The Coastal Protection Benefits & Cost Effectiveness of Coral Reefs

Michael W. Beck

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UNIVERSITY OF CALIFORNIA
SANTA CRUZ

USGS
science for a changing world

Guidelines for Valuing Coastal Protection Services from Mangroves and Reefs

M W. Beck & G-M Lange (eds)

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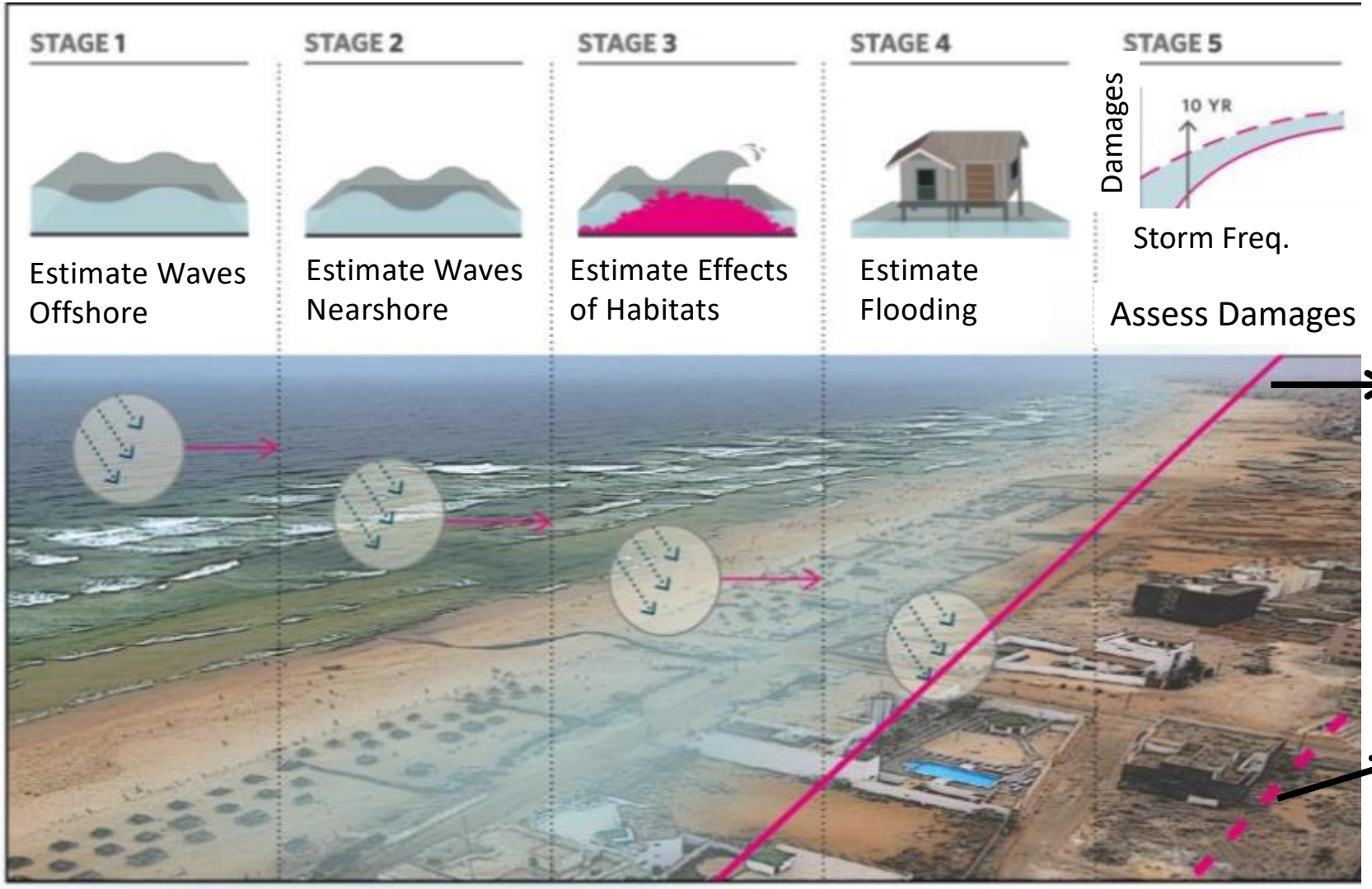
Recommended Approach: Expected Damage Function



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The Nature Conservancy

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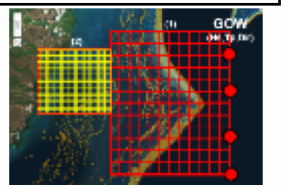
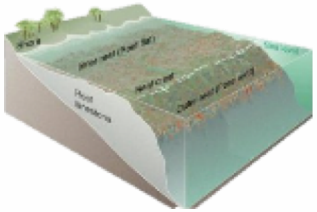
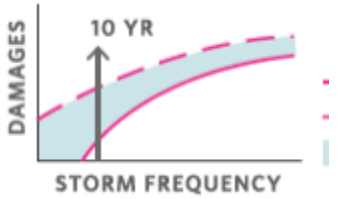
OFFSHORE DYNAMICS → NEARSHORE DYNAMICS → HABITAT → IMPACTS → CONSEQUENCES







Wind
Hindcast (1979-2016)

Mean Water Level
Observations (1950-2010)

Astronomical Tide
Hindcast (Harmonic)
Forecast (Harmonic)

Storm Surge (Wind, TC)
Hindcast (vortex formulation 1992-2010)
Hindcast (statistical model 1971-1992)

Waves (Wind, TC)
Hindcast (1979-2016)

Tropical Cyclones
Historical (1951-2014)-IBTrACS Synthetic (5000 years)

Sea Level Rise
Projections (2081-2100)

Wind
MWL
AT
Storm Surge
Waves
Set up
Orbital velocity
Waves
Storm Surge
SLR

Selection
1. Kmeans
2. SOM
3. MaxDiss

Downscaling
1. Dynamic
2. Hybrid

Propagation
1. SWAN
2. Snell

Approach
1. Worst case
2. Historical
3. Probabilistic

Vortex Model
1. SLP
2. WIND

Generation
1. DELFT 3D (2DH)
2. DELFT 3D (2DV)
3. 1D analytical

Downscaling
1. Dynamic

With vegetation
Without vegetation

WAVES
1. Coupled
2. Uncoupled
STORM SURGE
TOTAL WATER LEVEL

Propagation
1. SWAN (2DH/2DV)
2. IH2VOF (2DV)
3. 1D analytical

Propagation
1. DELFT3D (2DH or 2DV)
2. 1D analytical

WAVES
TOTAL WATER LEVEL
Probabilistic Future scenarios
RIVER & RAIN

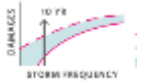
Roughness
Vegetation model

Modeling EROSION
1. Analytical
2. X-Beach
3. Others

Modeling FLOODING
1. GIS
2. DELFT 3D
3. RFSM-EDA

EROSION
Historical Future scenarios
FLOODING
Historical Future scenarios

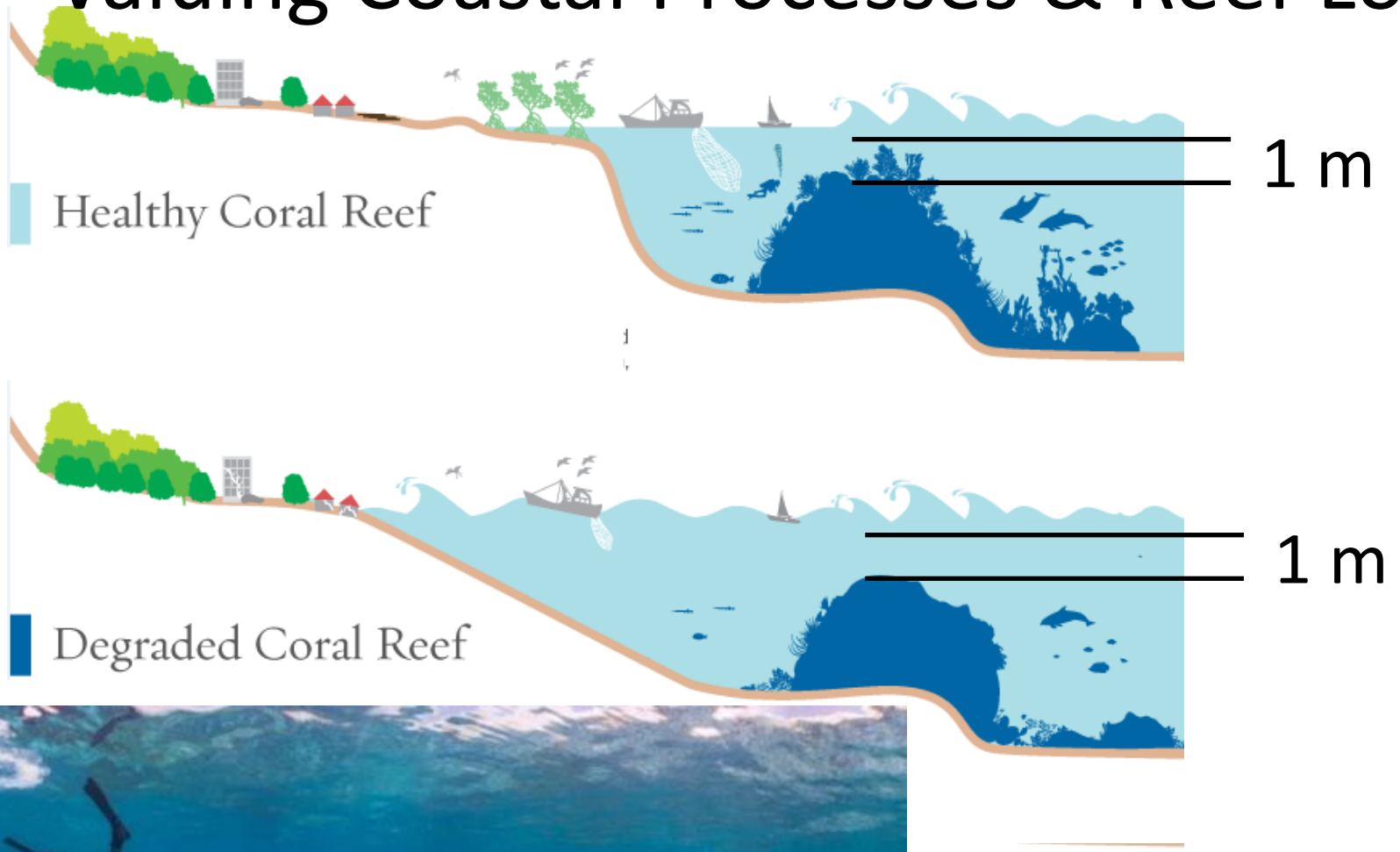
CONSEQUENCES
Flow *Assets*
Exposure
Land use
Poverty index
Wealth
Population
GDP
Built Capital
Damage and loss Functions

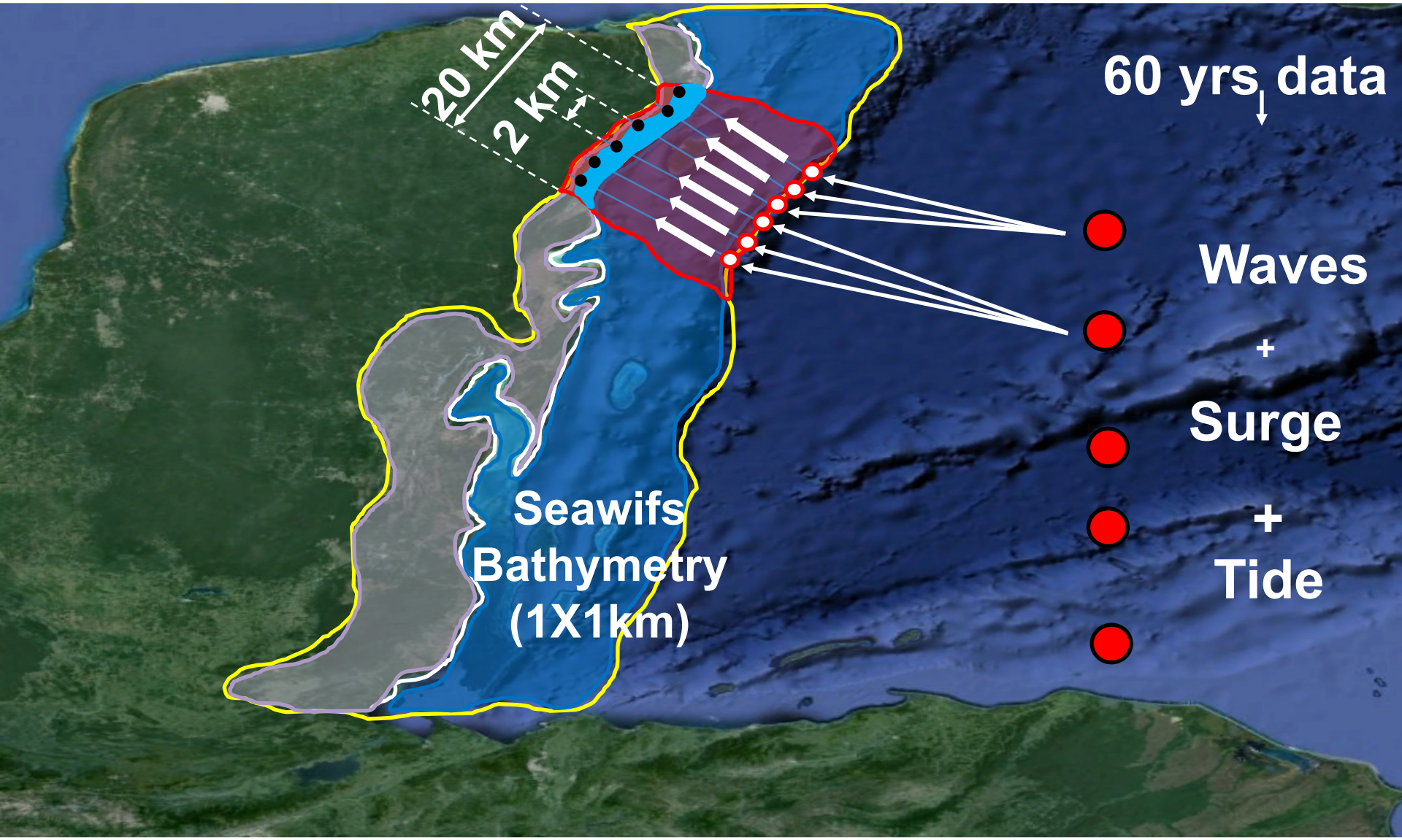


Annual Expected Benefits

UNCERTAINTIES

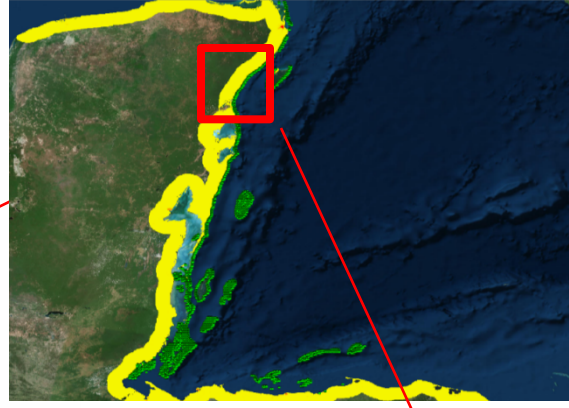
Valuing Coastal Processes & Reef Loss



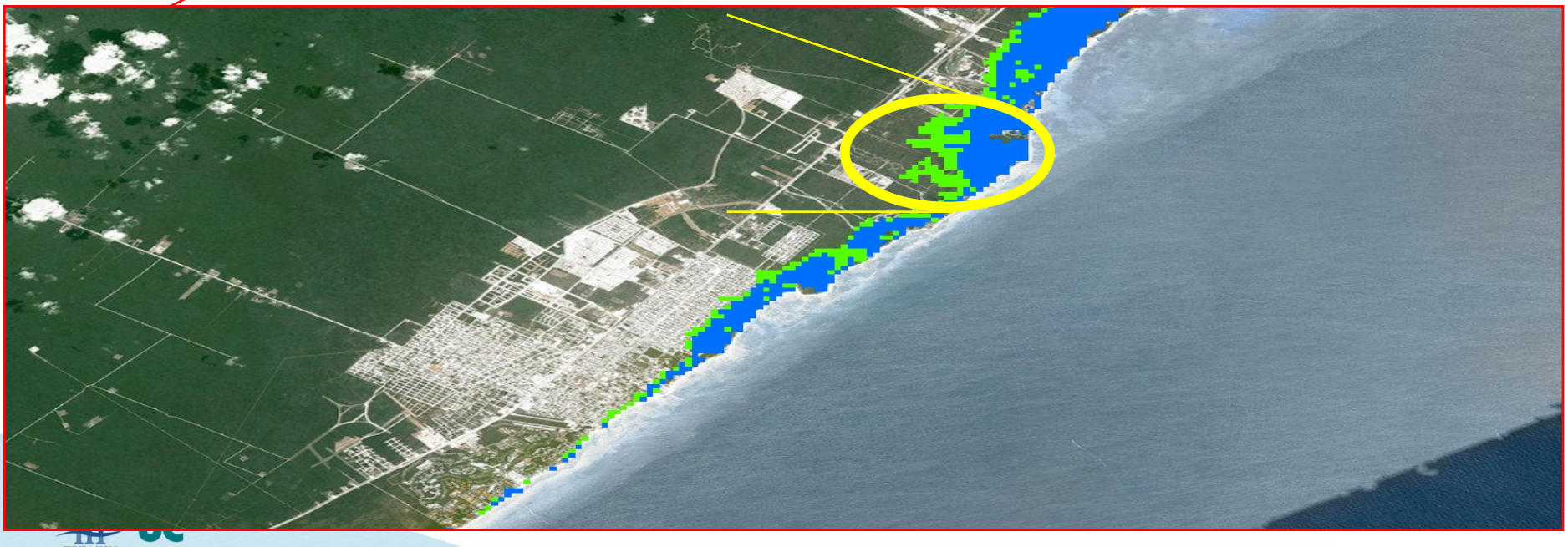

20 km
2 km
60 yrs data
Waves
+
Surge
+
Tide
Seawifs
Bathymetry
(1X1km)

Flooding (25 - Year Event)

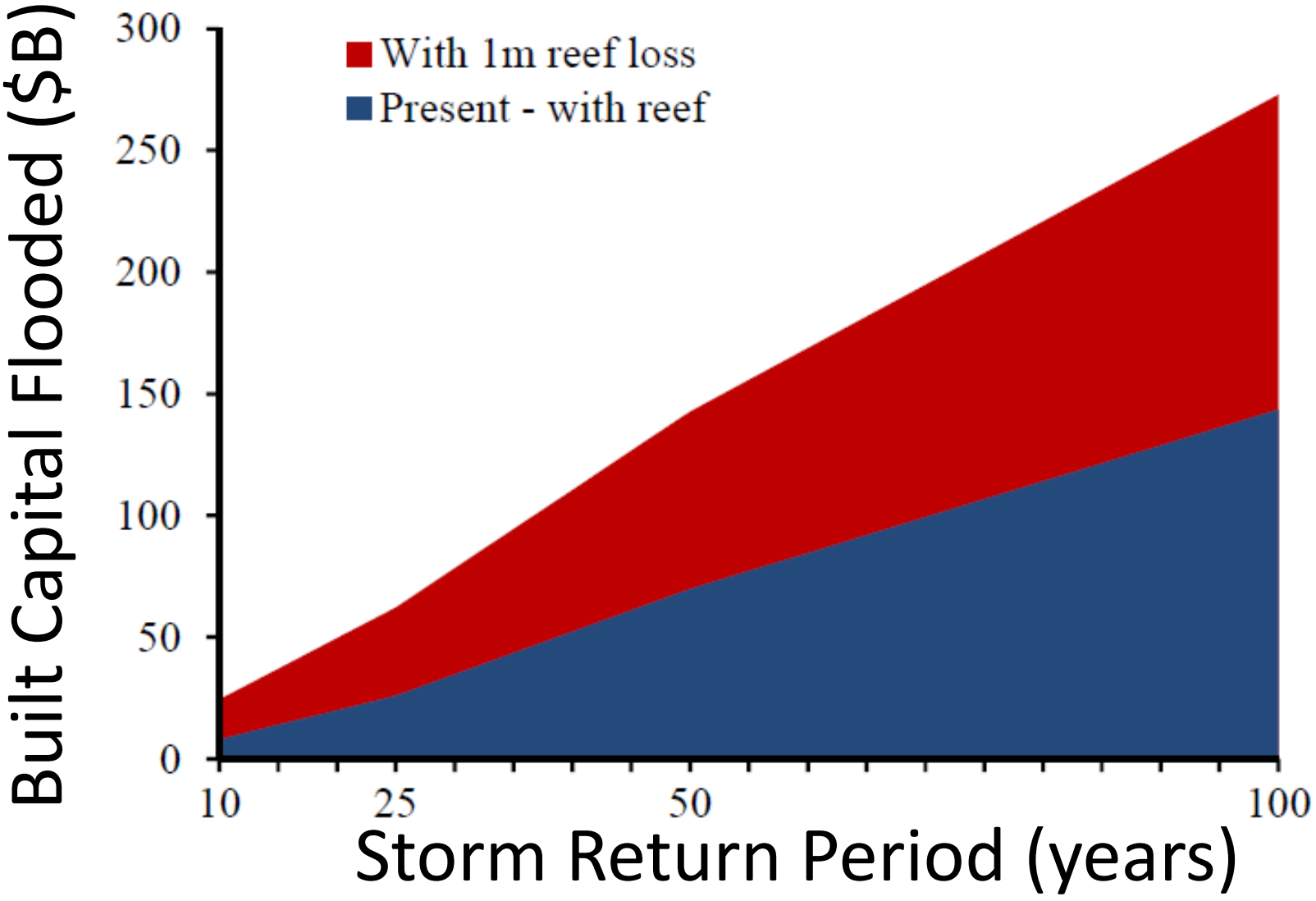
- Current Flooding
- Flooding With 1m Reef Loss



Playa del Carmen



Global Flood Risk and Saving from Coral Reefs



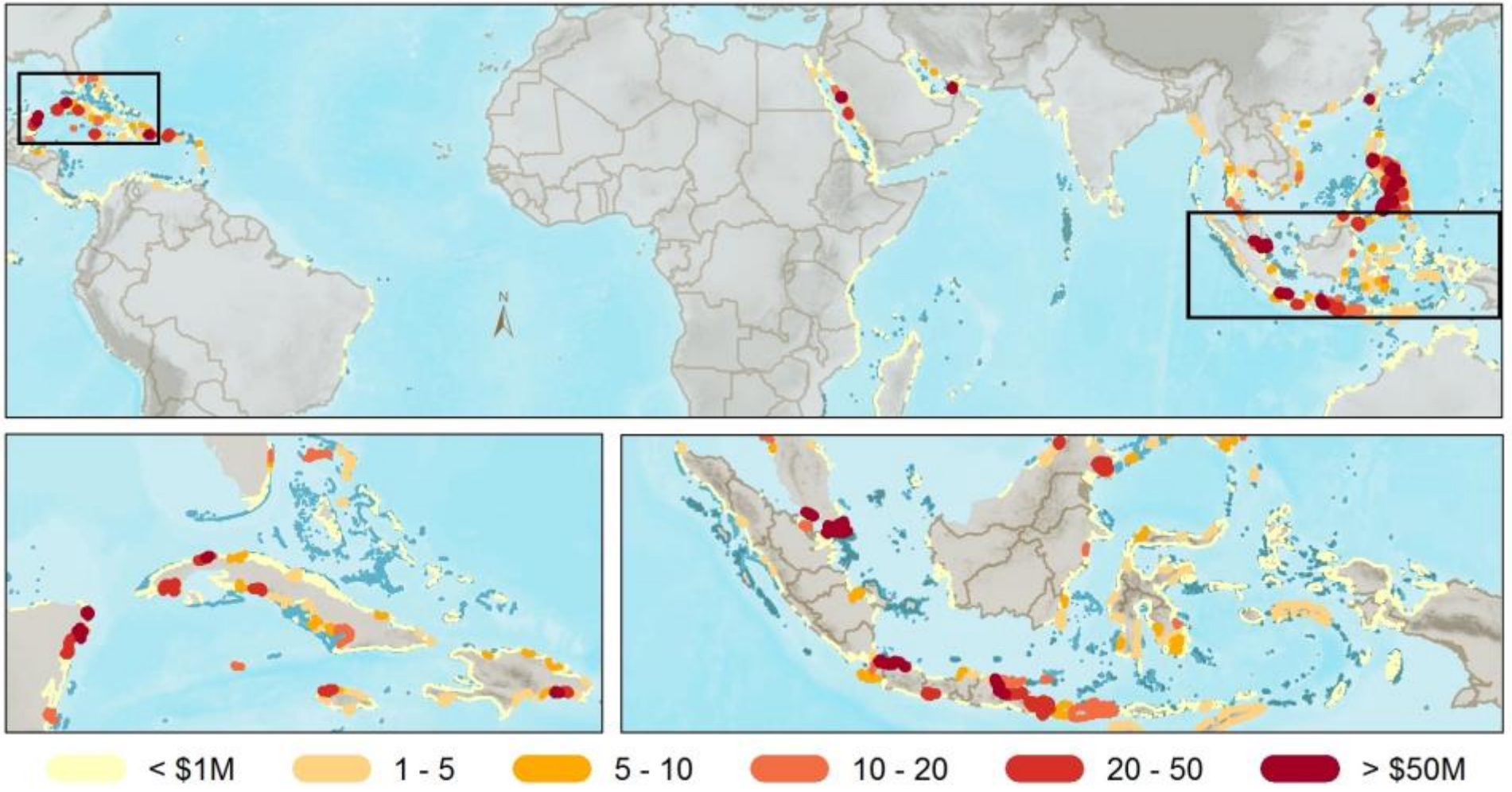
Beck et al. 2018. *Nature Communications*.

Annual Expected Benefits of Reefs for Flood Protection

	Annual Averted Damages ($Millions)		Annual Averted Damages/GDP	
1	Indonesia	639	Cayman Islands	0.98
2	Philippines	590	Belize	0.37
3	Malaysia	452	Grenada	0.30
4	Mexico	452	Cuba	0.25
5	Cuba	401	Bahamas	0.16
6	Saudi Arabia	138	Jamaica	0.14
7	Dominican Republic	96	Philippines	0.13
8	United States	94	Antigua and Barbuda	0.13
9	Taiwan	61	Dominican Republic	0.11
10	Jamaica	46	Malaysia	0.09
11	Vietnam	42	Seychelles	0.06
12	Myanmar	33	Turks and Caicos	0.06
13	Thailand	32	Guadeloupe	0.05
14	Bahamas	14	Indonesia	0.04
15	Belize	9	Solomon Islands	0.04

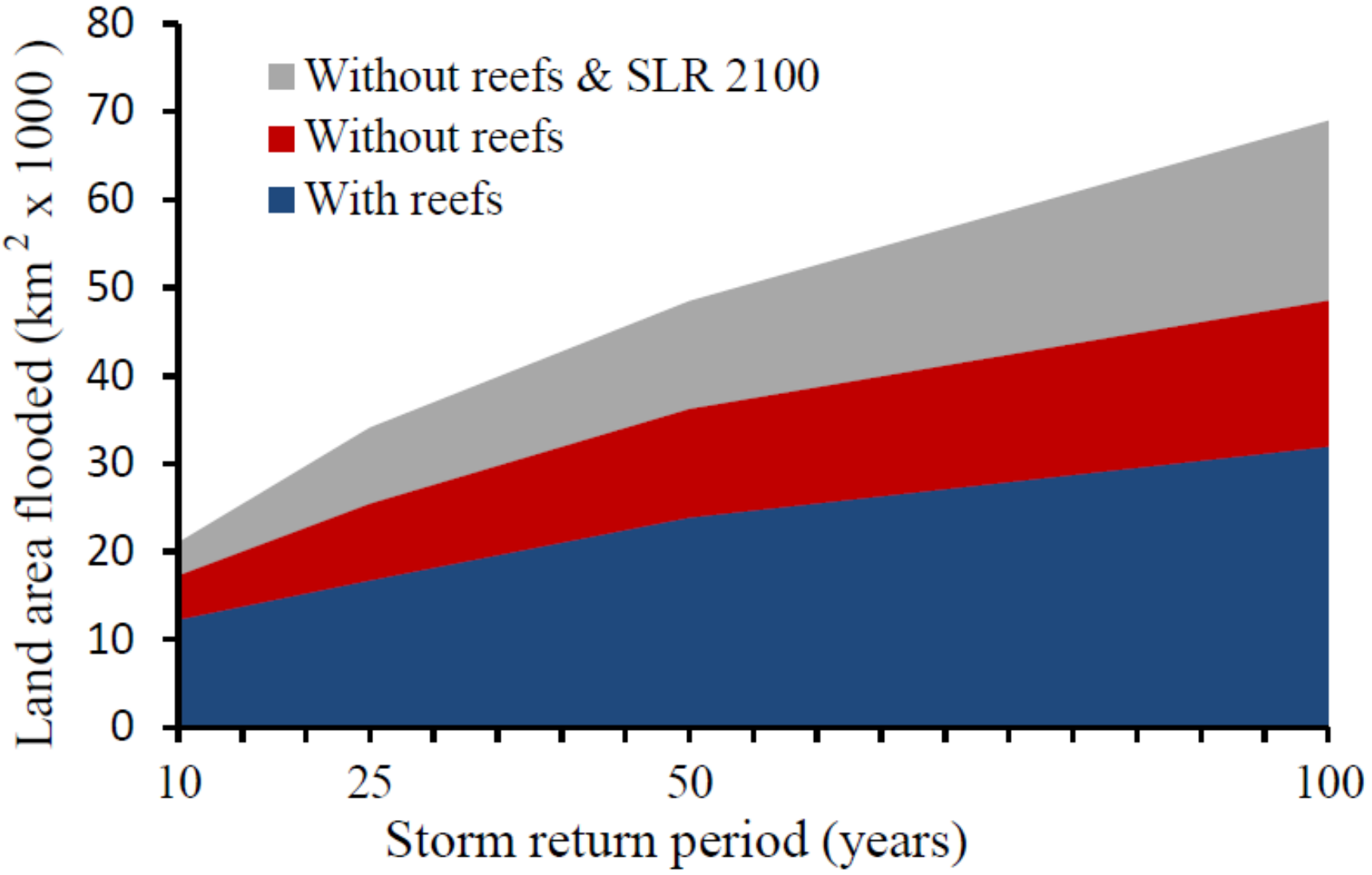
Beck et al. 2018. *Nature Communications*.

Annual Expected Benefits from Reefs:
Avoided Flood Damage in $M/20 km coastline



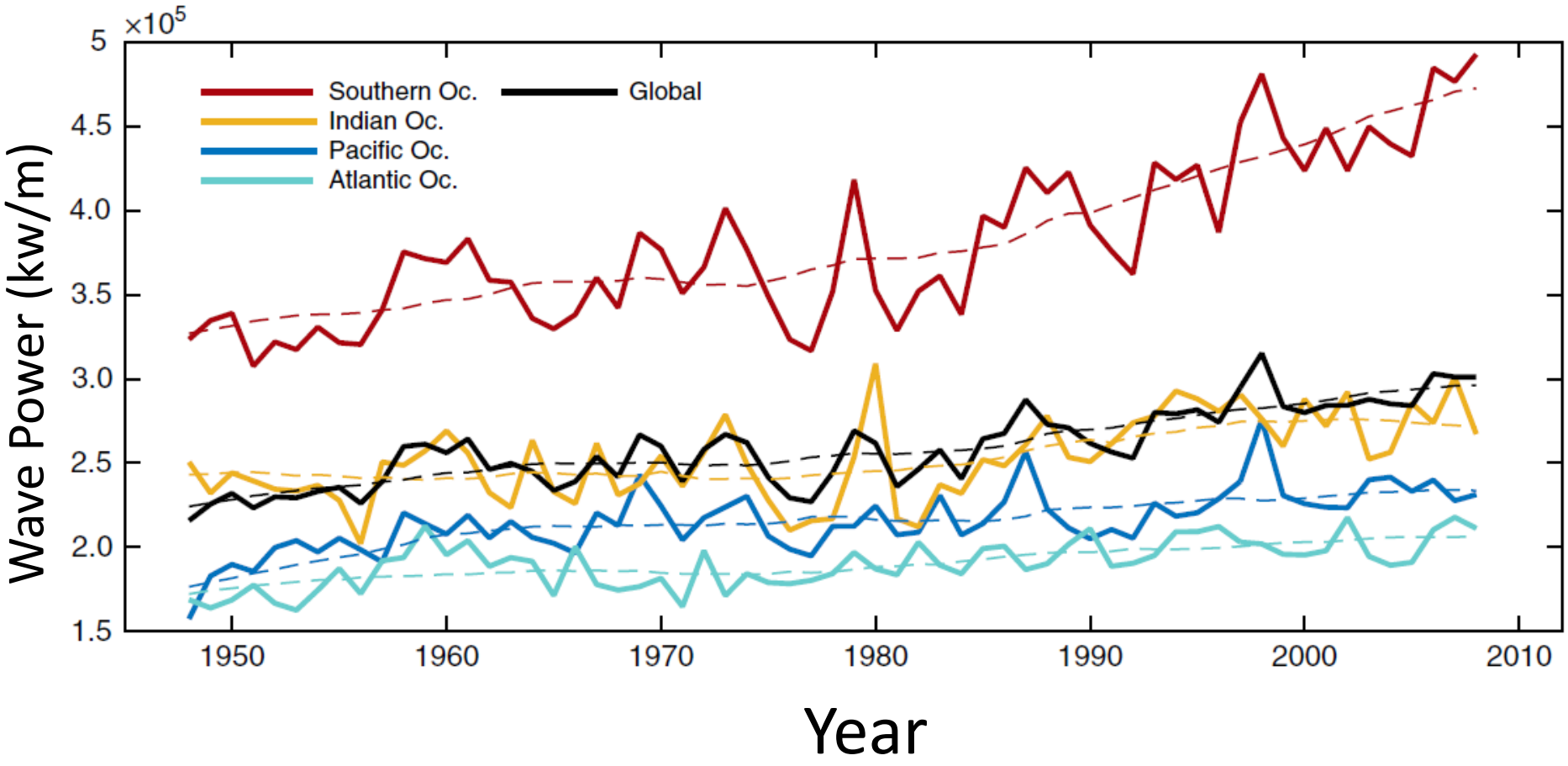
Beck et al. 2018. *Nature Communications*.

Risks Increase with Sea Level Rise



Beck et al. 2018. *Nature Communications*.

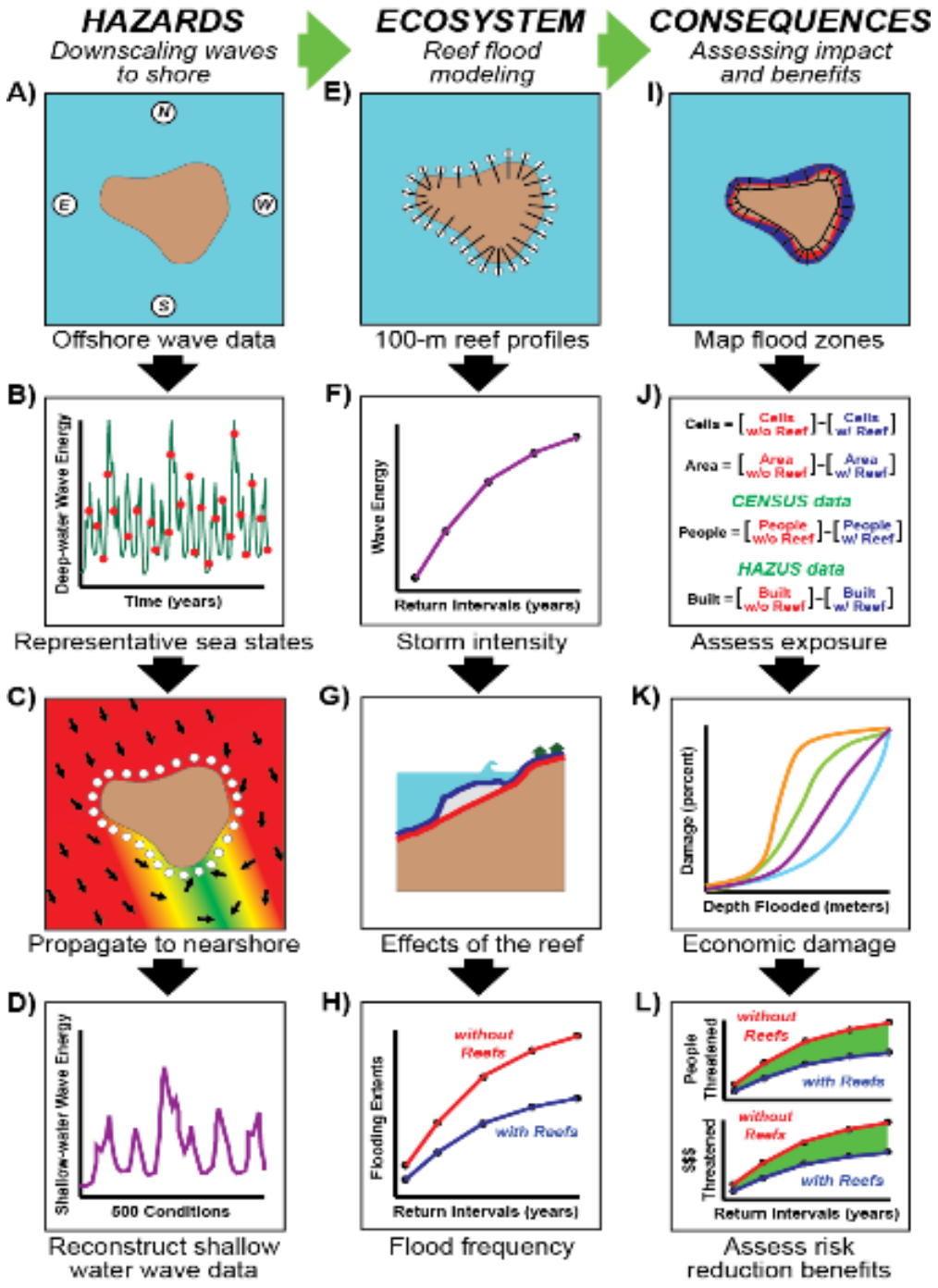
Global Wave Power Increasing



Reguero et al. (2019). Nature Communcations

Our Approach for Assessing Coastal Protection Value:

….with a few more orders of resolution and precision



Storlazzi, Reguero, Beck et al. (2019)

1-in-100yr


Legend
RP100yr_wrf
RP100yr_worf
Transects_KeyWest_070617
Miles
0 0.1 0.2 0.4 0.6 0.8
Floodplain 1-in-100yr

USA Hi-Res Reef Benefits:
$ of Averted Damages by Storm Return Period

Location	Sublocation	Storm Return Interval			
		10-year	50-year	100-year	500-year
American Samoa	Tutuila	$45,062,194	$50,235,092	$55,296,346	$45,151,430
American Samoa	Ofu-Olosega	$133,904	$190,098	$256,618	$343,816
American Samoa	Tau	$1,332,694	$1,705,537	$1,913,229	$1,714,184
CNMI	Saipan	$8,440,917	$13,510,503	$14,037,252	$33,267,181
CNMI	Tinian	$1,135,367	$1,901,951	$2,095,199	$2,870,504
Guam	Guam	$12,523,985	$10,845,848	$14,307,264	$21,479,597
Florida	Mainland	$223,690,621	$456,121,628	$635,436,306	$3,336,517,208
Florida	Keys	$51,302,037	$114,538,932	$152,395,028	$115,357,921
Hawaii	Hawaii	$42,875,759	$50,655,894	$52,324,393	$59,566,784
Hawaii	Maui	$202,802,131	$234,104,090	$225,630,115	$194,479,455
Hawaii	Lanai	$97,224	$104,730	$105,981	$106,313
Hawaii	Molokai	$72,094	$92,642	$128,534	$354,783
Hawaii	Kahoolawe	$0	$0	$0	$0
Hawaii	Oahu	$368,841,786	$353,116,245	$340,006,994	$314,872,587
Hawaii	Kauai	$10,080,787	$14,529,798	$18,675,364	$23,309,226
Hawaii	Niihau	$0	$0	$0	$0
Puerto Rico	Puerto Rico	$107,237,273	$195,128,049	$277,282,495	$514,413,849
Puerto Rico	Culebra	$232,754	$498,925	$693,718	$1,439,420
Puerto Rico	Vieques	$175,922	$126,877	$148,189	$207,562
USVI	St Croix	$30,521,477	$50,437,724	$63,035,367	$57,335,990
USVI	St John	$852,151	$1,489,952	$3,965,600	$1,880,331
USVI	St Thomas	$5,910,764	$7,253,756	$7,139,596	$8,204,784

USGS
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Rigorously Valuing the Role of Guam and the CNMI's Coral Reefs in Coastal Hazard Risk Reduction

Estimated Annual Benefits

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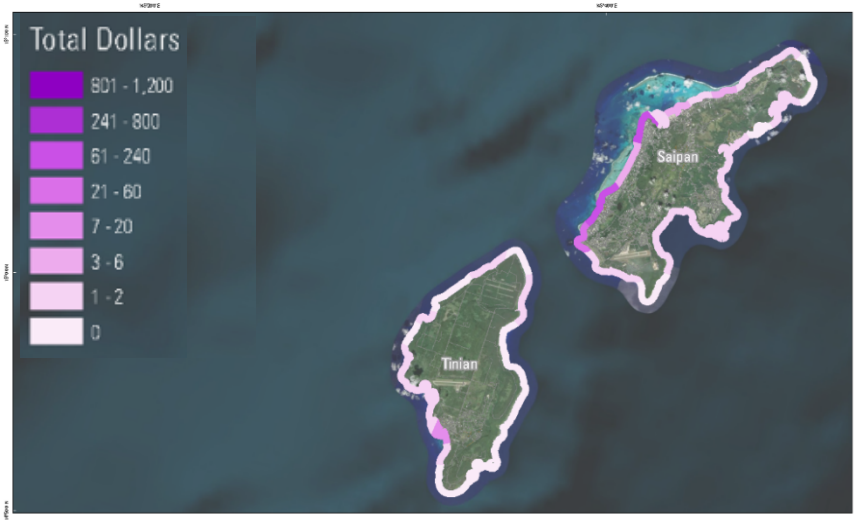


The USGS open file report can be found at https://doi.org/10.3133/ofr20191027

0 10 20 40 Kilometers

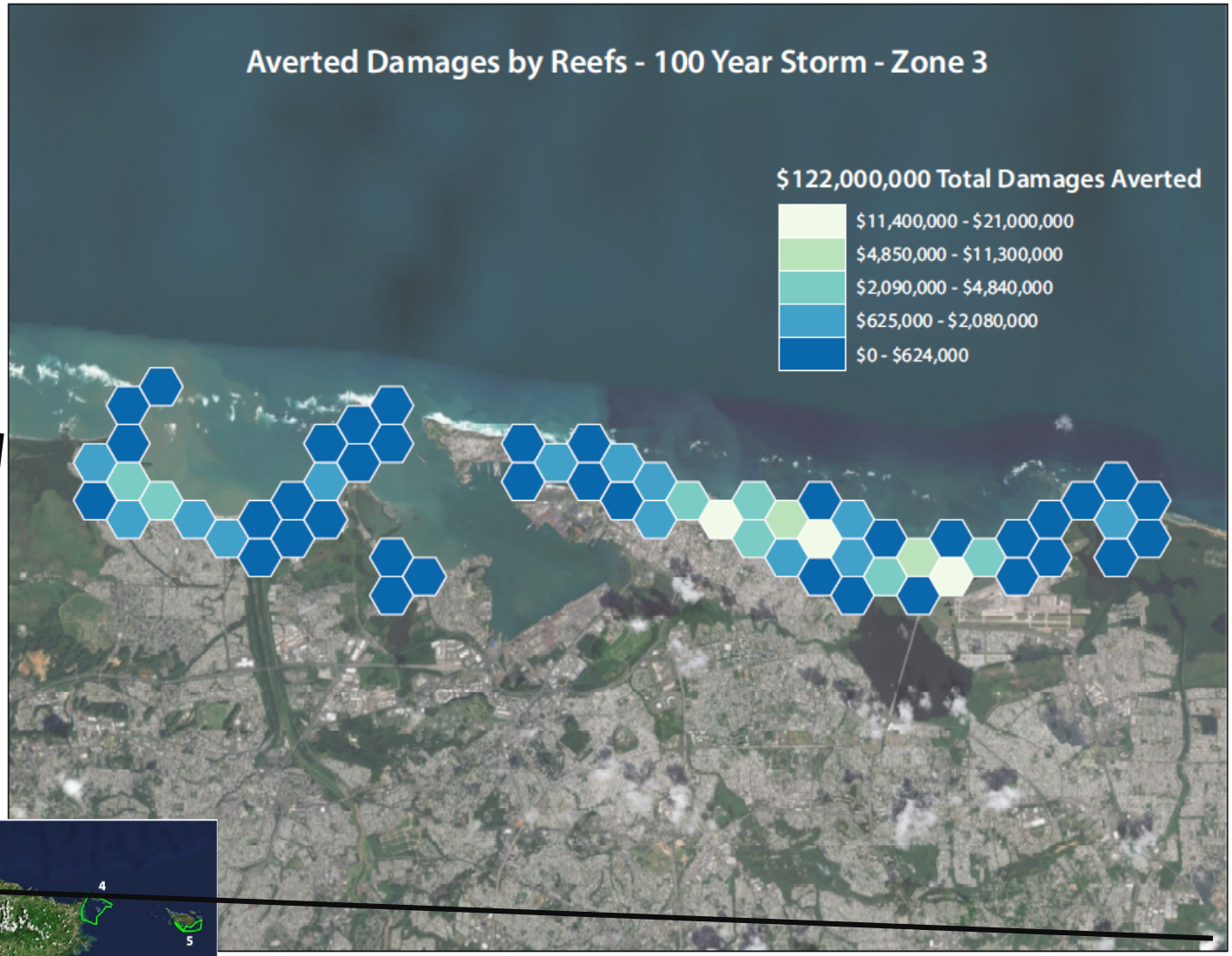
The digital data used to produce these maps can be found at https://doi.org/10.5066/P9KMH2VX

Storlazzi, Reguero, Beck et al. (2019)

Benefits of Coral Reefs for Risk Reduction

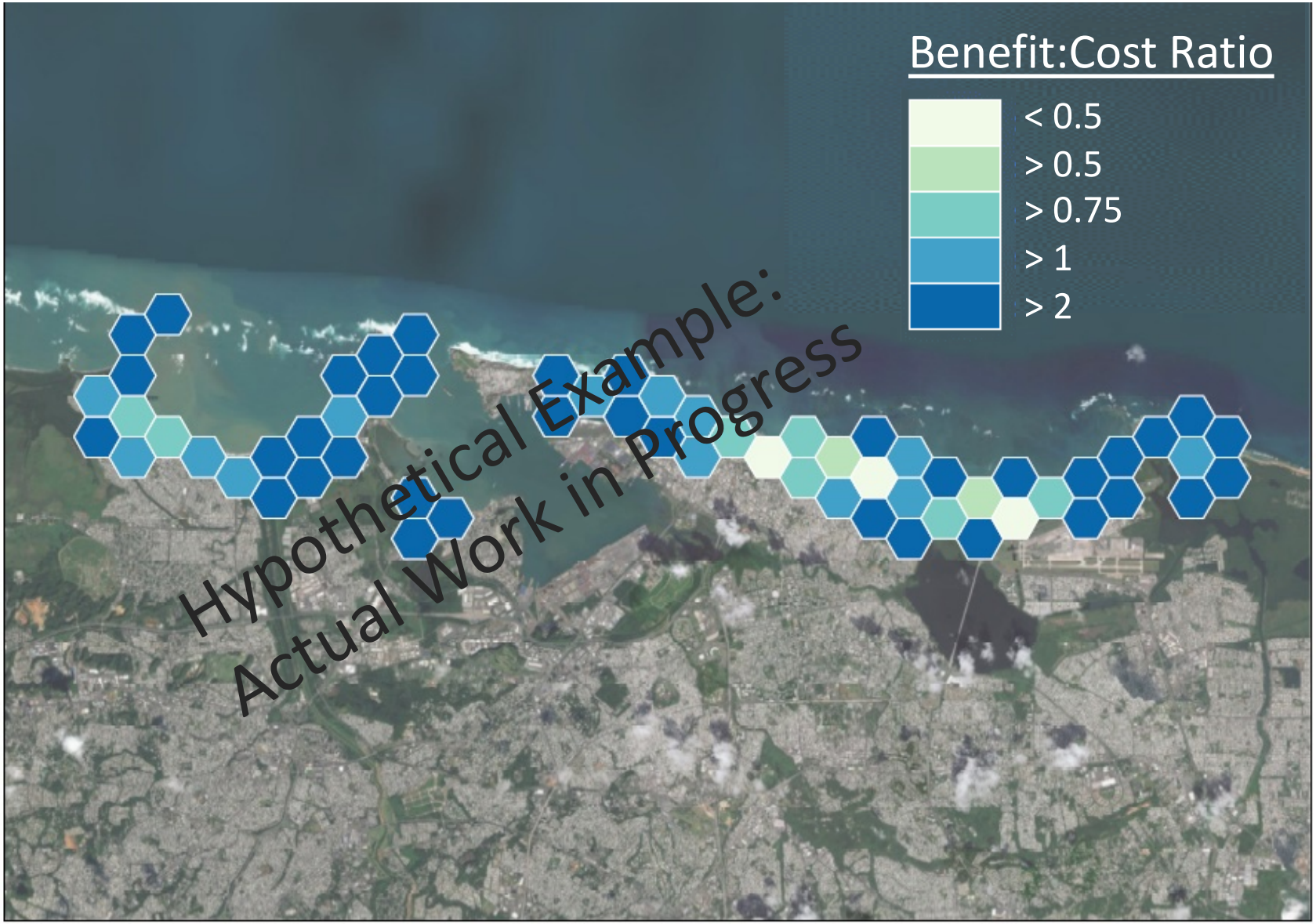
Informing FEMA & Puerto Rico Recovery Efforts

$100 Billion in
Recovery Funding
For 2017 hurricanes

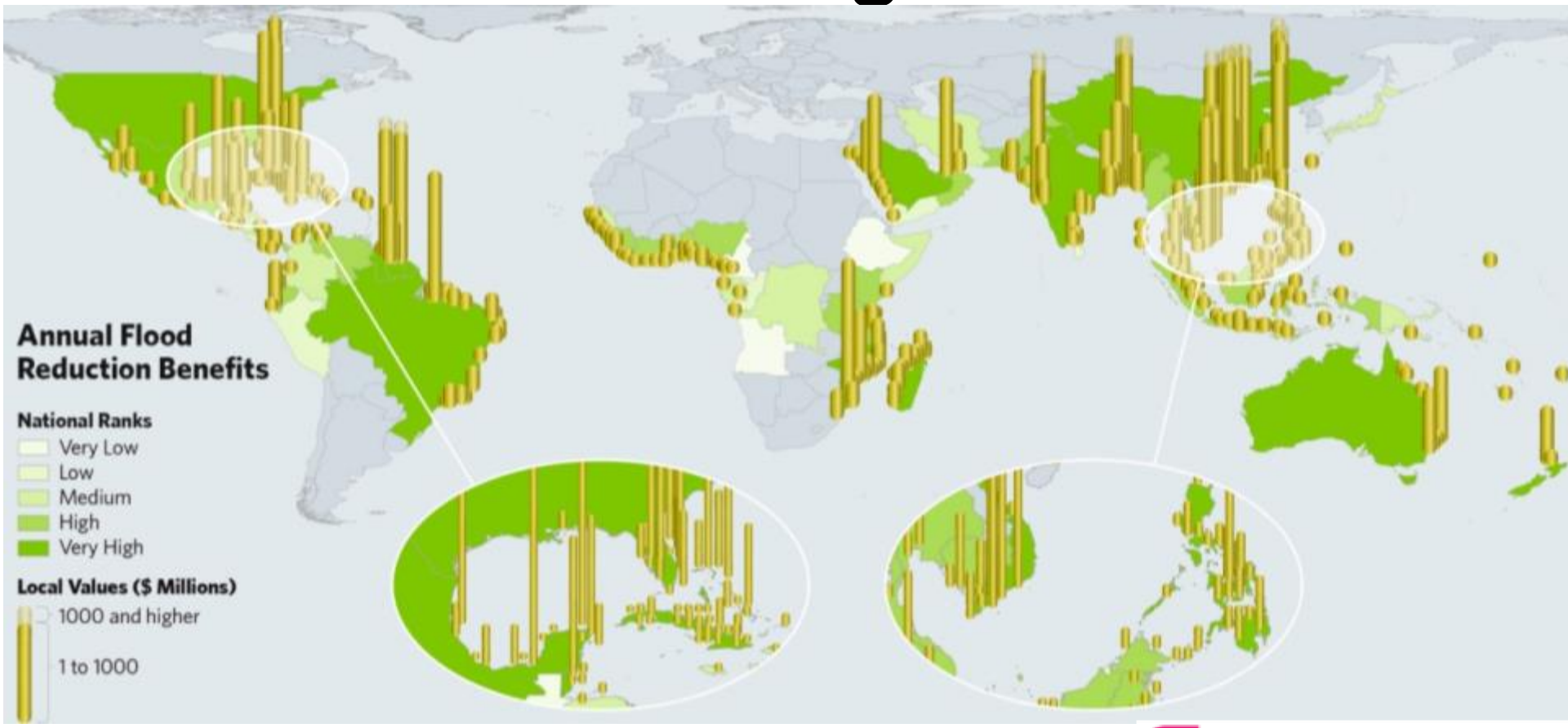


Benefit:Cost (B:C) for Reef Restoration

Using FEMA's BC Analysis Tool



Annual Flood Reduction Benefits from Mangroves

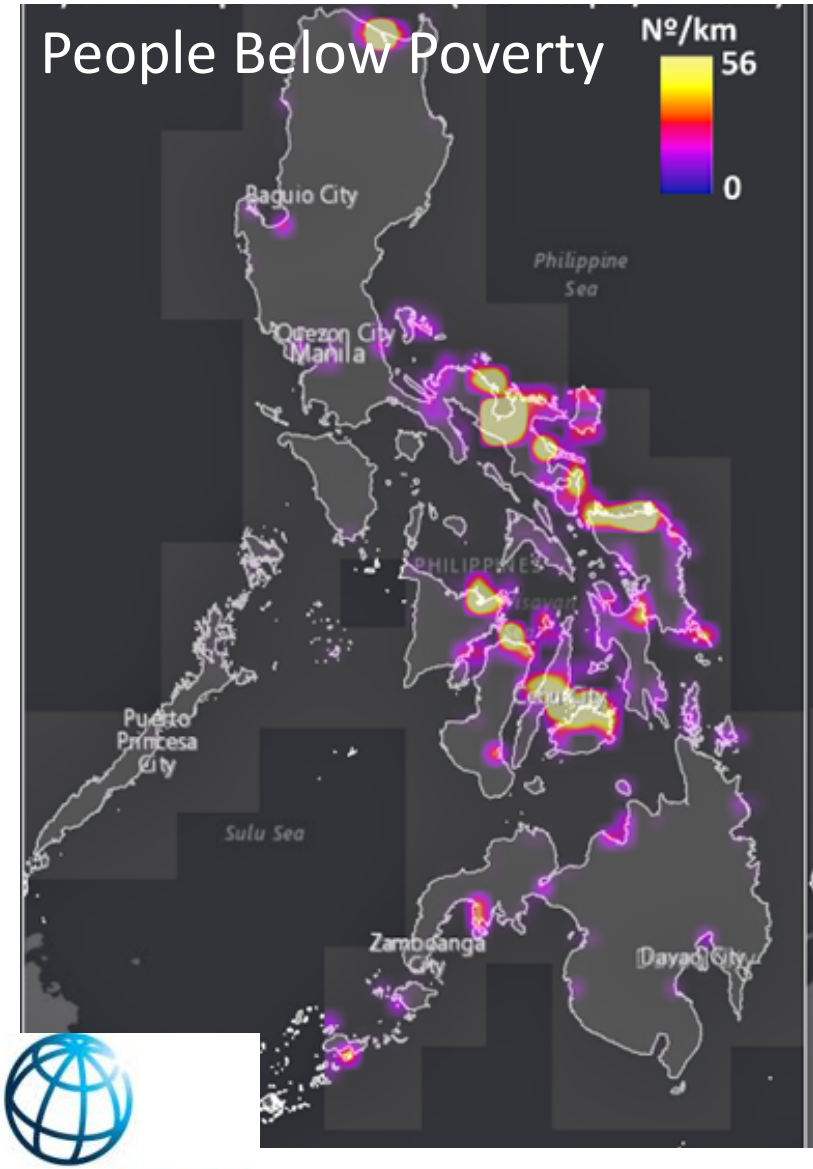


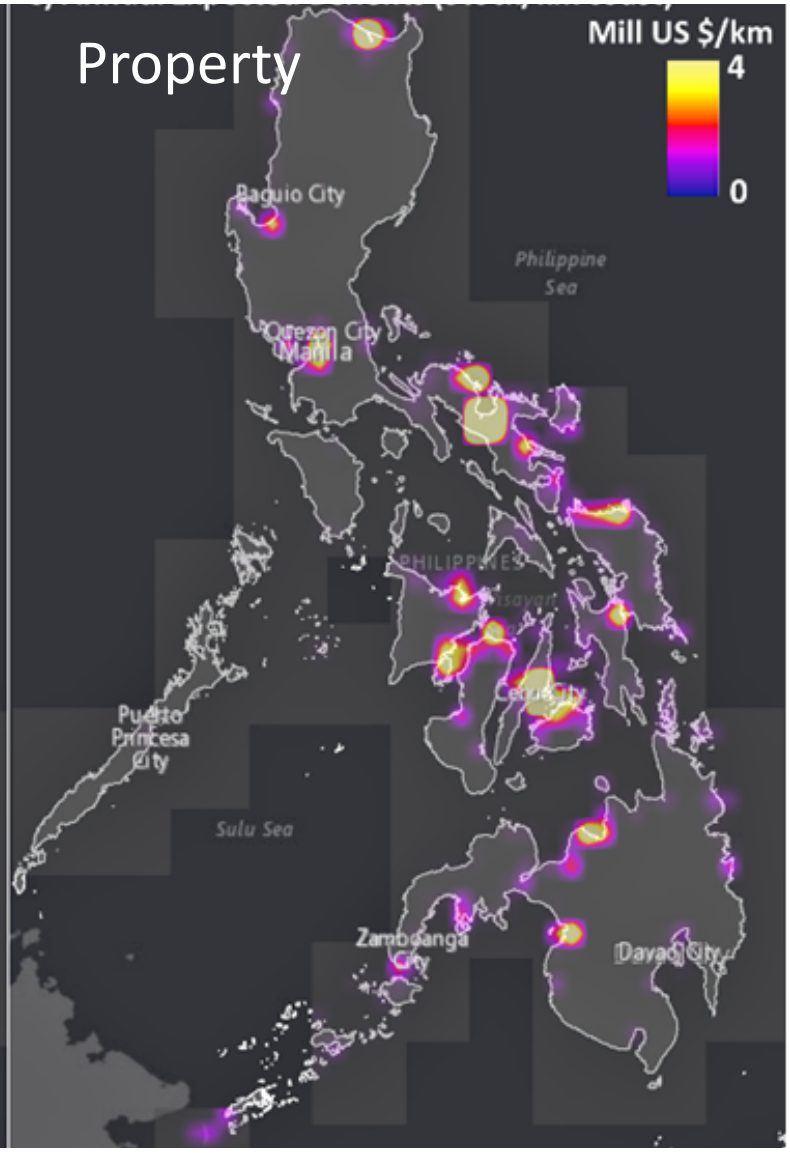
Losada, Beck etal. 2018. The global value of mangroves for risk reduction. TNC, Berlin.

Bündnis Entwicklung Hilft

Gemeinsam für Menschen in Not

Benefits of Mangroves in the Philippines: Comparing Benefits to Socially Vulnerable People vs Property





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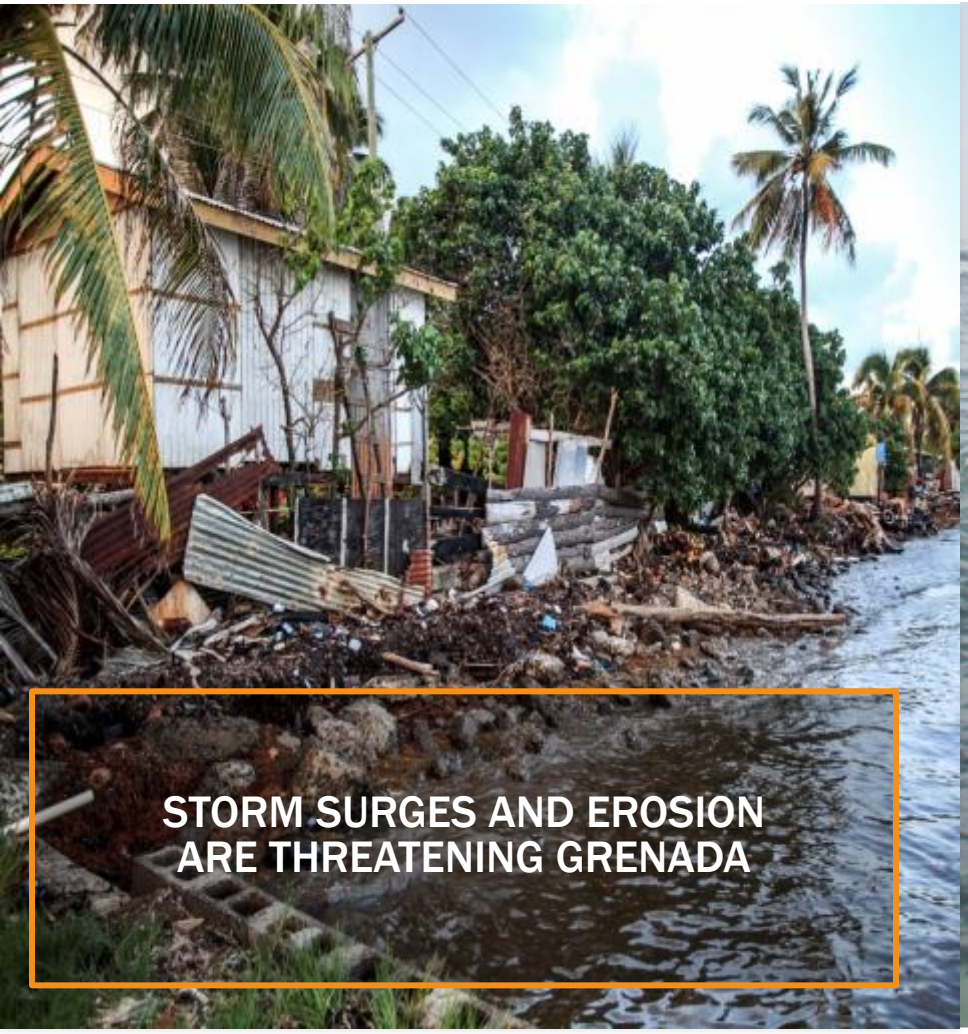
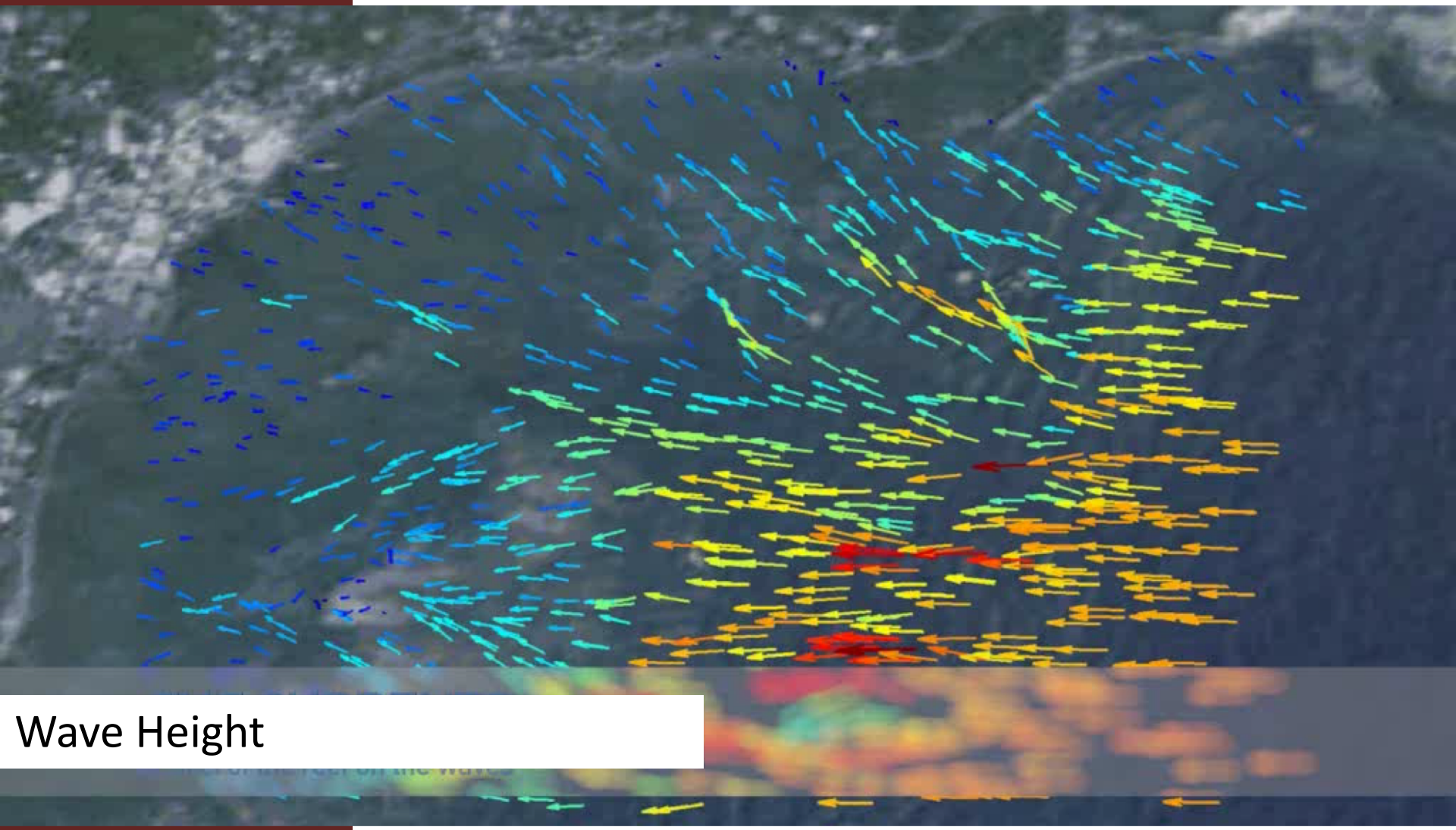
Menéndez, Losada, Beck et al. 2018. Ecosys Services

Global to Local Connection
PILOT PROJECT: GRENVILLE BAY, GRENADA





Wave Height

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Reguero, Beck, et al. 2018. Env. Mgmt. 210:146-161.

The reef at low tide

Catalyzing Public and Private Investment In Reef Restoration

- Significant Funding
- Insurance opportunities
- Recovery Funding is biggest source
- Need critical data on benefits & costs
- All approaches for funding gray infra open to Nat Infra

Financing Natural Infrastructure
For Coastal Flood Damage Reduction

LLOYD'S

www.lloyds.com/coastalresilience

Middlebury Institute of International Studies at Monterey
Center for the Blue Economy

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The Nature Conservancy

Wildlife Conservation Society

REEF RESILIENCE & INSURANCE FUND

IN QUINTANA ROO, MEXICO

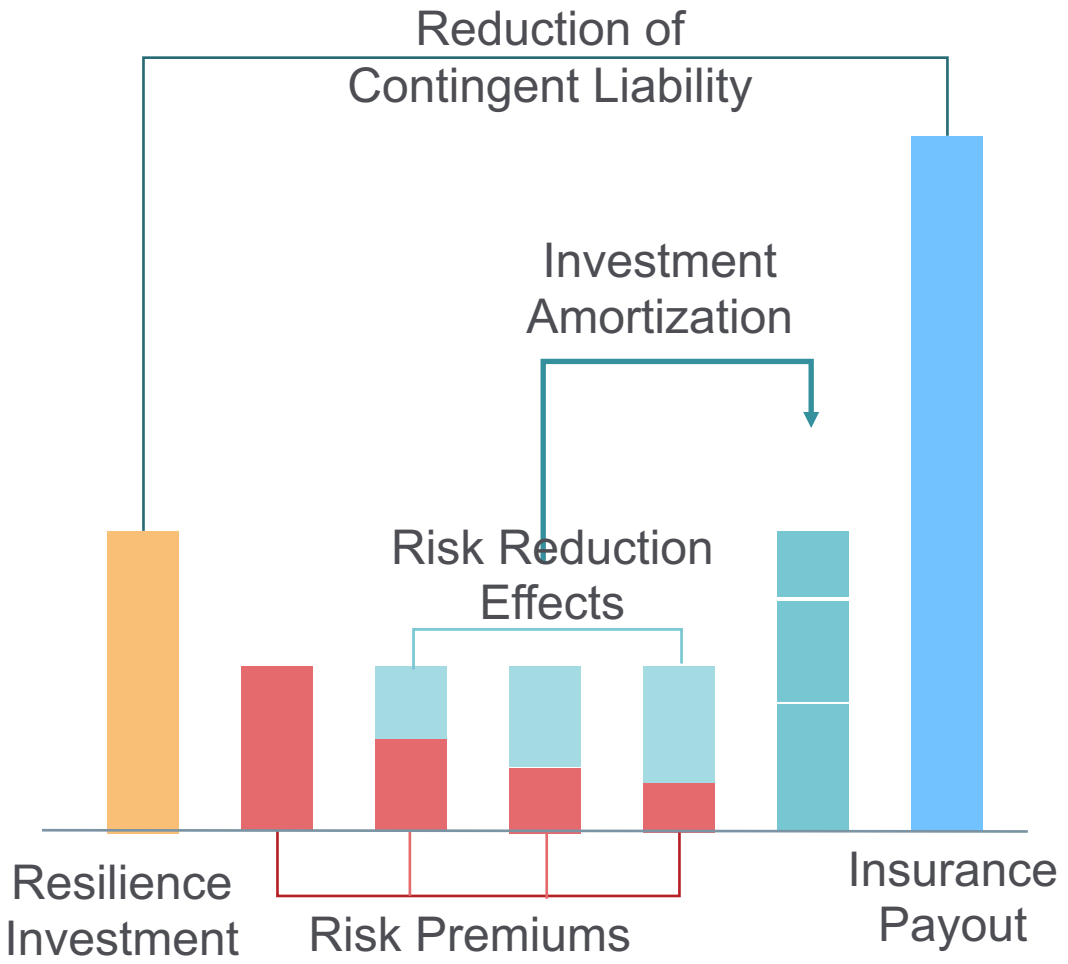
The Nature Conservancy
Protecting nature. Preserving life.

Swiss Re

Combining Reef Restoration & Insurance to Build Resilience

A resilience insurance solution overcomes trade-off between risk reduction & risk transfer:

- Up front reef restoration investment reduces risk
- The risk mitigating impact reduces premiums
- An incentive is created for restoration & risk transfer



Munich RE

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CCRIF SPC
The Caribbean Catastrophe Risk Insurance Facility

SUMMARY

- Reefs reduce flooding and erosion
- We can rigorously values these benefits
- We can prioritize based on Benefit:Cost
- And identify innovative funding opportunities



Thanks

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http://coastalresilience.ucsc.edu

U.S. DEPARTMENT OF THE INTERIOR · MARCH 3, 1849
USGS science for a changing world
THE PEW CHARITABLE TRUSTS
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
International Climate Initiative
GLOBAL RESILIENCE PARTNERSHIP
CONVENED BY THE ROCKEFELLER FOUNDATION AND USAID
KINGFISHER FOUNDATION
SNAPP Science for Nature and People PARTNERSHIP
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MAPPING OCEAN WEALTH
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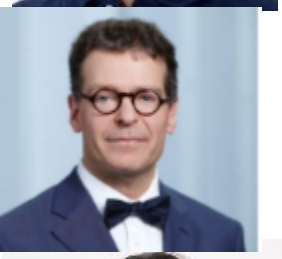
Economics of Climate Adaptation

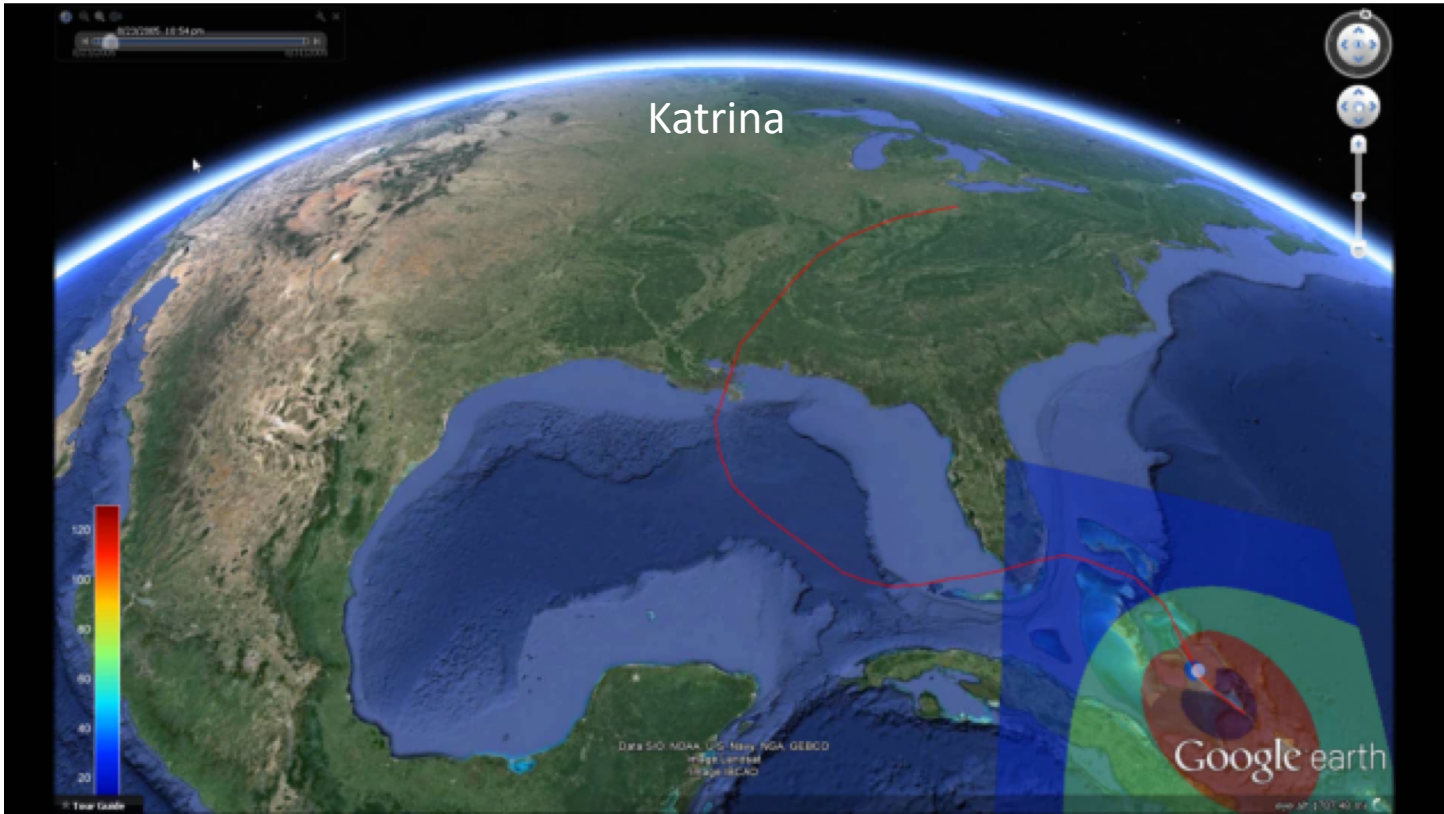
ETH zürich

Aims

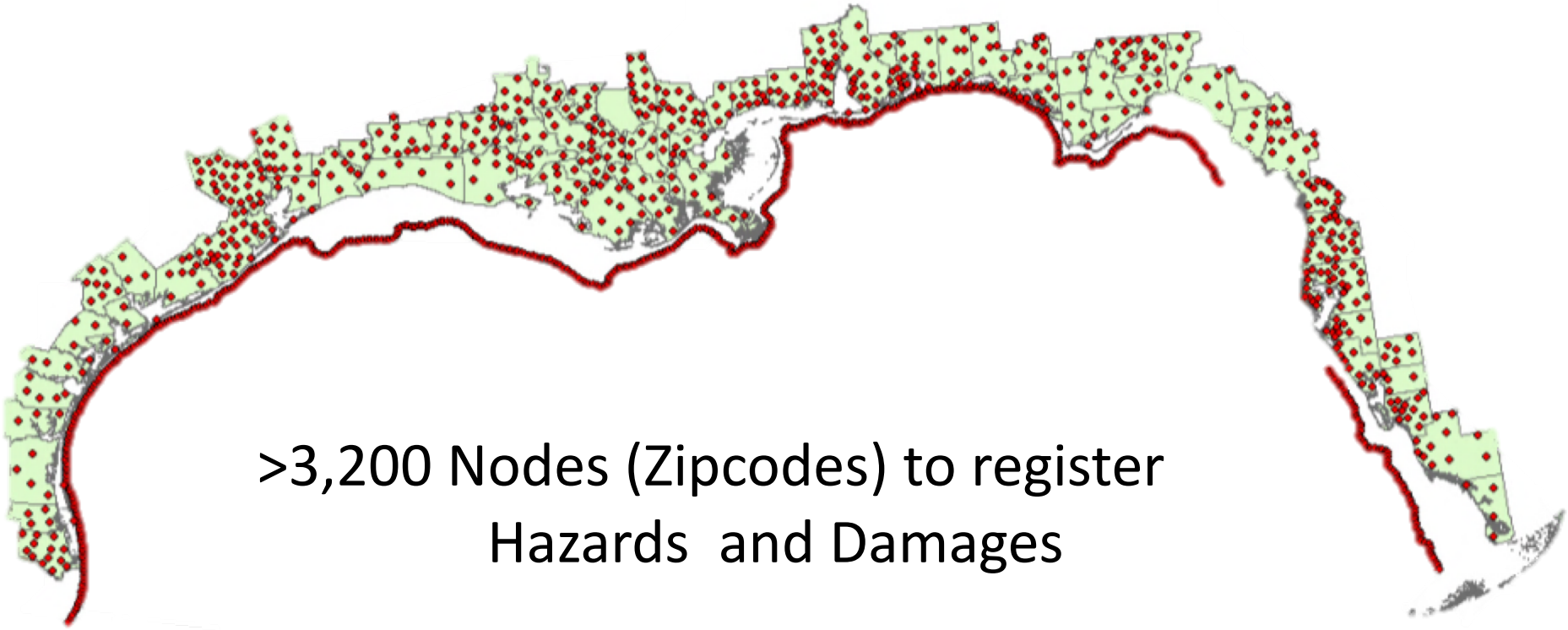
- Work with worlds 2nd largest re-insurer
- Public cost effectiveness model that includes nature
- Identify where nature-based defenses are cost effective

Reguero, Beck et al (2018). PLOS ONE.





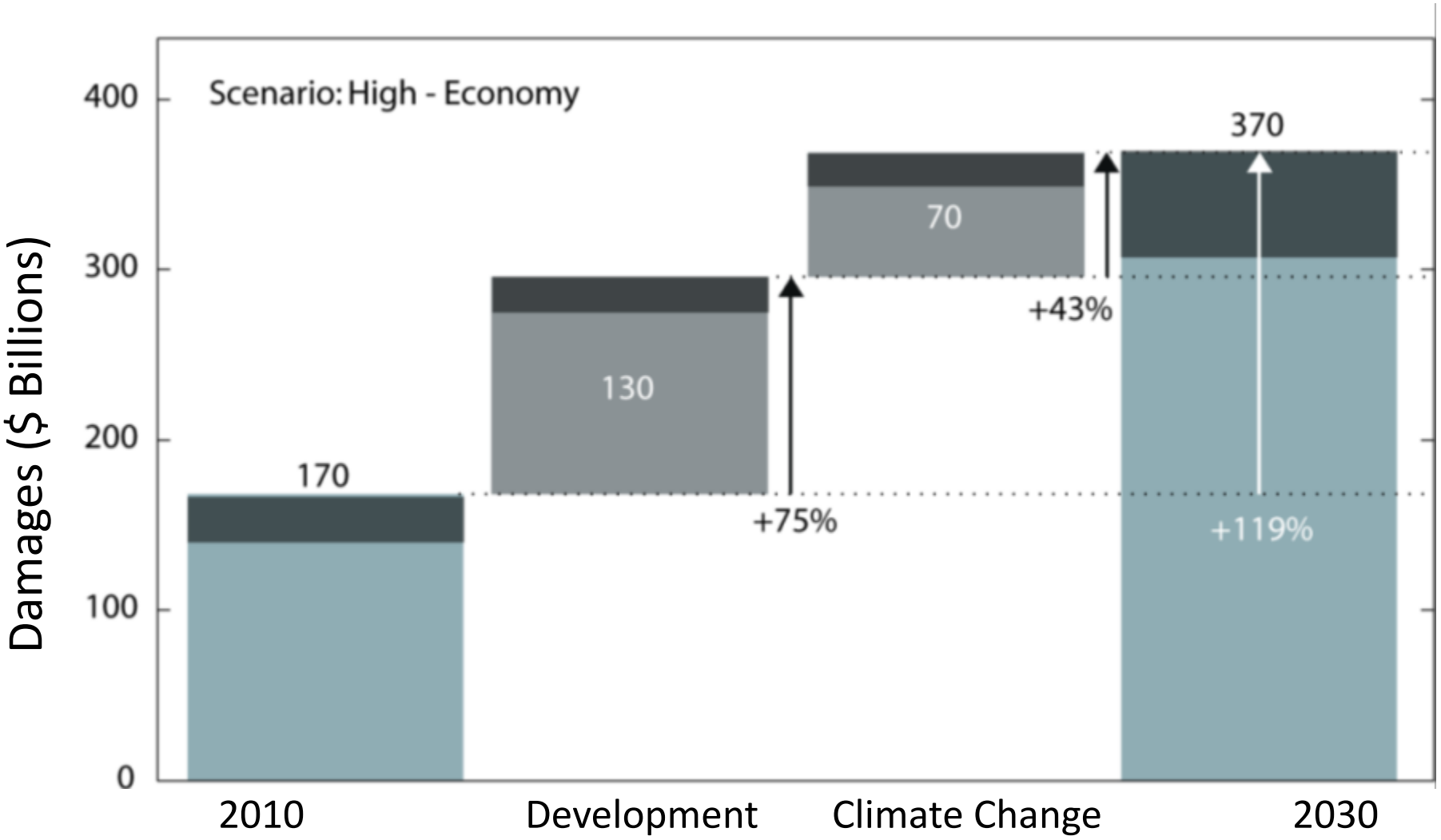
The regional domain: The Gulf Coast of US



>3,200 Nodes (Zipcodes) to register Hazards and Damages

Risk in 2030

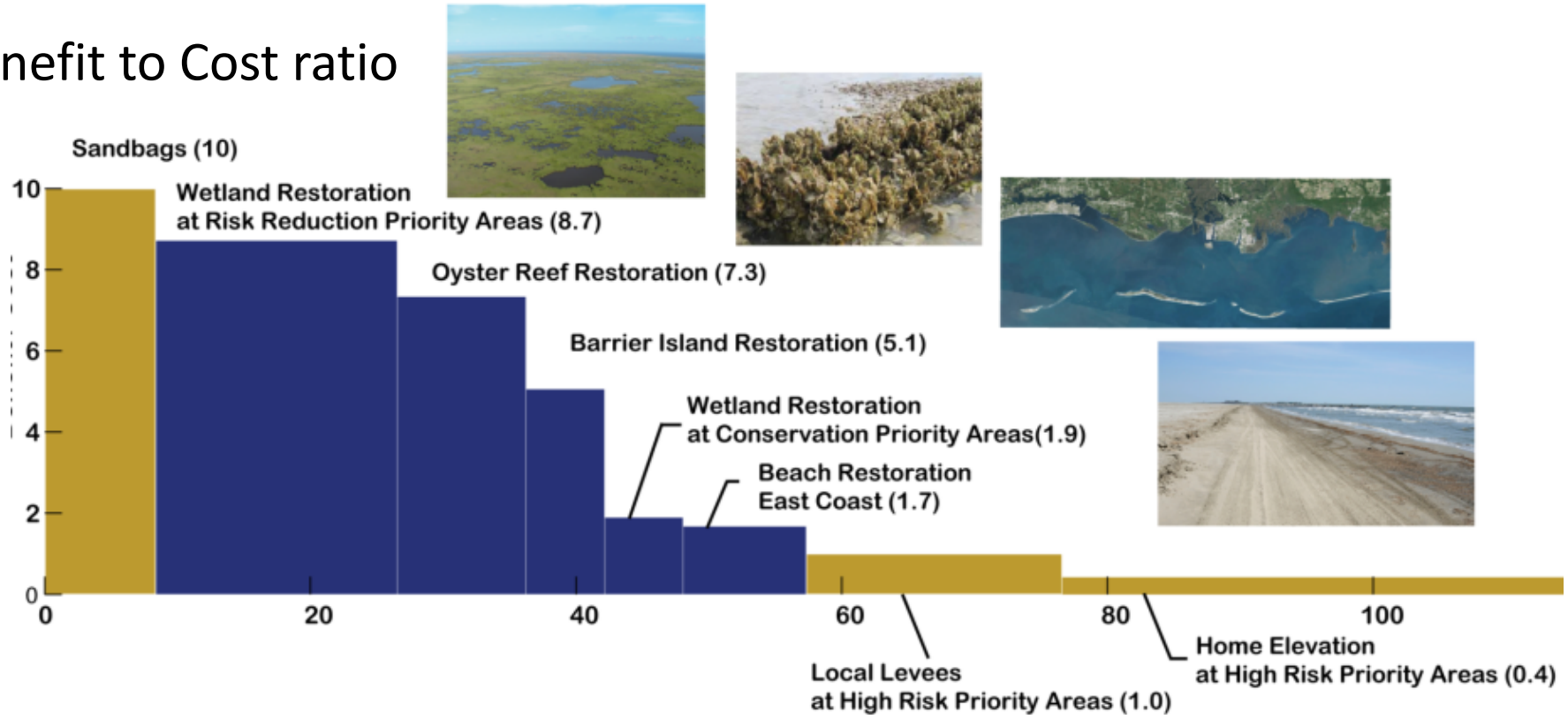
High Economic Growth (3%)



Reguero, Beck et al (2018). PLOS ONE

Economics of Coastal Adaptation

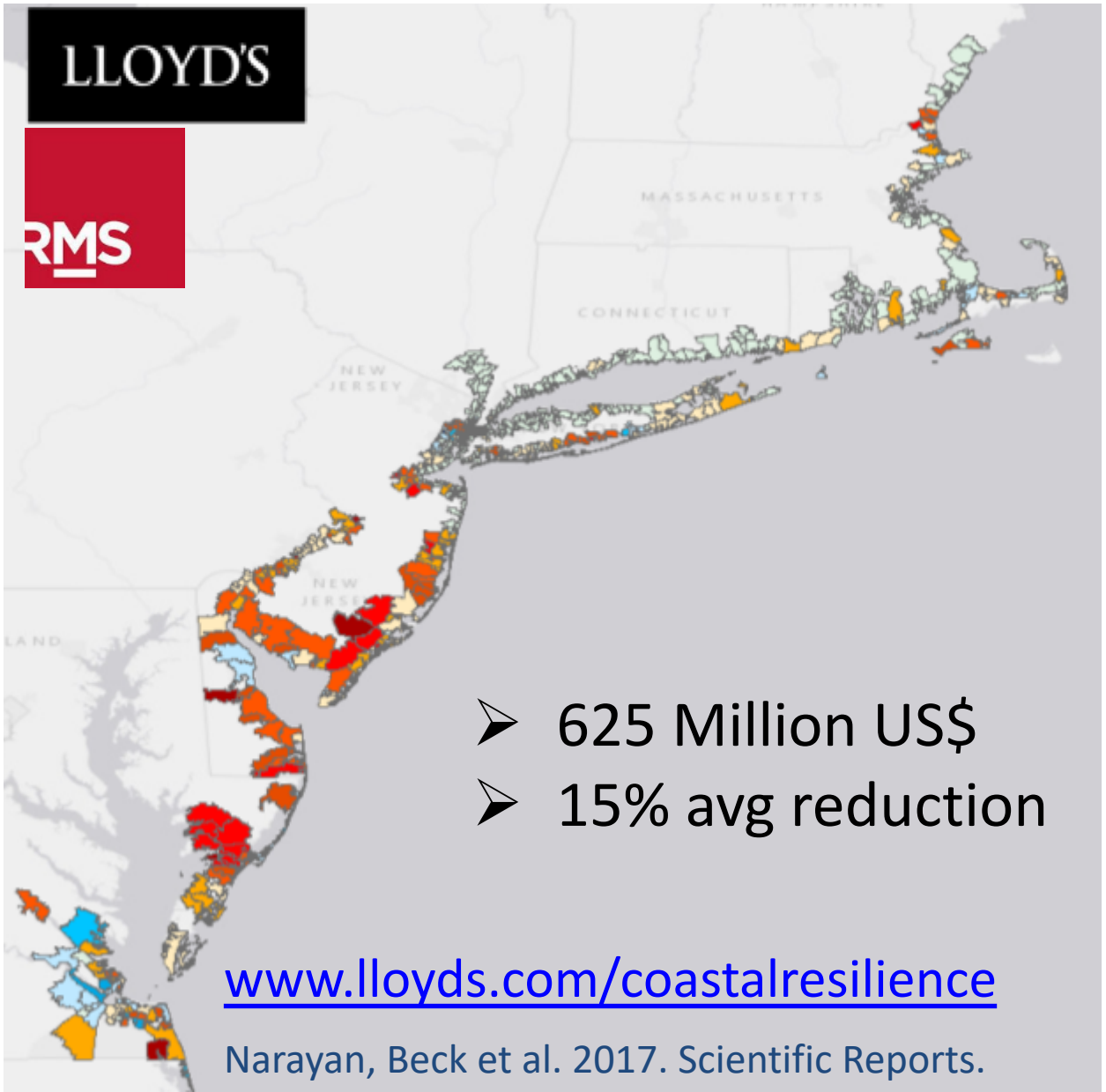
Benefit to Cost ratio



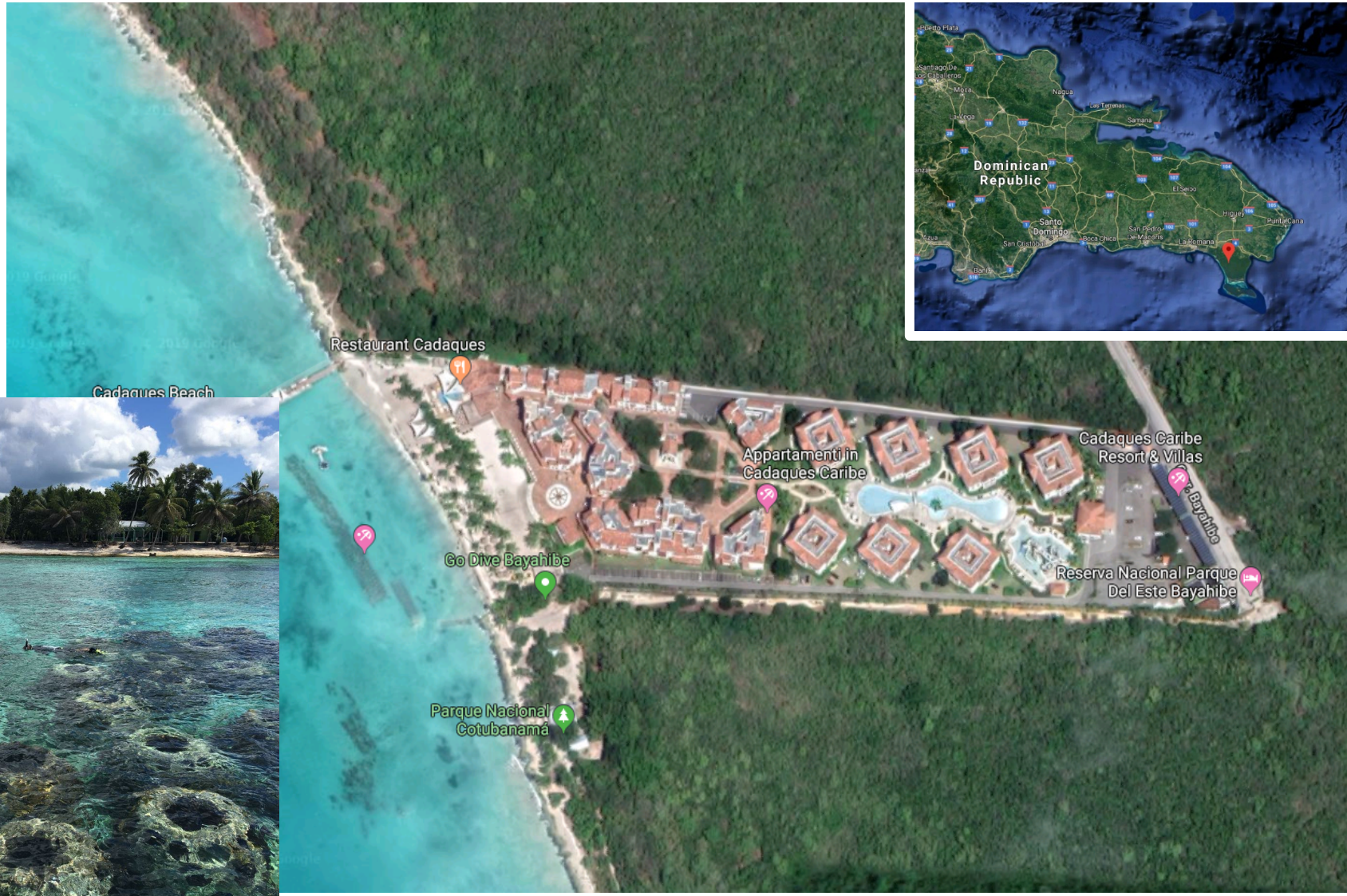
Averted Damages ($ Billions)

Reguero, Beck et al (2018). PLOS ONE

Effects of Marshes on Sandy Flood Damages



Reef Restoration and Resorts in Dominican Republic



Implications and Opportunities

- **Include Nature in Industry Risk Models**
- **Private incentives-** Insurance, Resilience Bonds
- **Public incentives-** Pre- and Post- disaster spending, Green bonds
- **Prioritizing Adaptation & Resilience-building Investments**
- **Prioritizing Natural Infrastructure in Policy** (Philippines Greening Program, US ACoE)

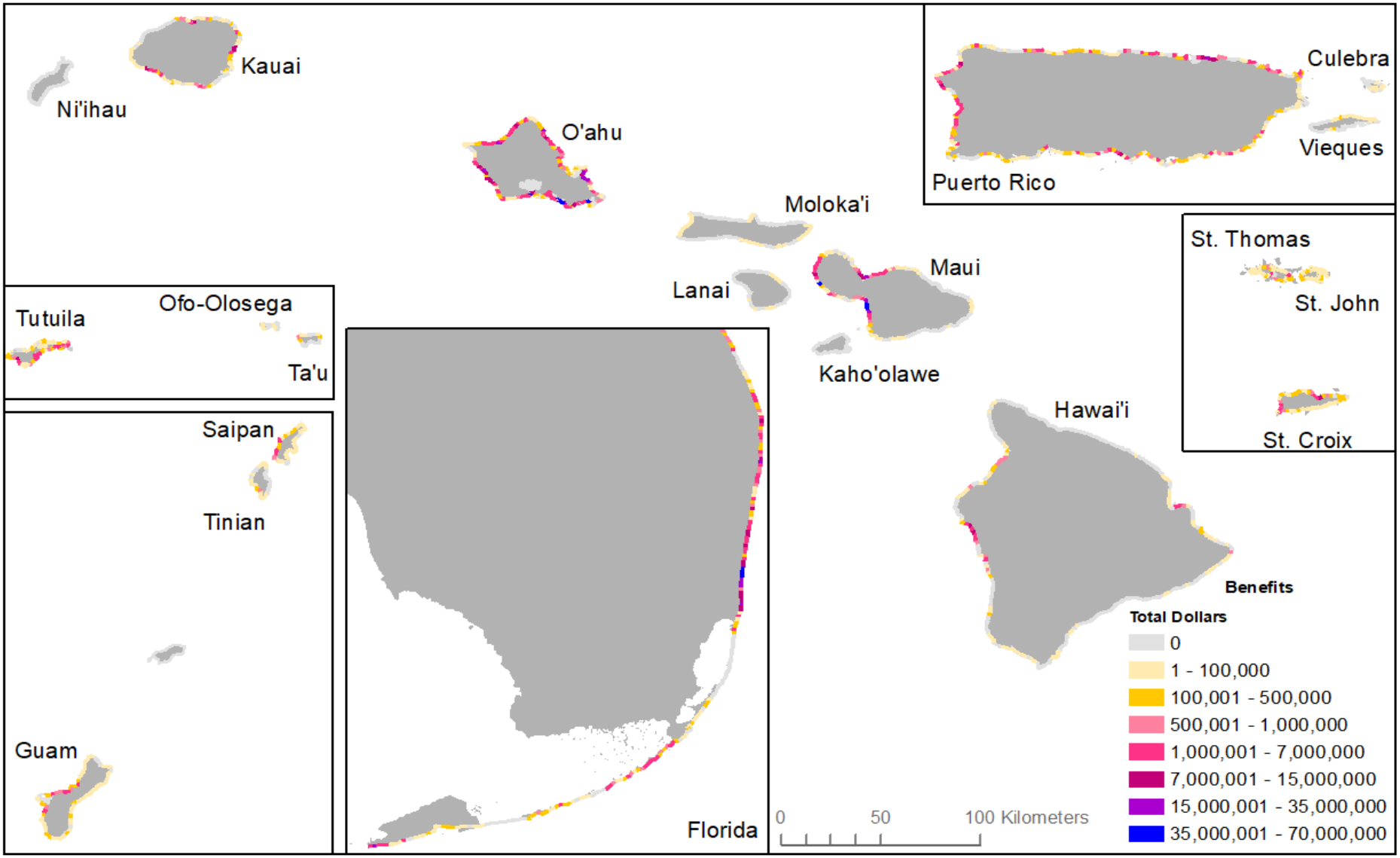
Costs of Restoration for Flood Protection

Type	Sub-type	Jamaica	DR	Grenada	Florida	All Other Caribbean	Global
Coral Reefs	Planting Fragments	640,000 (4)	2,025,000 (1)	--	2,469,000 (7)	1,286,000 (3)	61,000 (14)
	Structural Restoration	--	--	3,136,000 (1)	11,300 (9)	2,964,000 (4)	60,000,000 (15)
Mangrove	Planting Saplings	32,000 (2)	--	14,000 (1)	45,000 (47)	23,000 (3)	2,000 (57)
	Hydrological Restoration	--	--	--	141,000 (22)	--	4,000 (8)
Structures	Seawalls	--	--	3,671,000	19,935,000 (1)	19,818,000 (3)[1]	5,712,000 (1)
	Levees	--	--	--		24,757,000 (2)[1]	3,136,000 (1)
	Breakwaters	--	--	17,871,000 (1)		--	20,658,000 (17)
	Sea Dykes	11,675,000 (2)	--	--		--	--

USGS
science for a changing world

Benefits

Pacific Coastal and Marine Science Center



Creating Awareness
(and hopefully Political Will)

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VALUABLE RESOURCE

Hawaii's reefs provide more than $835 million in flood protection, a new study finds

LOCAL / B1

NATURAL BARRIER

Pictured is an aerial view of the Waimanalo coastline. Hawaii's reefs serve as nature's breakwaters, buffering the coastline and sheltering nearshore homes. A new report calculates the annual value of protection provided by coral reefs by island.

$395M OAHU

$377M MAUI

$51M HAWAII ISLAND

$12M KAUAI

Source: Arguments Valuing Coral Reef Coastal Protection

SUNKEN TREASURE

Hawaii's reefs provide more than $835M in flood protection, study shows

By Nina Wu
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A new study places a dollar value on Hawaii's reefs — not for their natural beauty or as a tourist attraction, but for their function in providing flood protection.

Hawaii's reefs are valued at more than $835 million, according to a report recently released by the U.S. Geological Survey, The Nature Conservancy and the University of California Santa Cruz. That's how much they provide in flood protection, more than any other state or territory in the nation.

Reefs across the U.S. provide more than $1.8 billion in flood protection every year, the report found, including about $12 million on Kauai, $385 million on Oahu, $377 million on Maui and $51 million on Hawaii island.

In a 50-year storm, TNC said, coral reefs off Honolulu alone could provide more than $435 million in flood protection.

"Most people have no idea how valuable coral reefs are for coastal protection," said co-author Michael Beck, a research professor at UC Santa Cruz, in a news release. "Now we do. Reefs act as submerged breakwaters, 'breaking' waves and dissipating up to 97% of their energy offshore. While those may look like general, 'back of the envelope' numbers, they are not. They are based on what are now the best flood risk maps available for U.S. coastlines, predicting risk at 10 meters by 10 meters, which is about one one-hundredth the area of a city block."

Standing at a beach in Waikiki, for example, Beck said waves might lap at one's feet. But if one were to look offshore, one would see the reef breaking the wave energy from afar.

"What you sort of forget is that if that reef wasn't offering that protection, you and that beach would not be there," he said.

Beck, a former lead scientist for TNC's Global Oceans Program, said the team worked with the engineering

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Coral reefs save us from flooding. We must save them from destruction

BY MICHAEL W. BECK
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The 2019 Atlantic hurricane season is almost upon us; the last two hurricane seasons were devastating to Florida. The race is on to recover and build resilience ahead of the next storms. And we need to invest in one of Florida's

lize the public and private investments that we need for this kind of reef management. Indeed there are a number of innovative pathways for action that can completely change the scale of support for reef conservation and restoration.

First, disaster recovery funding must support the recovery of national natural defenses. The United States already has appropriated more than $100 billion to recover from hurricanes Harvey, Maria and Irma; more of those funds should go to rebuilding reefs and other natural