

Considering Coral Reefs as Natural, National Infrastructure for Coastal Protection

Curt Storlazzi
Kristen Cumming
Ann Gibbs
Ben Norris

US Geological Survey

Mike Beck
Borja Reguero
James Shope
Aaron Cole
Camila Gaido

University of California, Santa Cruz

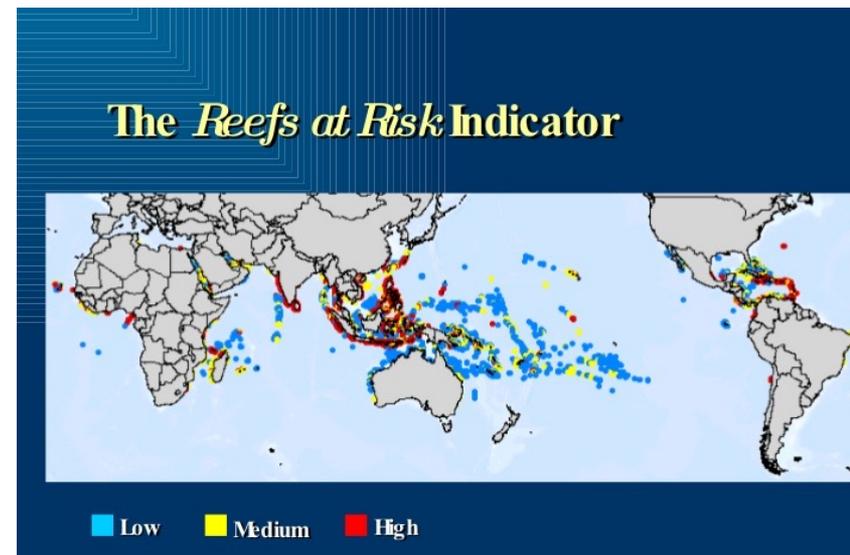
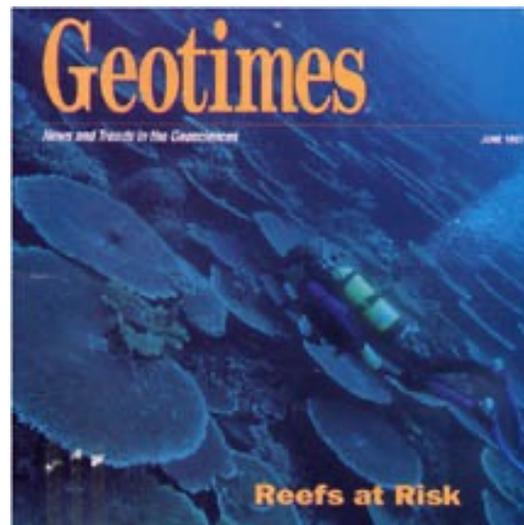
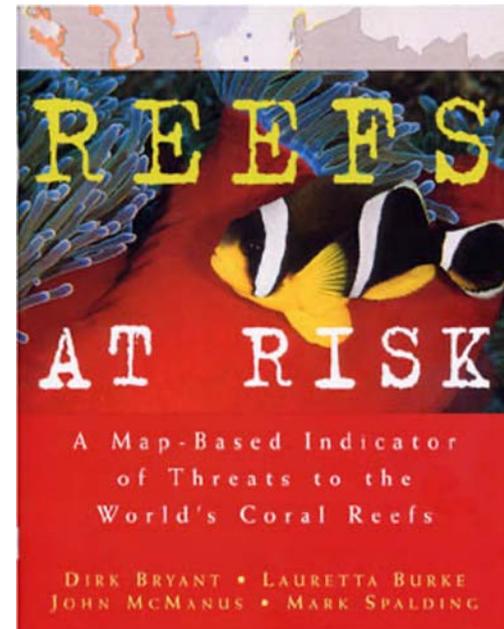
*Funded by the US Geological Survey's Coastal and Marine Hazards and Resources Program
and the US Office of Insular Affairs*

Coral Reefs at Risk

~25% of the world's coral reefs have already been damaged beyond repair and 75% are threatened by global and local stressors



World Resources Institute



Coral Reefs Threats

Global

- Thermally-induced bleaching
- Ocean acidification (atm CO₂)

Local

- Land-based pollution (sediment, nutrients, contaminants)
- Disease
- Coastal acidification (nutrients)
- Overfishing and poor fishing practices
- Physical destruction (groundings, development)



Ecosystem Services of Coral Reefs:

Biodiversity – “Rain forests of the sea”; cover <1% of sea floor but home to >25% of all marine species

Food – a primary source of protein for most island nations; nursery habitat for many commercial species

Tourism – a primary source of income for most island nations

US coral reefs generate **\$2.064 billion**** annually in these ecosystem services

Brander and van Beukering, 2013, *NOAA Report*

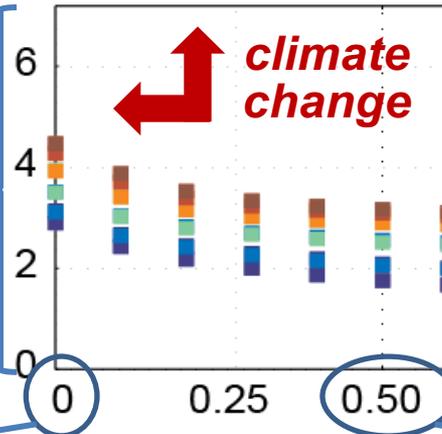


Coral Reefs & Coastal Protection

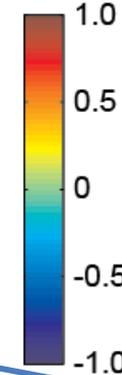


Wave-driven
Run-up
[m]

Quataert et al., 2015, *Geophysical Research Letters*



Offshore
water
level [m]



↑
*sea-level
rise*

Reef Hydrodynamic
Roughness
[-]

←
*reef
degradation*



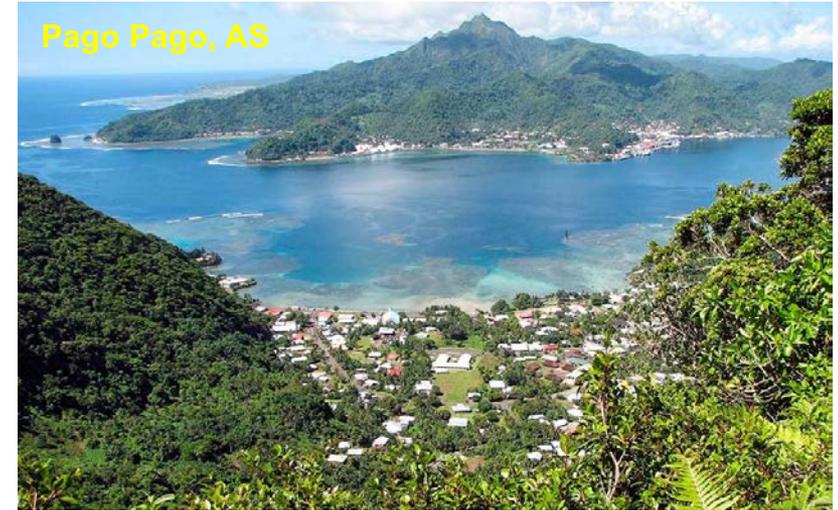
CMHRP Coral Reef Research

Infrastructure, freshwater supplies, and natural, cultural, and historic resources on coral reef-lined coasts are threatened by coastal flooding.

If nothing is done, forecasted reef degradation and sea-level rise will **exacerbate that flooding** and **increase the threat to coastal communities.**

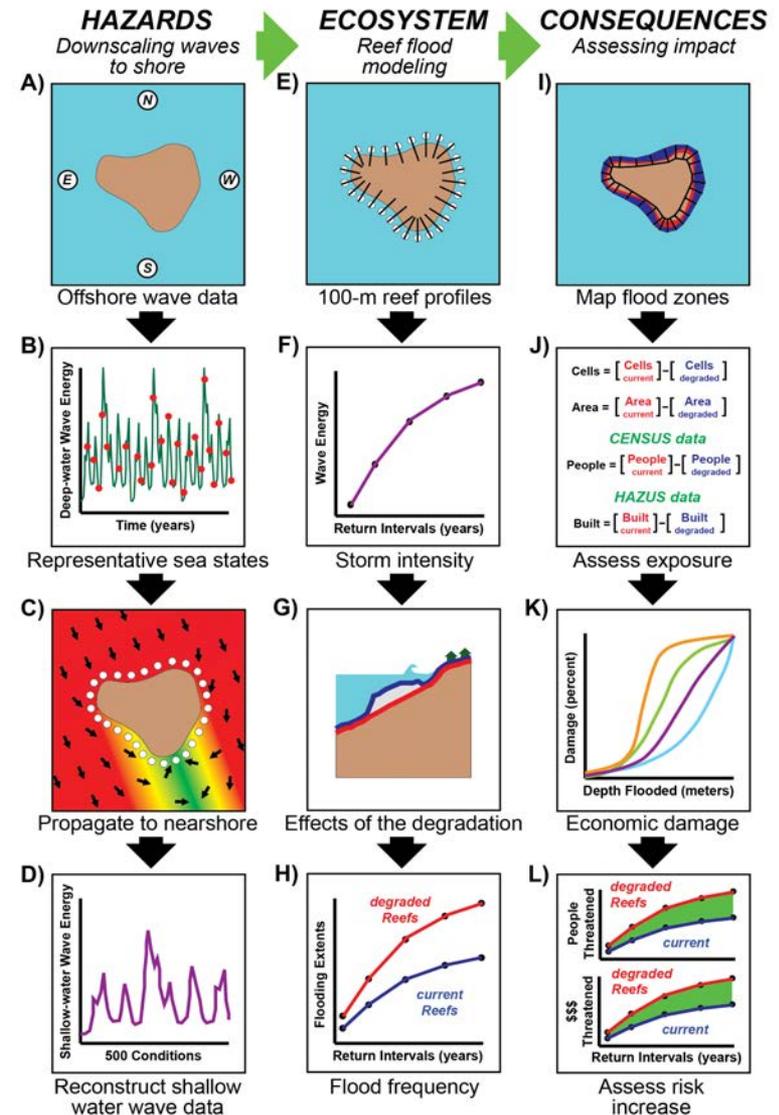


CMHRP Coral Reef Research



Our approach for assessing Coastal Protection Value:

A combination of oceanographic, coastal engineering, ecologic, geospatial, social, and economic models



Flooding



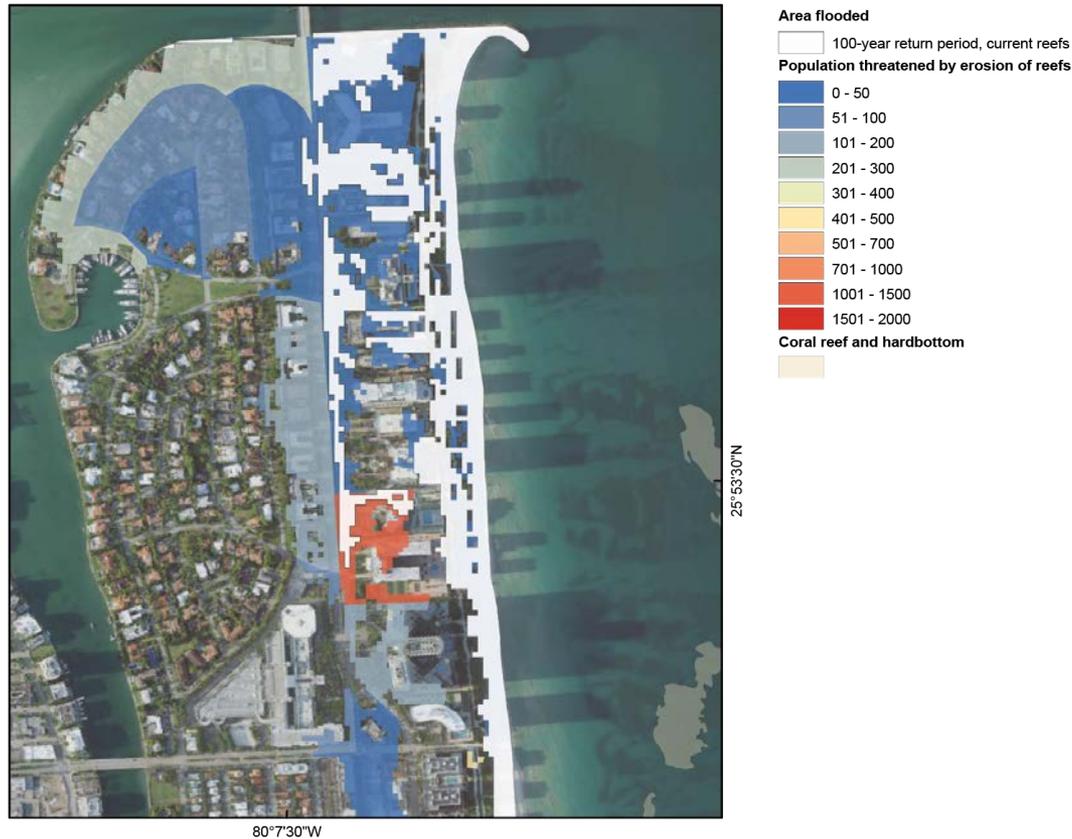
- 100-year return period, current reefs
- Coral reef and hardbottom

Flooding



- 100-year return period, current reefs
- 100-year return period, mean erosion scenario
- Coral reef and hardbottom

People Threatened



Property Threatened



Area flooded

100-year return period, current reefs

Total infrastructure exposed due to reef erosion (\$)

- 0 - 1,000
- 1,001 - 5,000
- 5,001 - 10,000
- 10,001 - 15,000
- 15,001 - 20,000
- 20,001 - 30,000
- 30,001 - 50,000
- 50,001 - 100,000
- 100,001 - 200,000
- 200,001 - 400,000

Coral reef and hardbottom

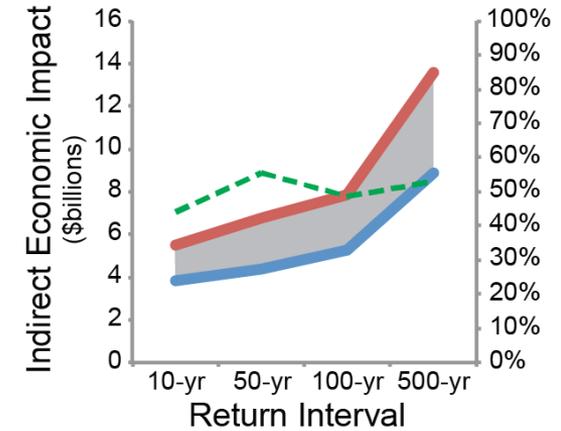
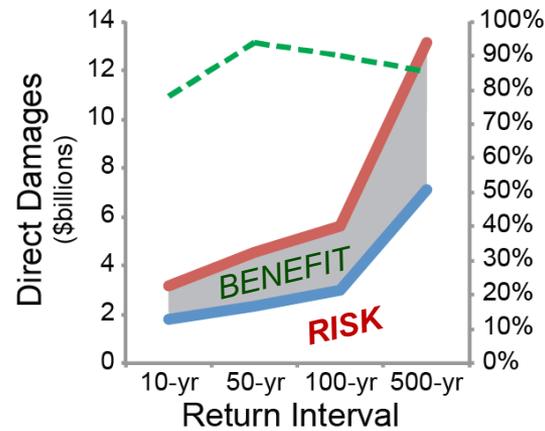
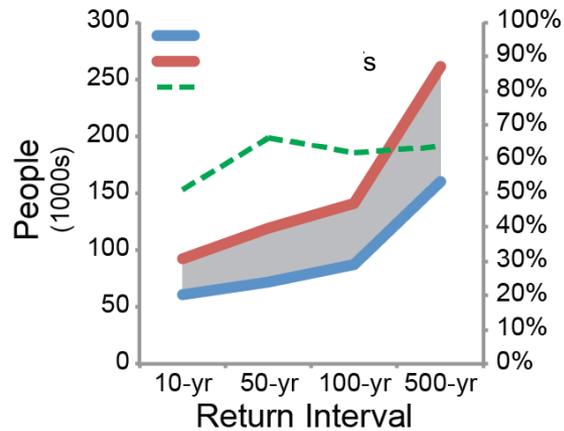


25°53'30"N

80°7'30"W

Storm Values

Risk and Benefits



RISK = white area under blue line

BENEFIT = gray area between blue and red lines

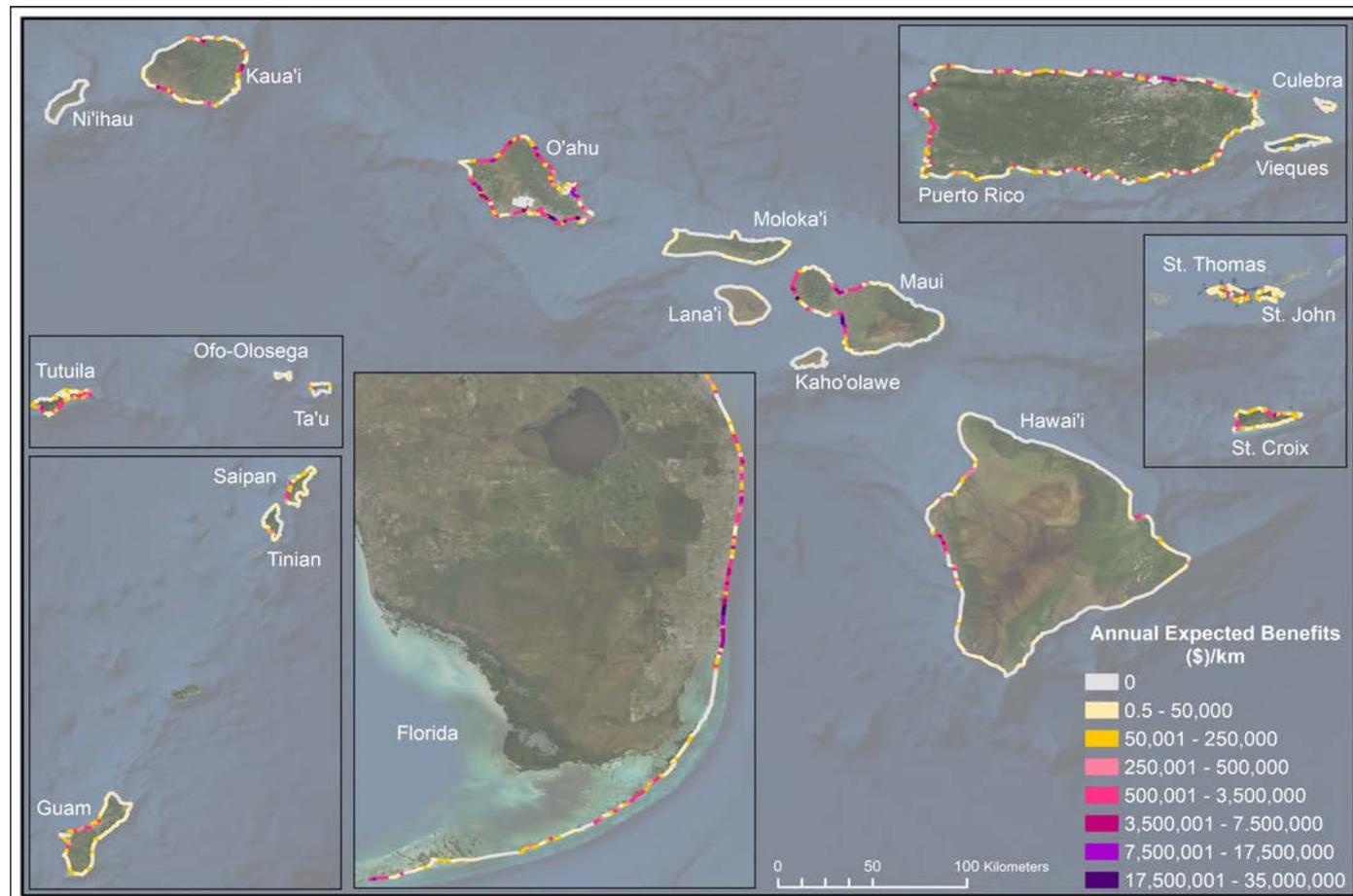
Annual **RISK** or **BENEFIT** = integral of white or gray area

Annual Benefits

18,180 people
(2010 census)



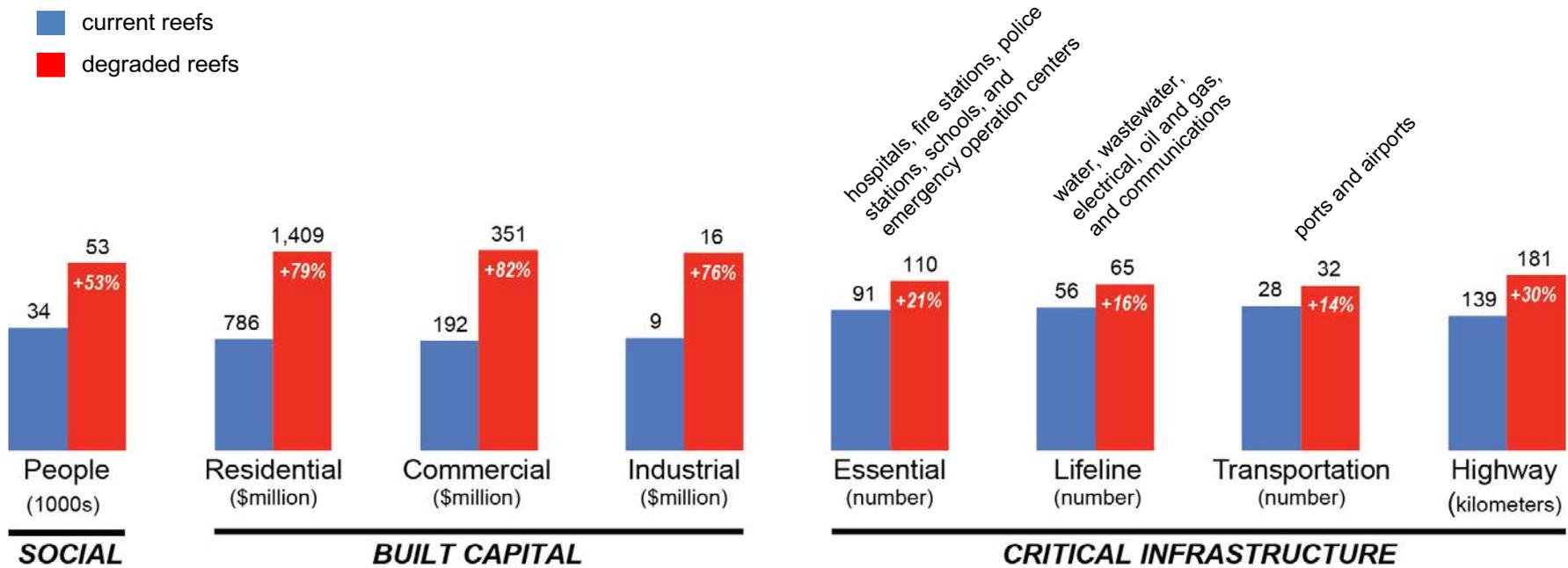
Annual Benefits



\$1,805,511,877
(2010 USD)

Increase in Risk by Sector

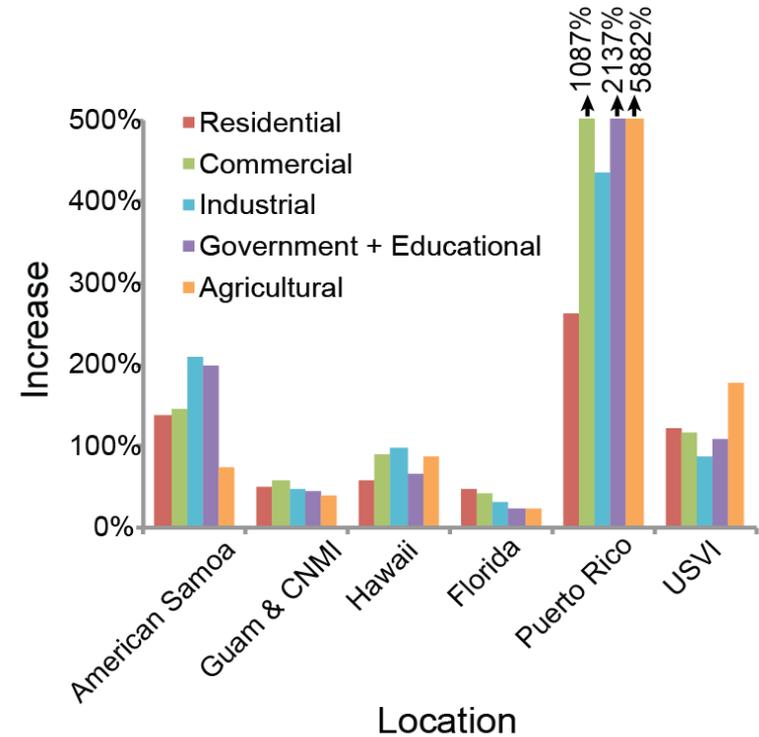
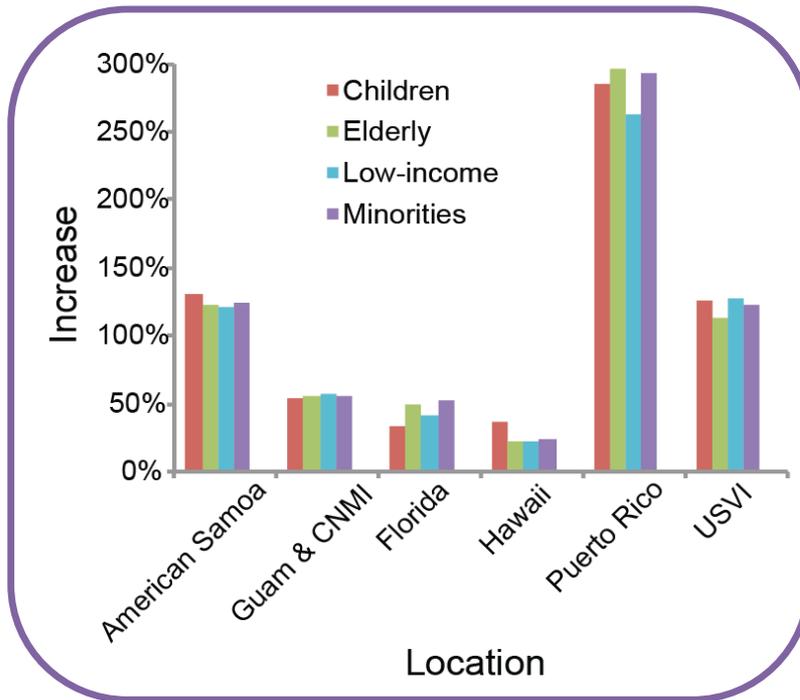
■ current reefs
■ degraded reefs



Private Sector

Public Sector

Relative Increase in Risk by Region



Coastal communities in the territories are at **relatively greater risk** of increased flooding due to projected coral reef degradation due to climate change, **especially the young, old, low-income, and minorities.**

The Solution: Reef Restoration

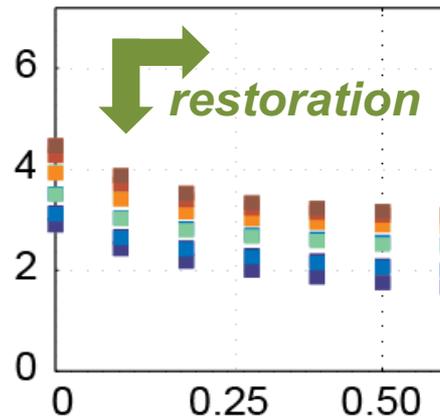


Coral Reefs & Coastal Protection

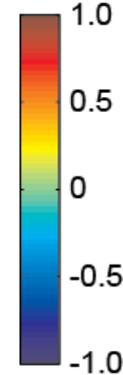
Quataert et al., 2015, *Geophysical Research Letters*



Wave-driven
Run-up
[m]



Offshore
water
level [m]



restoration

Reef Hydrodynamic
Roughness
[-]

restoration →



Flooding



- 100-year return period, current reefs
- Coral reef and hardbottom

Flooding with Potential Restoration



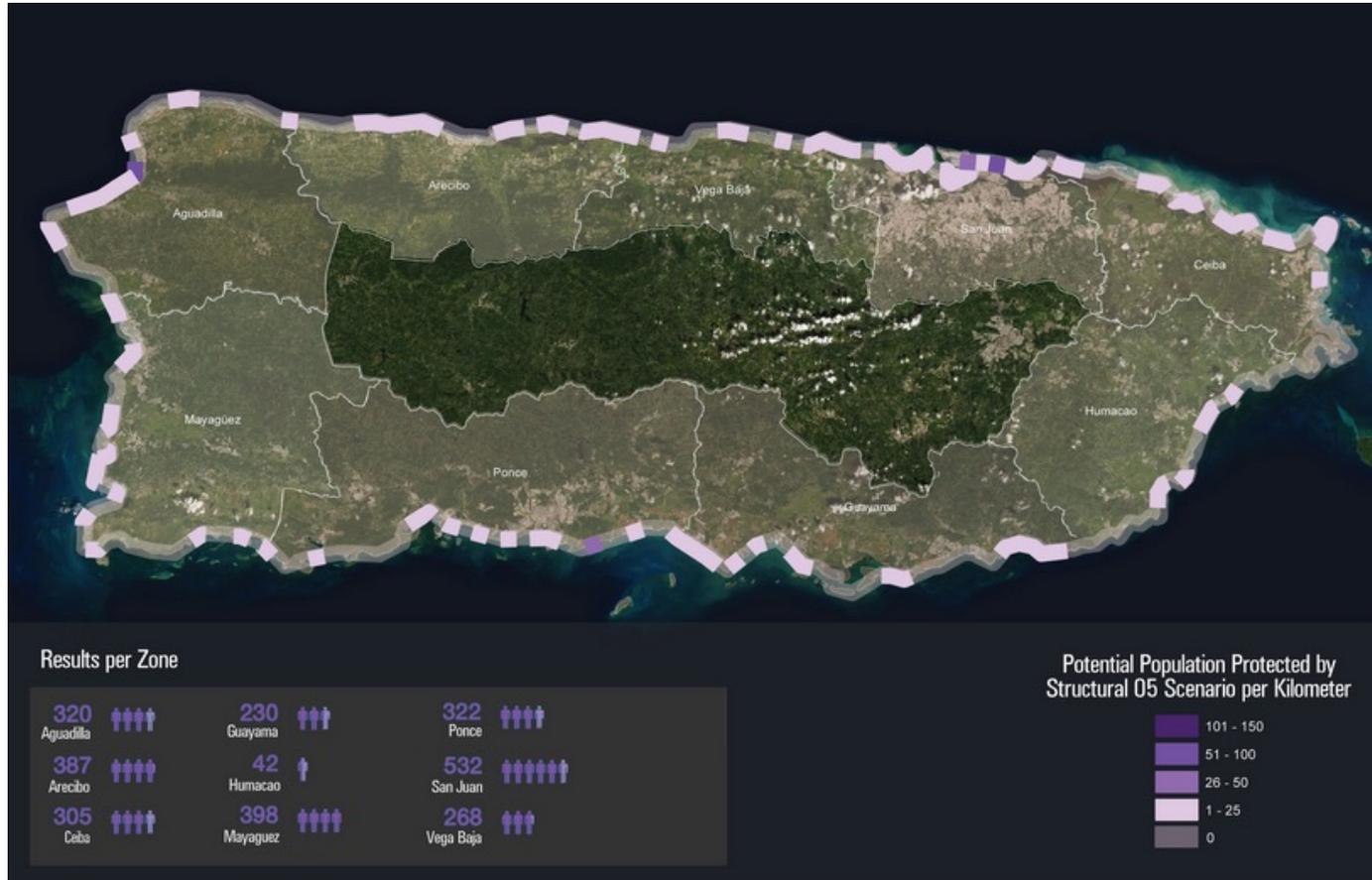
- 100-year return period, s05 restoration scenario
- 100-year return period, current reefs
- Coral reef and hardbottom

80°7'30"W

Protection Provided by Potential Restoration

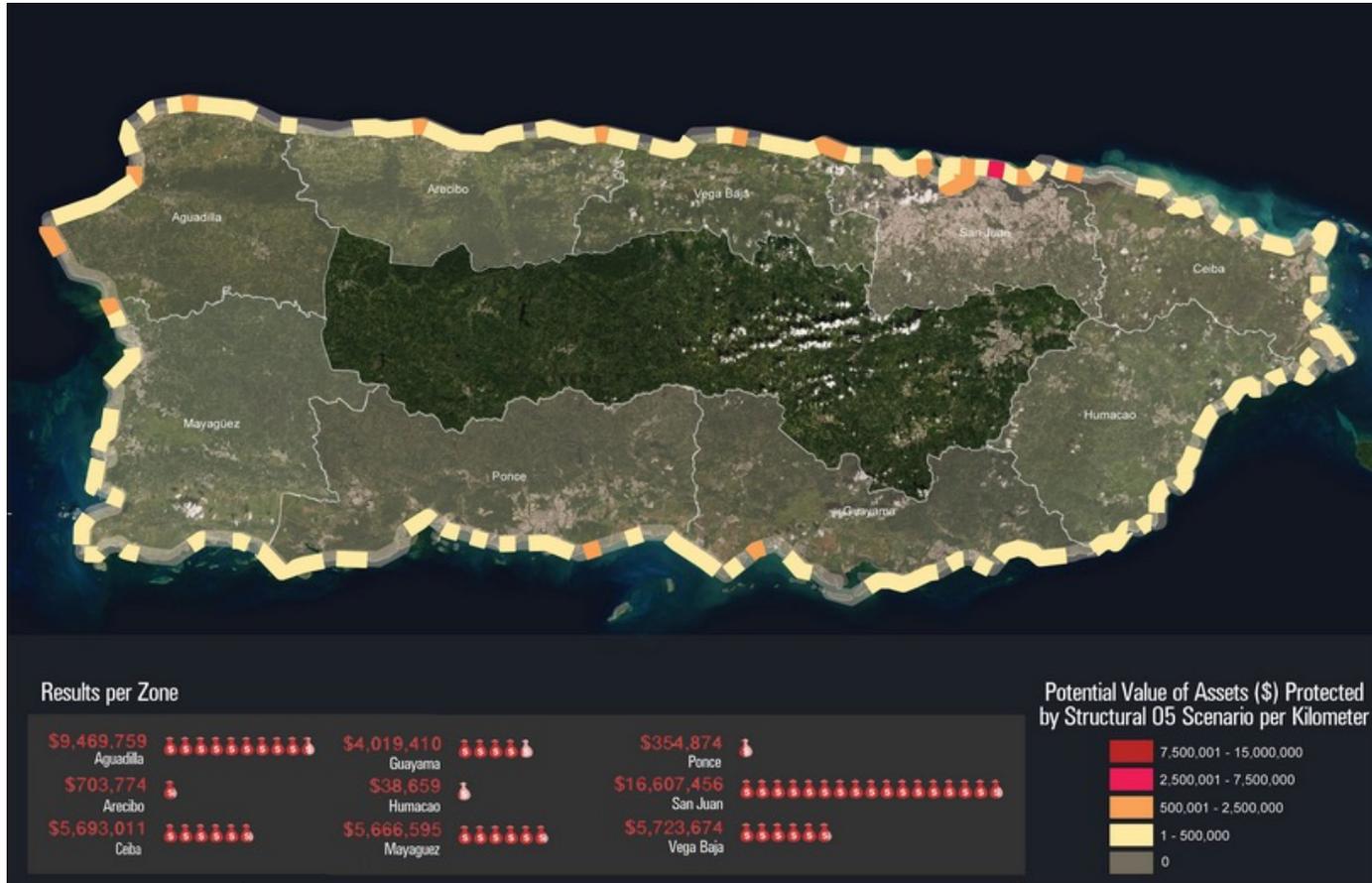


Total People Protected



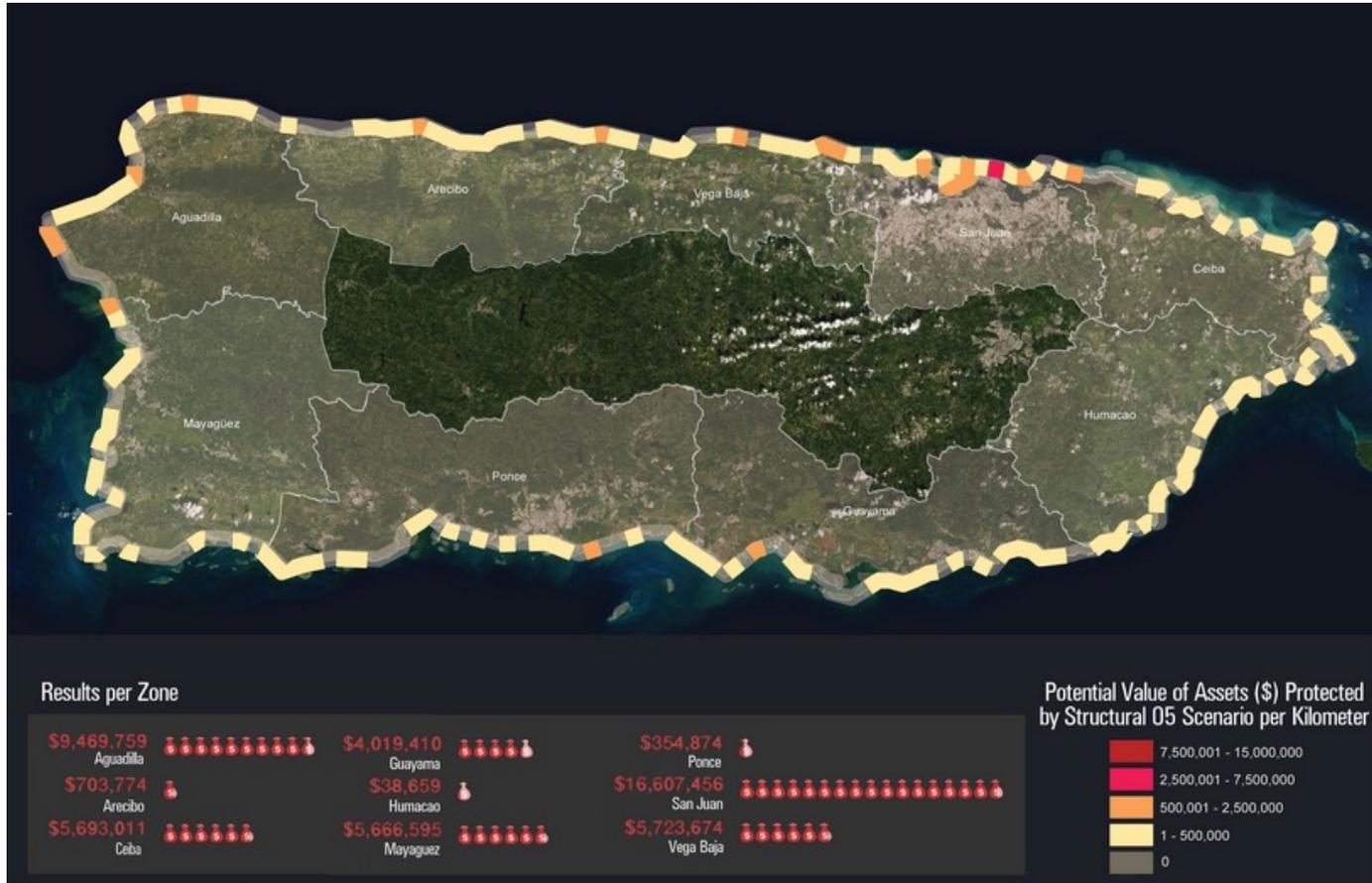
>920 people in Puerto Rico annually

Total Property Protected



>\$40 million in Puerto Rico annually

Total Property Protected



>\$720 million over 30 years with a 4% discount rate

How Does the US Decide to Fund Pre-disaster Mitigation and Post-disaster Restoration?

Benefit : Cost Analysis

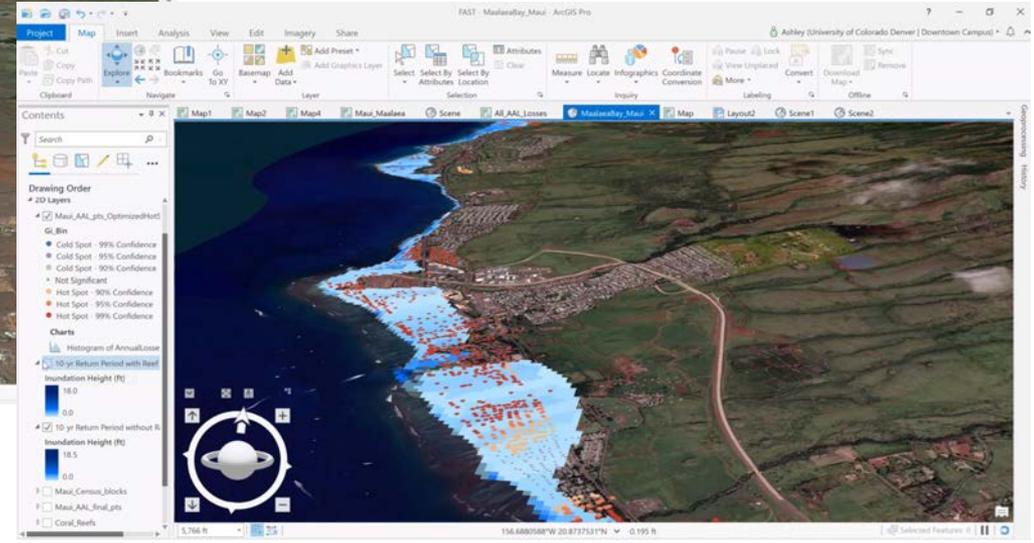
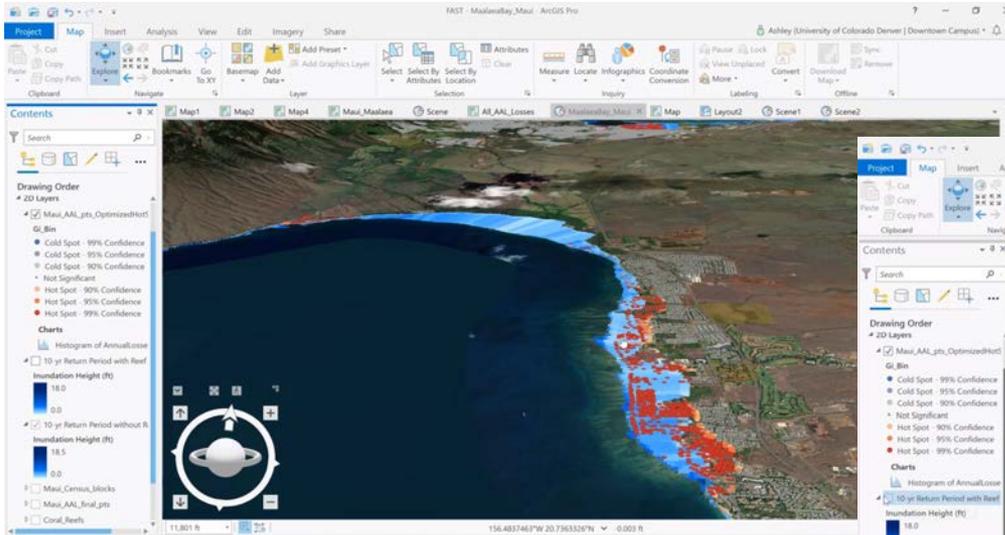
*Hazard risk reduction vs cost**

Needs to be done at a **spatial resolution** and in an **economically rigorous manner** to meet the needs defined in the **US Stafford Act** and the **US Office of Management and Budget's Circular A-94**



*Coral reef restoration cost: \$500,000 to \$2,000,000 per kilometer

Public Sector: Benefit analyses



Public Sector: Benefit analyses

Island	UDF Source	AAL without Reef	AAL with Reef	Annual Losses Avoided	USGS Annual Losses Avoided
Maui	NSI	\$ 100,003,882.58	\$ 28,028,783.89	\$ 71,975,098.68	\$ 112,716,317
Hawaii	NSI	\$ 1,687,502.95	\$ 1,562,248.94	\$ 125,254.01	\$ 23,997,824
Oahu	NSI	\$ 560,978,962.71	\$ 350,613,356.41	\$ 210,365,606.29	\$ 200,942,259
Molokai	NSI	\$ 51,583.50	\$ 26,414.35	\$ 25,169.15	\$ 42,071
Kauai	NSI	\$ 40,520,600.73	\$ 16,069,215.36	\$ 24,451,385.37	\$ 5,854,742
Total Annual Losses Avoided				\$ 306,942,513.51	\$ 343,553,213

Island	Population	
	NSI (Day) People Protected 100-year	USGS People Protected 100-year
Maui	5,624	4,235
Hawaii	694	743
Oahu	1,389	3,957
Molokai	0	3
Kauai	1,554	313

FEMA, 2021, HAZUS Report

Where can this lead us?

All of the tools used to fund
gray infrastructure
(seawalls, breakwaters, etc)
 can be used to fund
green infrastructure
(ecosystem restoration)

National Institute of Building Sciences, 2019
Natural Hazard Mitigation Saves Report:

Every **\$1 spent in mitigation** saves **\$4 in averted damage** for tropical storms

WHO PAYS	
PUBLIC	
WHO BENEFITS	<p>PUBLIC</p> <p>Funds are provided by general taxes, benefits cannot be assigned to any specific beneficiary.</p> <p>Pre-Disaster Funding</p> <p><i>Globally</i></p> <ul style="list-style-type: none"> Infrastructure spending (e.g. transportation, energy, water) may include flood protection <p><i>In the United States</i></p> <ul style="list-style-type: none"> Army Corps of Engineers Coastal Wetlands Restoration Fund Estuary Habitat Restoration Act Funds Louisiana Coastal Wetlands Restoration FEMA Pre-Disaster Mitigation Grants Oil Spill Wetlands Restoration Funds State Infrastructure Banks <p><i>In Europe</i></p> <ul style="list-style-type: none"> Natural Capital Financing Facility <p><i>In Developing Countries</i></p> <ul style="list-style-type: none"> World Bank Green Climate Fund Global Environmental Facility Small Grants Mexico Fund for Disaster Prevention <p>Post-Disaster Funding</p> <p><i>In the United States</i></p> <ul style="list-style-type: none"> FEMA Flood Mitigation Assistance Program <p><i>In Developing Countries</i></p> <ul style="list-style-type: none"> World Bank's Global Facility for Disaster Risk Reduction & Recovery World Bank's Crisis Response Window World Bank's Catastrophe Deferred Drawdown Mexico's FONDEN
	<p>PRIVATE</p> <p>Private funds provide benefits that are greater than the usual return on investment. Decisions about what to fund combine expectations of private return and of broader benefits.</p> <ul style="list-style-type: none"> Pre and Post Disaster Funding Green Bonds
	<p>PRIVATE</p> <p>Private funds provide benefits to a narrow group.</p> <p>Infrastructure Finance</p> <p><i>In the United States</i></p> <ul style="list-style-type: none"> Special Purpose Districts Flood Control Districts Storm water Districts Tax Increment Financing Districts <p><i>Globally</i></p> <ul style="list-style-type: none"> Public-Private Infrastructure Partnerships <p>Insurance – Pre-Disaster</p> <p><i>In the United States</i></p> <ul style="list-style-type: none"> FEMA Community Rating System <p>Insurance – Post-Disaster</p> <p><i>Globally</i></p> <ul style="list-style-type: none"> Insurance and Reinsurance Payouts Catastrophe Bonds Resilience Bonds
	<p>PUBLIC</p> <p>Public expenditures, either directly or through tax subsidies, provide benefits to a narrow group.</p> <ul style="list-style-type: none"> Tax Expenditures Disaster Recovery Deductions Deductions for Contributions to Conservation

Funding Options for Natural Infrastructure
 This table provides a simple economic framework for describing the many approaches to financing natural infrastructure based on where the funding will come from and who will benefit from the reduced flood risk.

Colgan and Beck, 2017, *Lloyd's Tercentenary Research Foundation Report*

Who in the public sector cares?

FEMA

- Community Infrastructure Resilience Branch
- Risk Analysis Branch
- Risk Reduction Division, Grant Analysis and Tools Section
- Benefit:Cost Analysis Program

DOD

- Defense Advanced Research Projects Agency
- Center of Excellence in Flood Risk Reduction
- ERDC, Engineering with Nature Initiative
- ERDC, Risk and Decisions Science Team

NOAA

- Coral Reef Conservation Program
- Restoration Center

States and Territories

- Hawaii, Florida, Puerto Rico, US Virgin Islands, Guam, American Samoa, C.Northern Mariana Islands

NGOs

- Coastal States Organization
- American Shore and Beach Preservation Association

Federal Partners
for Nature-Based
Solutions
Working
Group
(along w/
USGS)



Public Sector: Laws to designate reefs as critical infrastructure for coastal protection

Ley para Declarar los Arrecifes de Coral como una Estructura Esencial para la Protección de las Costas de Puerto Rico

Ley Núm. 72 de 23 de Julio de 2020

Para declarar los arrecifes de coral como una estructura esencial para la protección de las costas de Puerto Rico y su inherente relación en la conservación de playas y otros elementos de la naturaleza; ordenar al Departamento de Recursos Naturales y Ambientales de Puerto Rico a adoptar y/o enmendar toda la reglamentación necesaria para que estén cónsonas con esta declaración y facultarlos para la tramitación de fondos estatales o federales para su protección y mantenimiento; y para otros fines.

EXPOSICIÓN DE MOTIVOS

Los arrecifes de coral son grupos intrincados y diversos de especies que interactúan entre sí y con el entorno físico. Los corales son una clase de colonia de animales que se relacionan con los hidrozoos, las medusas y las anémonas de mar. Son el hábitat de una gran variedad de especies de la vida marina, que incluyen diversas clases de esponjas, ostras, almejas, cangrejos, estrellas de mar, erizos de mar y muchas especies de peces. Los arrecifes de coral también están relacionados ecológicamente con las comunidades de hierbas marinas, manglares y marismas circundantes. Por ello, constituyen el hábitat de una gran biodiversidad de especies marinas, entre estos los corales. Precisamente, uno de los motivos por los que los arrecifes de coral son tan valiosos radica en su función como centro de actividad de la vida marina.¹⁰

Los arrecifes de coral, además, son uno de los ecosistemas más valiosos y biológicamente diversos de la Tierra. Cumplen con diversas funciones, pero una de las más importante es la protección de la infraestructura costera y prevención de la pérdida de vidas a causa de tormentas, tsunamis, inundaciones y erosión. Los arrecifes de coral y las dumas reducen la energía del oleaje y, por ende, la erosión costera. Durante el huracán María, por ejemplo, el arrecife de coral disipó en más de 90% la energía de la marea de tormenta en Puerto Rico. Se estima por el Servicio Nacional de Pesca Marítima de los Estados Unidos que los arrecifes de coral proveen para la protección costera, unos \$9.0 mil millones.

Sin embargo, ha trascendido públicamente que el Gobierno de Puerto Rico no cuenta con los fondos necesarios para una protección óptima de estos ecosistemas. Se ha señalado que existe el acceso a ciertos programas federales de protección y conservación de estos arrecifes; no obstante, no se ha podido acceder a estos plenamente ya que los arrecifes no son considerados estructuras esenciales.

Por tanto, y con el fin de lograr una mayor protección de los arrecifes de coral en Puerto Rico, y cónsono con nuestras realidades geográficas y meteorológicas, es prioridad para esta Asamblea Legislativa declarar los arrecifes de coral como una estructura esencial para la protección y conservación de nuestras costas y otros ecosistemas. El cambio climático es una realidad hoy día, y nos compete adoptar las medidas que sean necesarias para cumplir cabalmente con nuestra responsabilidad de protección de nuestros recursos y allanar el camino para la obtención de recursos económicos que aporten a esta encomienda.

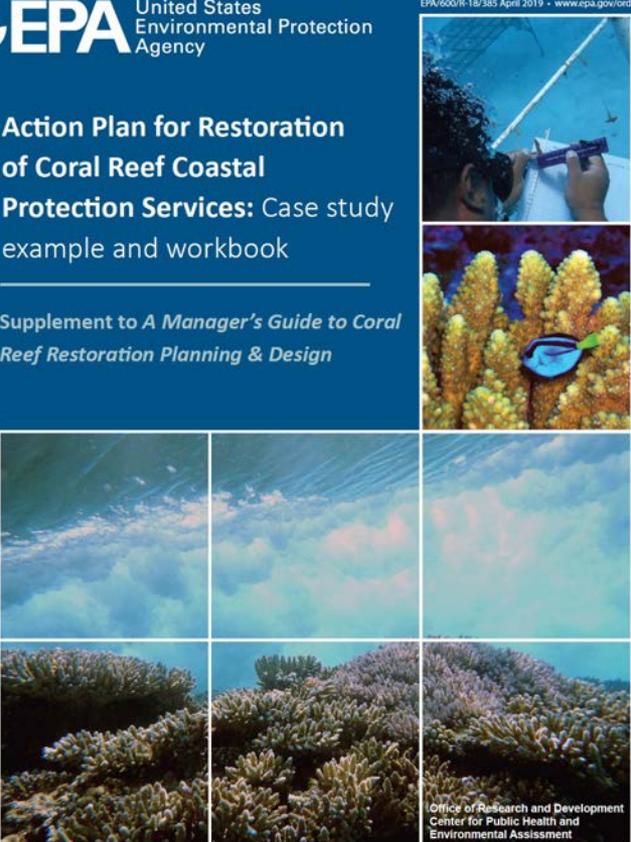
Public Sector: Advancing guidance

 **EPA** United States Environmental Protection Agency

EPA/600/R-18/385 April 2019 • www.epa.gov/ord

Action Plan for Restoration of Coral Reef Coastal Protection Services: Case study example and workbook

Supplement to *A Manager's Guide to Coral Reef Restoration Planning & Design*



Office of Research and Development
Center for Public Health and Environmental Assessment

Coral Reef Restoration for Risk Reduction (CR4): A Guide to Project Design and Proposal Development



Photo credit: Curt Storlazzi, USGS

Working Group

Austen Stovall, University of California Santa Cruz
Doug Bausch, NiyamIT Inc.
Mike Gill, Federal Emergency Management Agency
Juliette Hayes, US Army Corps of Engineers
Jen Koss, National Oceanic and Atmospheric Administration
Janan Reilly, Federal Emergency Management Agency
Curt Storlazzi, U.S. Geological Survey
Michael W. Beck, University of California Santa Cruz

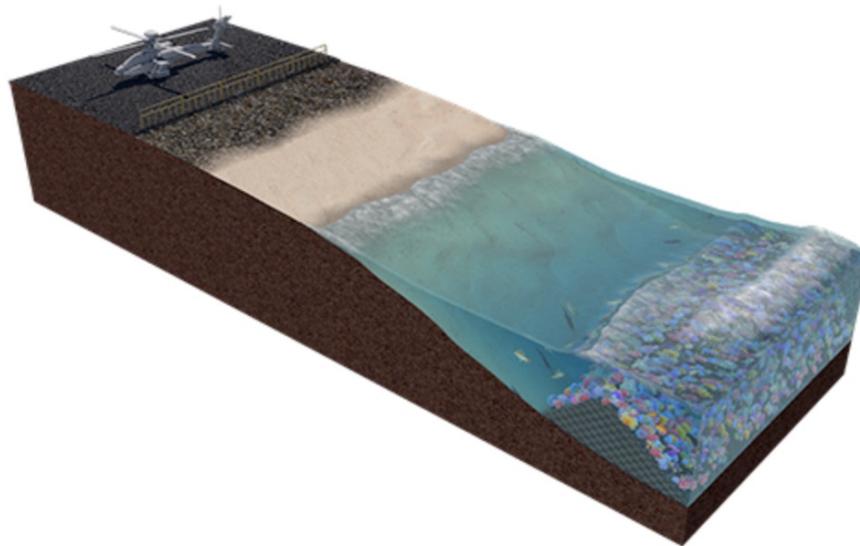
Public Sector: Advancing reef restoration

Defense Advanced Research Projects Agency > DARPA Launches Program to Mitigate Coastal Flooding, Erosion and Storm Damage

DARPA Launches Program to Mitigate Coastal Flooding, Erosion and Storm Damage

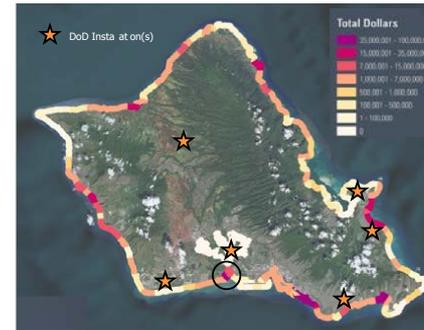
Reefense will integrate structural engineering, reef health and adaptive biology to address sea level rise

OUTREACH@DARPA.MIL
12/17/2020



Hazard Risk Reduction Benefits exceed \$1.8 billion annually for US Reefs

The top 1 m of Reef can protect infrastructure



Region	Location	Annual expected benefits		
		Length of reef (km) Length of reef (km) with benefits (\$1000/ft/ft/ft/ft/ft)	Length of reef (km) Length of reef (km) with benefits (\$1000/ft/ft/ft/ft/ft)	Length of reef (km) Length of reef (km) with benefits (\$1000/ft/ft/ft/ft/ft)
Hawaii	Kaunoi	12	12	12
	Maui	10	10	10
	Oahu	10	10	10
	Waikiki	10	10	10
Pacific Area	HI Kaneohe	10	10	10
	HI Kaneohe	10	10	10
Alaska	Alaska	10	10	10
	Alaska	10	10	10
Florida (USAF)	Florida	10	10	10
	Florida	10	10	10
USAF	USAF	10	10	10
	USAF	10	10	10
Total	Total	100	100	100
	Total	100	100	100

- These dollar figures represent the estimated cost savings per year by the top 1m of fringing coral reefs (Source: USGS 2019-1027 report and Reguero et al. 2021, Nature Sustainability)
- Protecting some areas in Hawaii (see circled area) could create large ROI where we have a lot of DoD Installations: (Joint Base Pearl Harbor, Hickman FTAC, Hickman AFB, NAVFAC Hawaii)
- There are 1,700 military installations in worldwide coastal areas that may be effected by sea level rise and storm surges
- It would cost \$30M to replace the top 1m of reef in a km so some places have a return of investment in a year (see circled area)

Source Selection Information - See FAR 2.101 and FAR 3.104

What is the Private Sector doing?

Resilience Infrastructure Bonds

Munich Re

Support pre-storm reef restoration based on projected hazard risk reduction benefits

Pay for defense through reduced cost of insurance bond

Insurance

Swiss Re

Set rates to promote reef protection

Fund restoration of damaged reefs

Private Sector: Reef insurance



NEWSROOM

World's First Coral Reef Insurance Policy Triggered by Hurricane Delta

The almost \$800K payout from the policy will fund the repair of a stretch of reef and beach along the Mesoamerican Reef in Quintana Roo, Mexico

December 07, 2020 | Cancun, Mexico

Private Sector: Reef insurance

THE SENATE
THIRTY-FIRST LEGISLATURE, 2021
STATE OF HAWAII

S.C.R. NO. 159

MAR 12 2021

SENATE CONCURRENT RESOLUTION

URGING THE DEPARTMENT OF LAND AND NATURAL RESOURCES TO EXAMINE AND CONSIDER REEF INSURANCE TO SUPPORT NATURE-BASED SOLUTIONS TO PROTECT HAWAII'S COASTLINES AND COASTAL INFRASTRUCTURE FROM NATURAL DISASTERS.

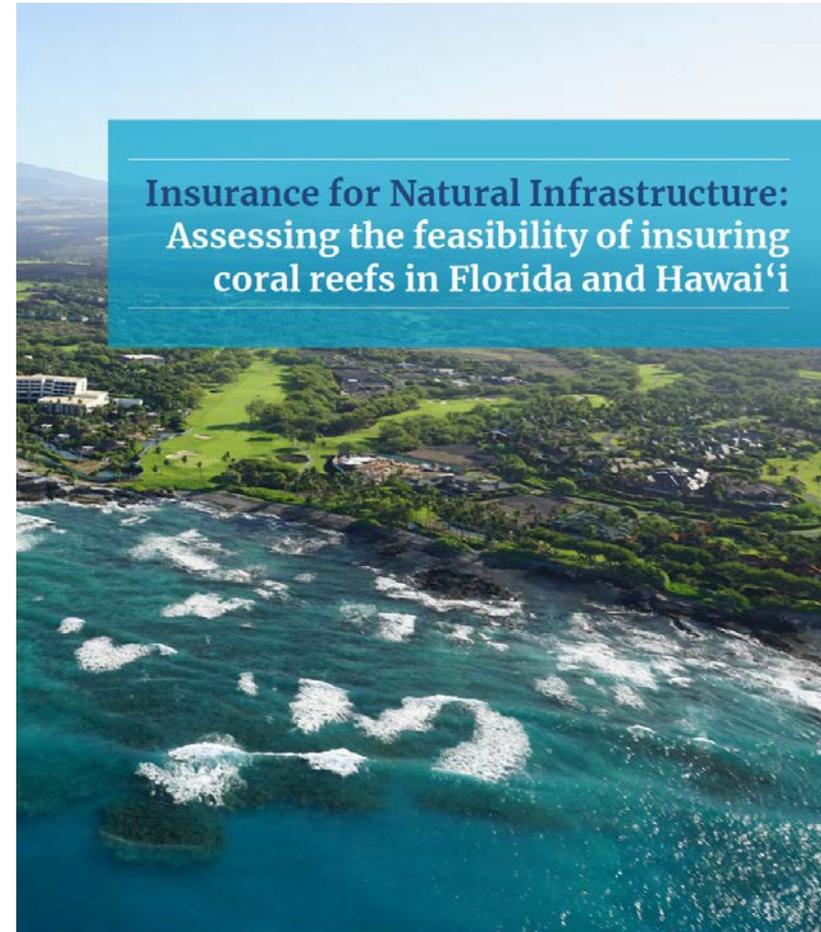
1 WHEREAS, the State has environmental resources such as
2 coral reefs, wetlands, forests, and other natural infrastructure
3 that, if healthy, effectively managed, and functioning, can help
4 mitigate the risks and related loss and damage from the effects
5 of climate change and natural disasters; and
6

7 WHEREAS, Hawaii's coastal areas and infrastructure are
8 facing exposure to climate change-related risks and disaster
9 events, including exposure to storms, high wave events, sea
10 level rise, and flooding; and
11

12 WHEREAS, climate scientists and other local and global
13 experts predict an increase in severity and frequency in such
14 events; and
15

16 WHEREAS, a study by a team from the United States
17 Geological Survey, The Nature Conservancy, and University of
18 California at Santa Cruz estimates that Hawaii's coral reefs
19 protect \$836,000,000 worth of coastal infrastructure from
20 flooding annually; and
21

22 WHEREAS, in addition to coastal protection, Hawaii's
23 nearshore coral reefs provide residents with income from fishing
24 estimated at \$13,400,000 annually, of which \$10,000,000 is
25 non-commercial catch; and



Summary

US coral reefs protect **>18,000 people** and **>\$1.805 billion** annually (vs \$2.064 billion for all other services)...and thus their most important ecosystem function in the US is ***protecting coastal communities.***

Coral reefs disproportionately protect the **young, old, low-income,** and **minorities.**

(ENVIRONMENTAL JUSTICE)



Opportunities

Include Nature in Industry Risk Models

Private incentives: Insurance, Resilience bonds

Public incentives: Pre-disaster mitigation funds, pre-disaster green bonds, and special purpose tax districts; Post-disaster restoration funds

Prioritizing Natural Infrastructure in Policy:

FEMA, USACE

Linking *coral reef health* and *restoration* to
coastal hazards risk reduction

Reduce risk to, and
increase the resiliency, of our Nation's
coastal communities

.....while also maintaining biodiversity,
fisheries, tourism, etc.



Thank you!

Any questions?