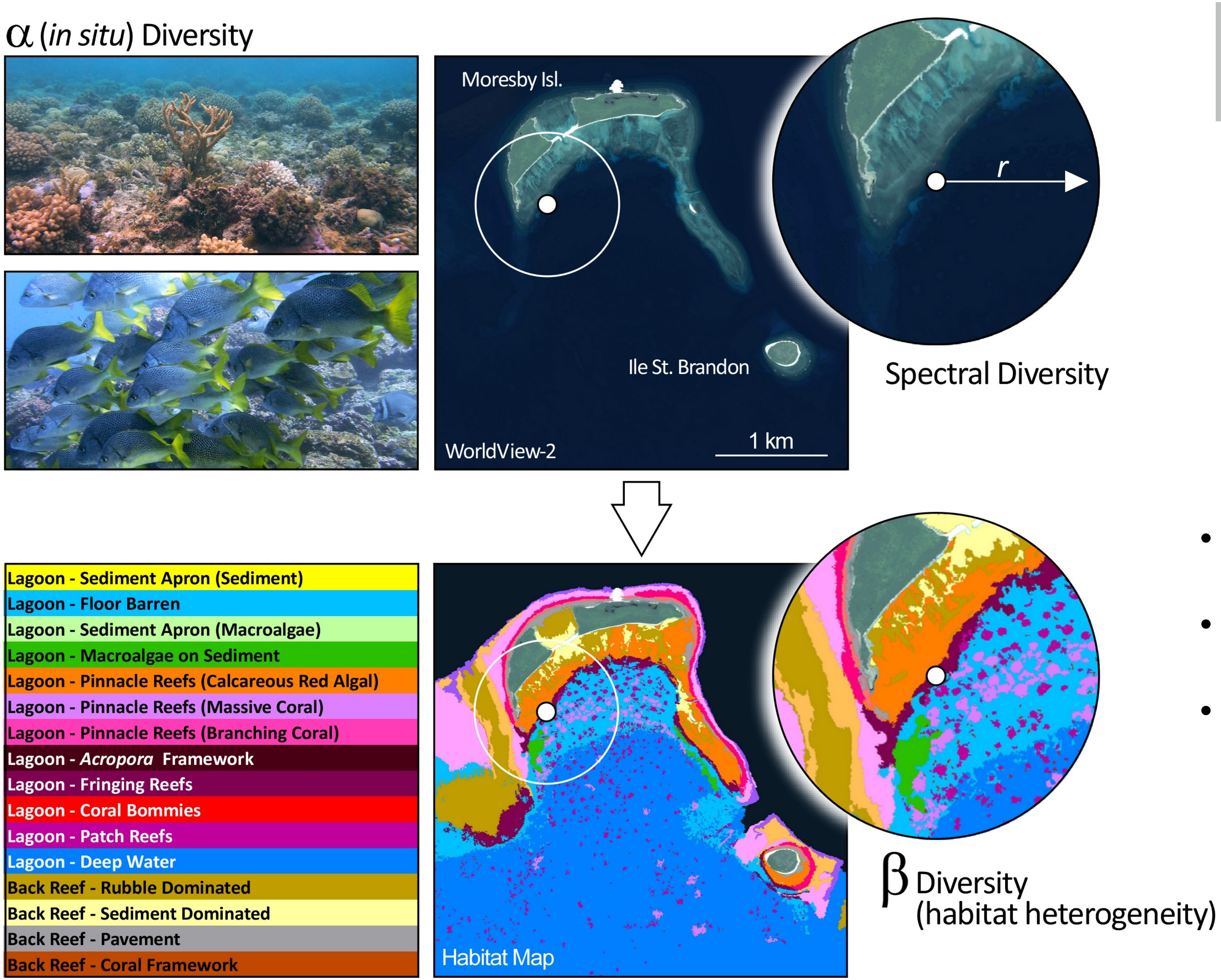
α (*in situ*) Diversity



Spectral Diversity

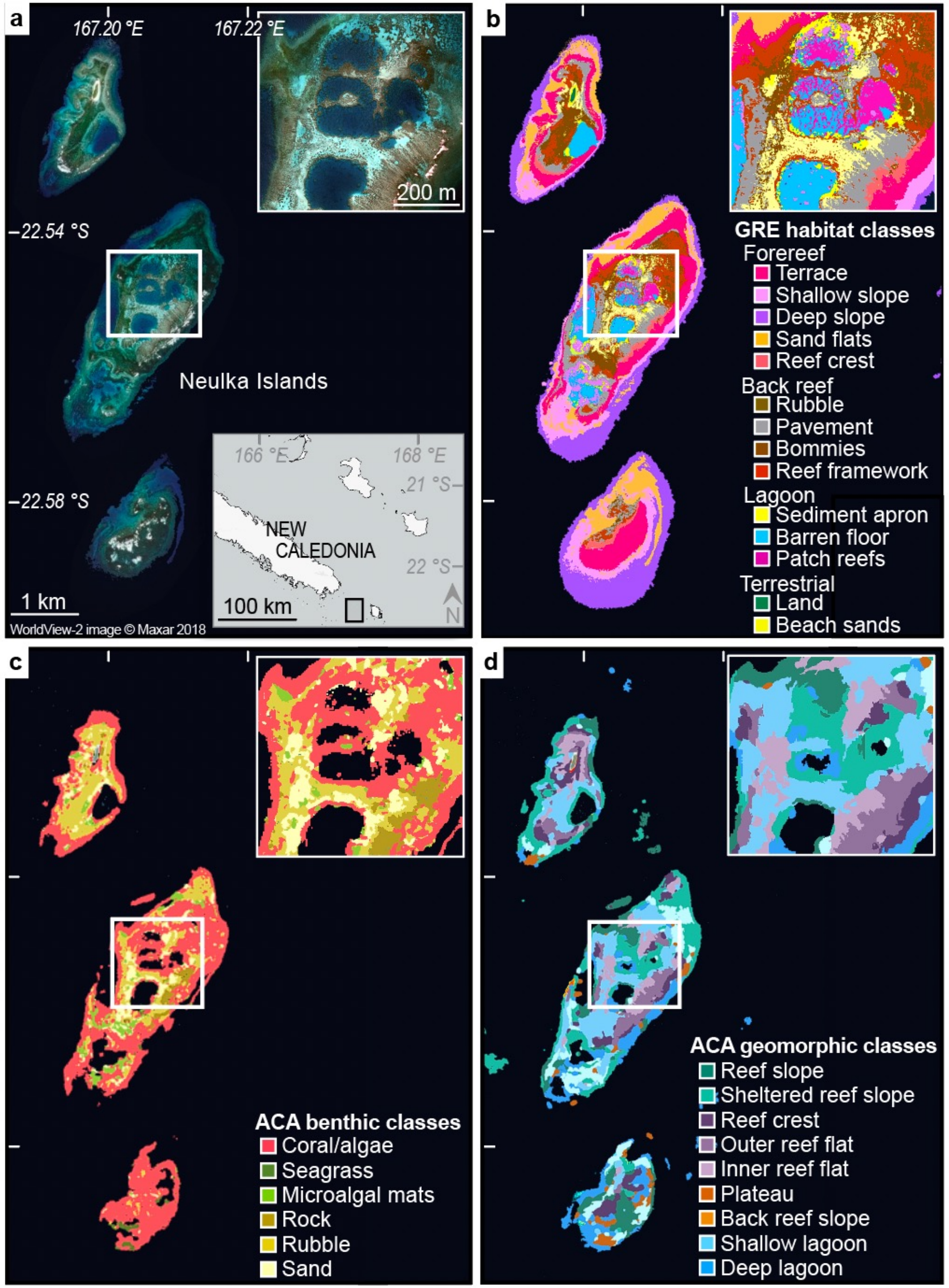
- Derived from remote sensing imagery
- Refers to variation in spectral intensity or reflectance, across sets of pixels
- **Rao’s Q**
- Terrestrial studies posit that spectral variation is a surrogate for ecological niches, in turn predictive of biodiversity

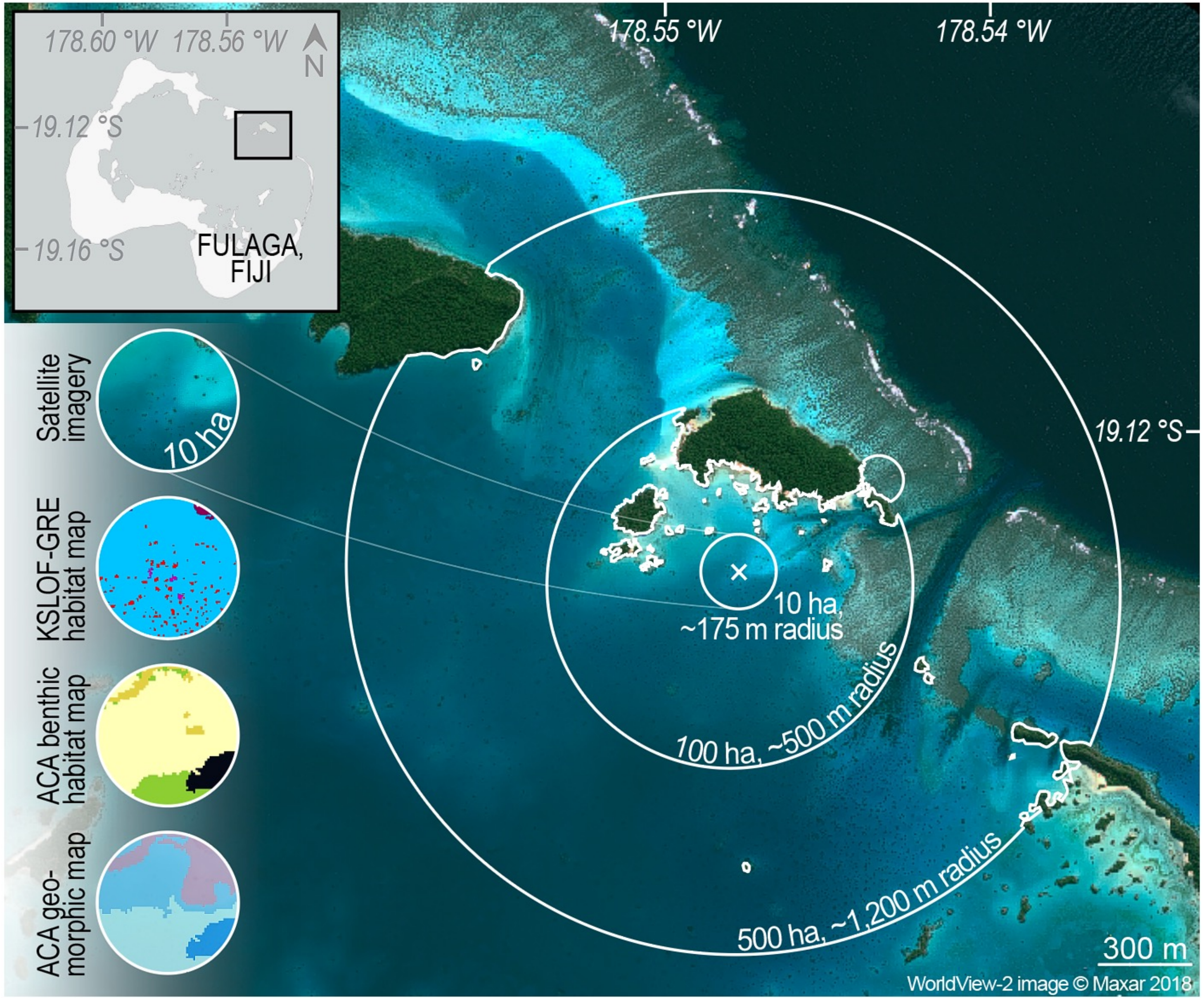
KEY TERMS



- A measure of spatial variation in benthic character
- Synonymous with 'habitat heterogeneity'
- **Shannon's** diversity found to work better than Beta

GLOBAL BENTHIC HABITAT MAPS





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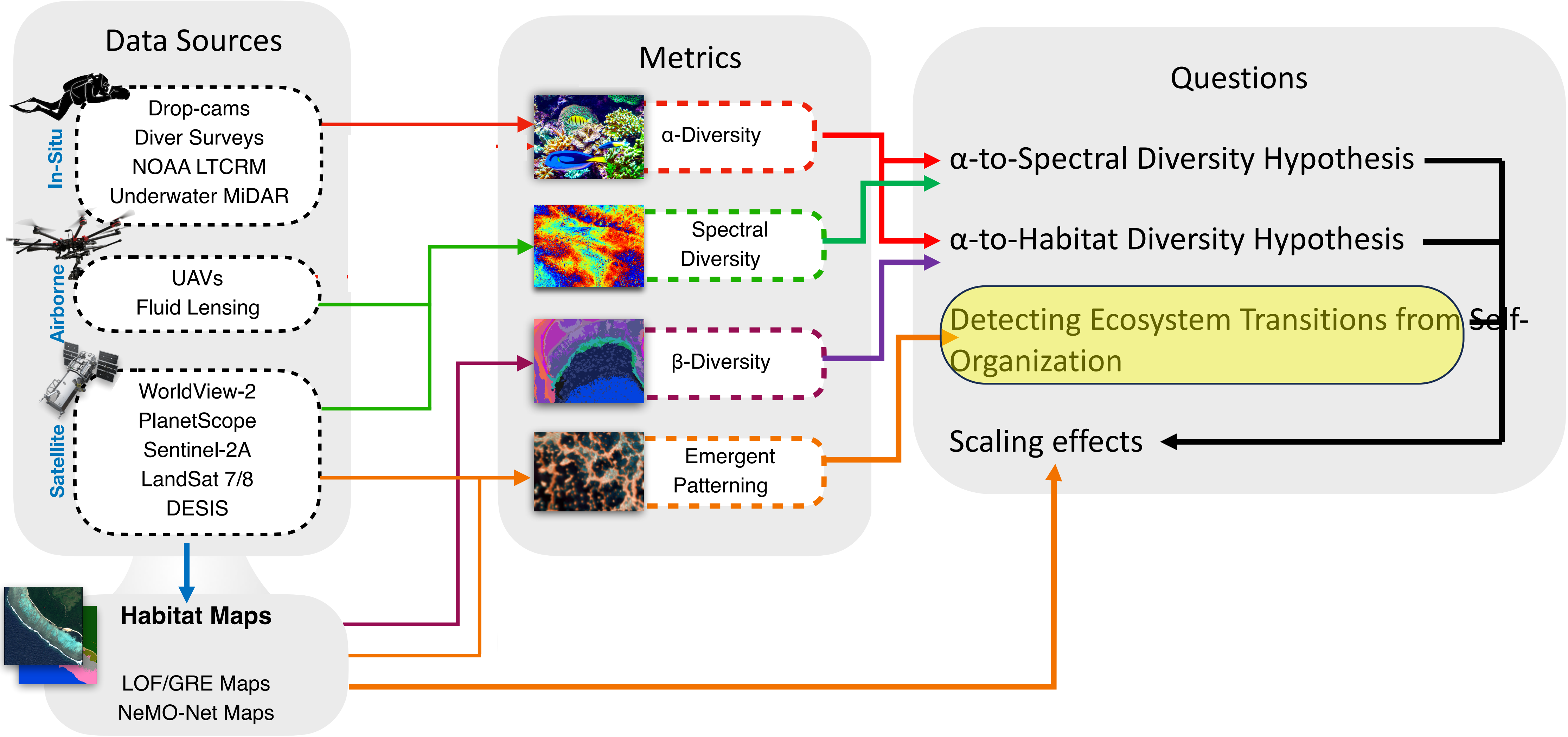

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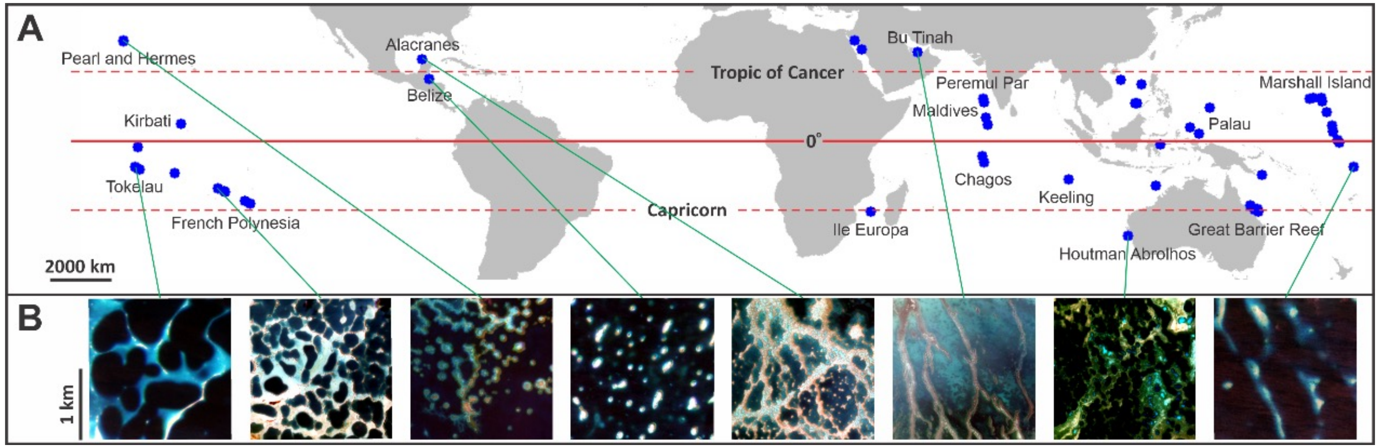
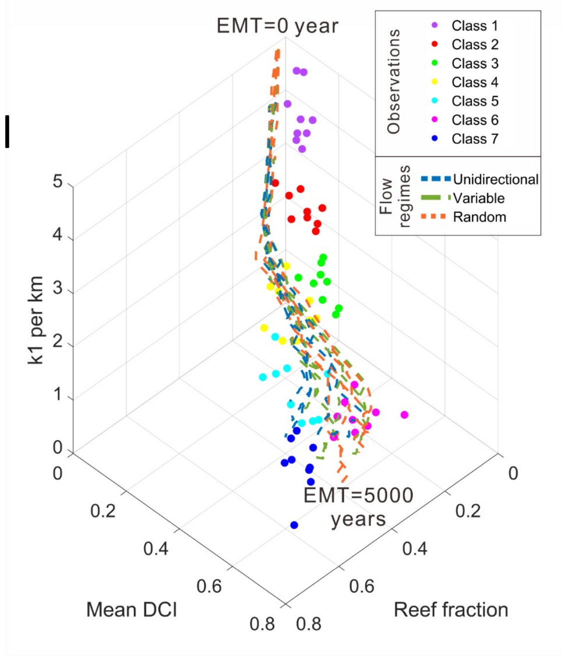
DETECTING ECOSYSTEM TRANSITIONS FROM SELF-ORGANIZATION

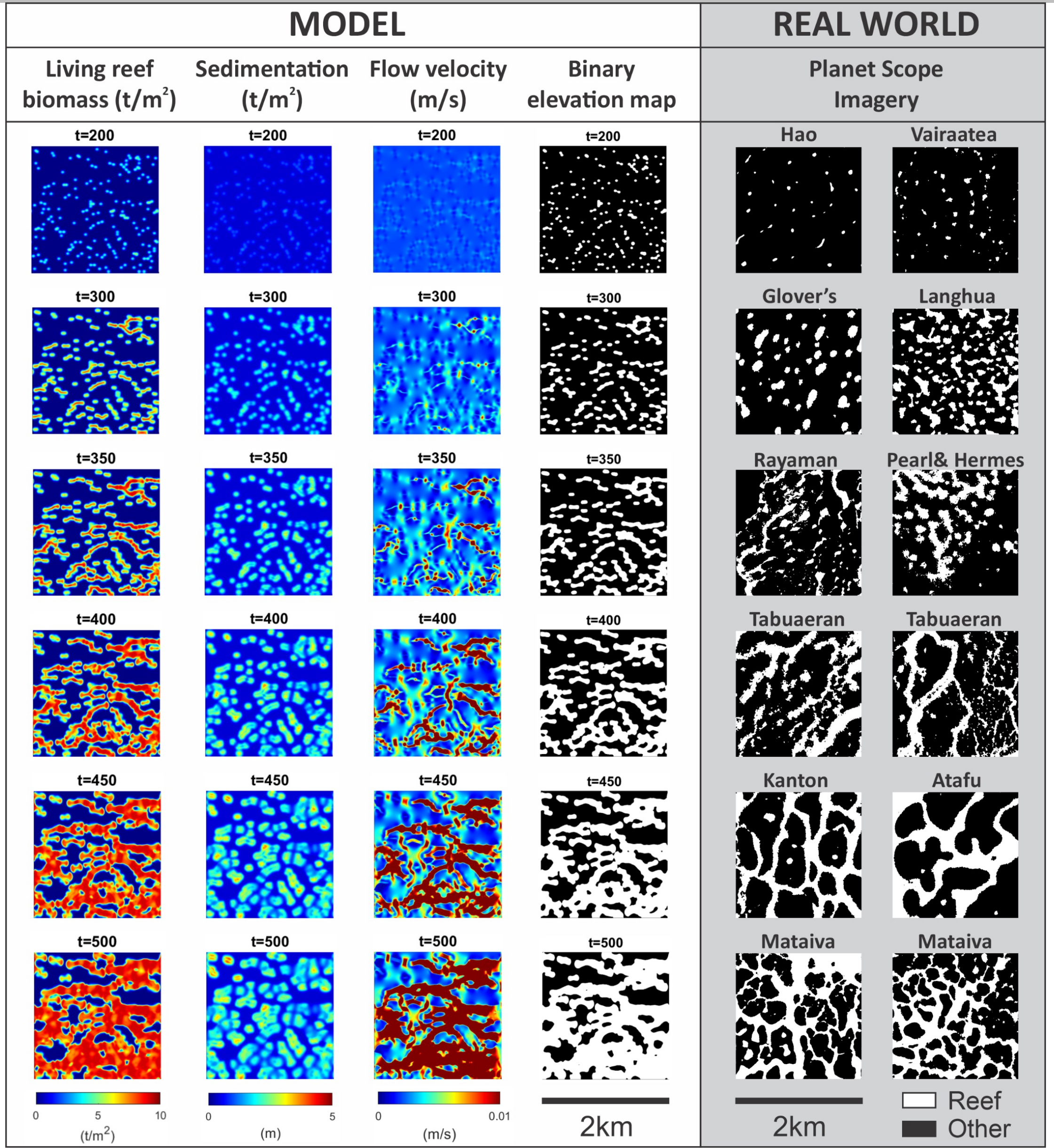
Xi, et al, Emergent Patterning in Coral Reefs Through Spatial Self-Organization. *in prep.*

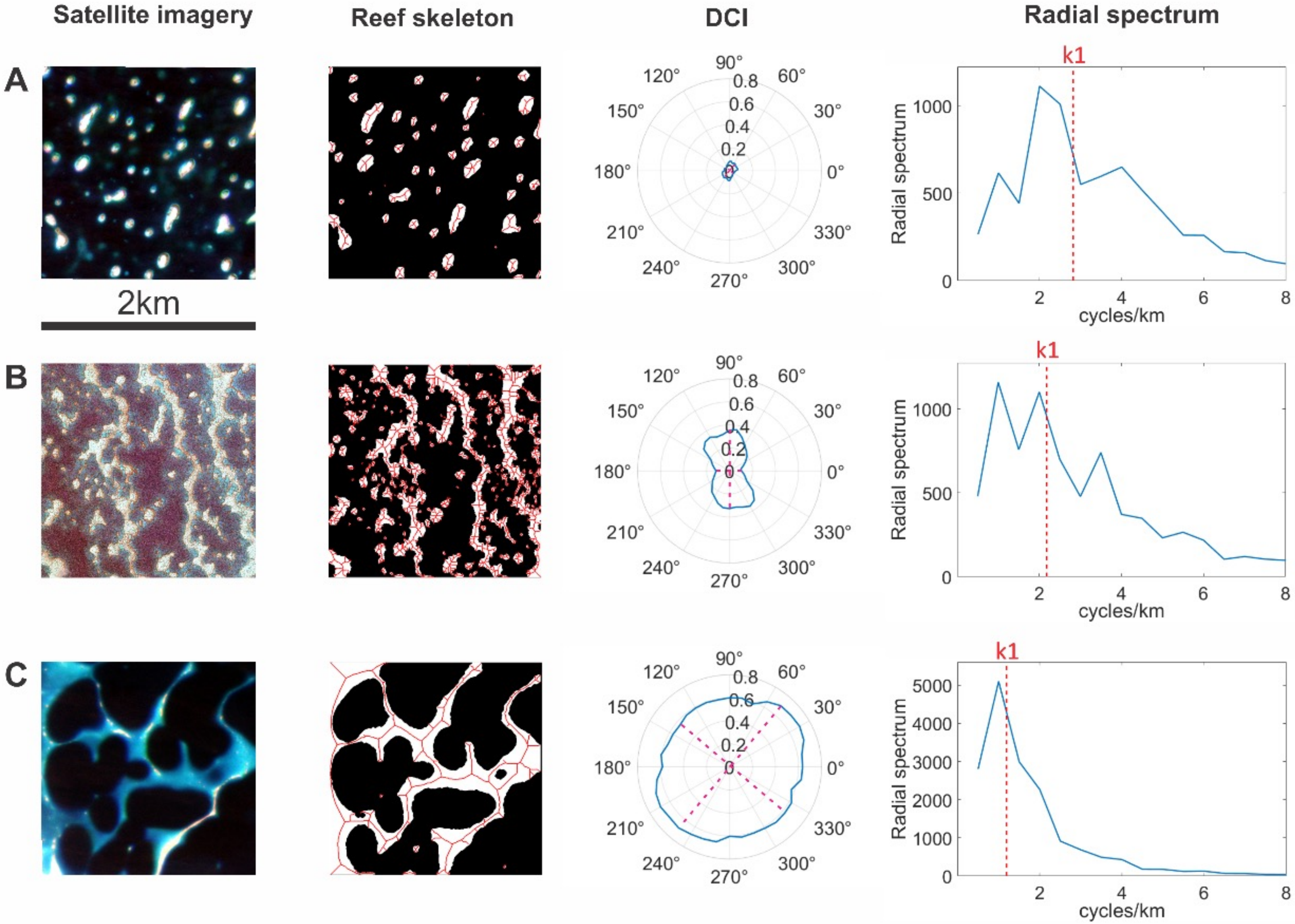
Dr. Haiwei Xi



- Reticulated reefs clustered by spatial patterns defines the diversity of coral reef morphogenesis
- Reaction-diffusion model simulates the mapped morphologies and their trajectories through time
- Reef evolution directly observable from space

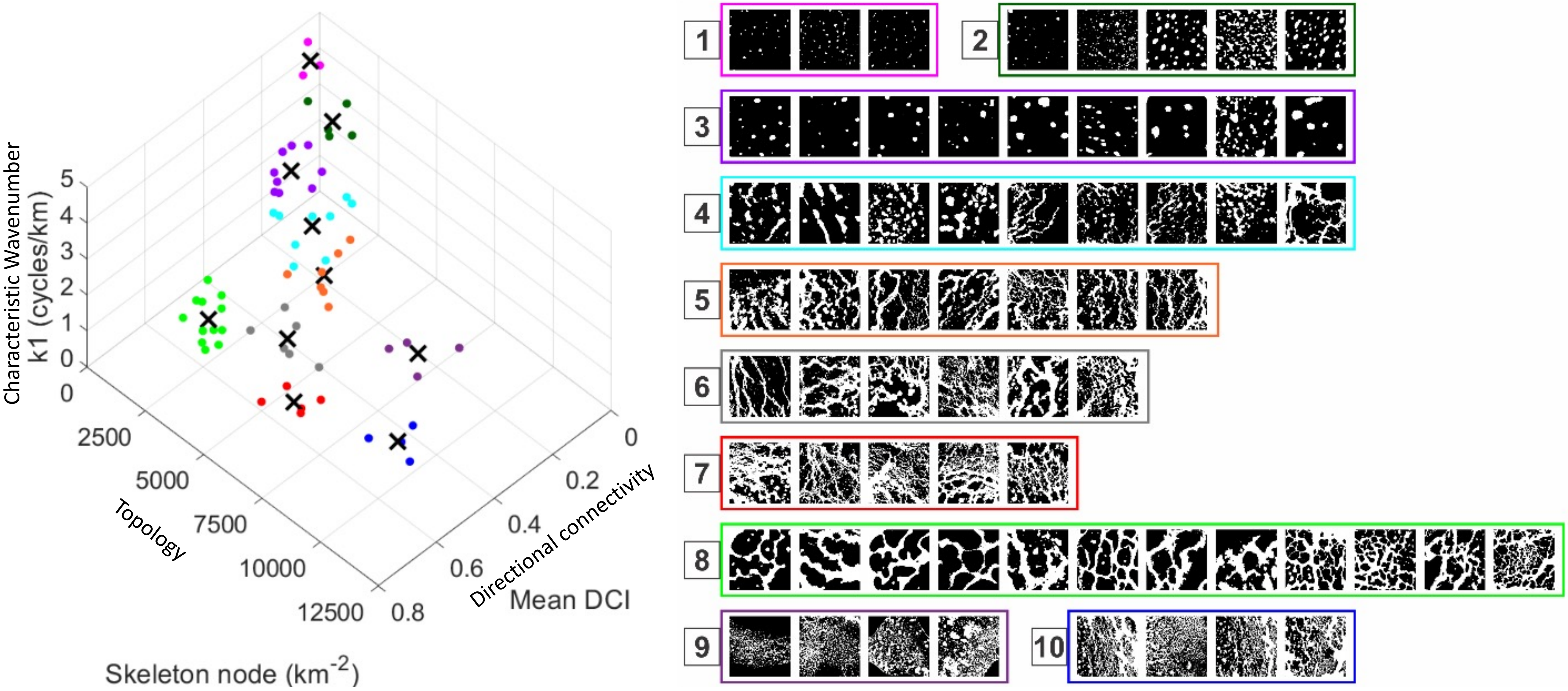






Site	Reef Fraction	Mean DCI	PAR	k1 (cycles/km)
Glover's Reef-Belize-Caribbean	0.0998	0.0605	2.0359	2.8184
Alacranes-1-Gulf of Mexico	0.2938	0.2368	3.1033	2.1806
Atafu-Tokelau-S.Pacific	0.2894	0.6294	1.1644	0.5822

MORPHOTYPES OF EMERGENT REEF PATTERNING



REACTION-DIFFUSION MODEL FOR REEF PATTERN FORMATION