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CMHRP Coral Reef Research

Coral Reefs as National Natural Infrastructure for Risk Reduction:

Implications for the Public and Private Sectors

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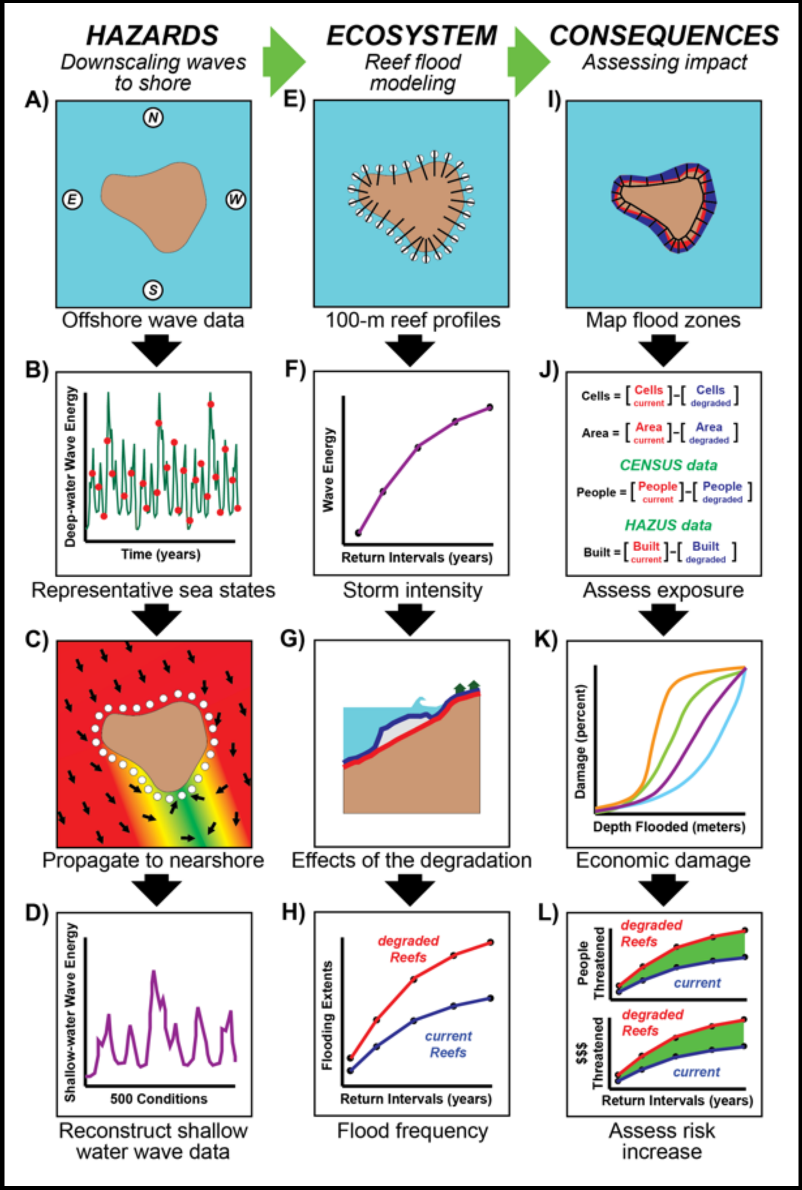
Approach for Assessing Coastal Protection Value of Coral Reefs



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

Reguero et al., 2021, *Nature Sustainability*

Modeling Coral Reef-lined Coastal Flooding

10 m^2 resolution

= 100 year floodplain with current reefs
= coral reefs

For a building in the 100-yr flood hazard zone *(1% chance of flood damage any given year)*, the probability of being flooded once in a 30-yr period *(a typical home mortgage)* is **26%**

Storlazzi et al., 2025, *Science Advances*

Flooding with Potential Restoration

10 m^2 resolution

= 100 year floodplain with restored coral reefs
= 100-year floodplain with current coral reefs

= coral reefs

With coral reef restoration, the probability of being flooded once in a 30-yr period
(a typical home mortgage)
decreases by **20%**

Storlazzi et al., 2025, *Science Advances*

Social Protection Provided by Potential Restoration

10 m^2 resolution

= 100 year floodplain with current reefs
= 10 people protected
= 20 people protected
= 30 people protected
= 40 people protected
= 50 people protected
= coral reefs

Storlazzi et al., 2025, *Science Advances*

Economic Protection Provided by Potential Restoration

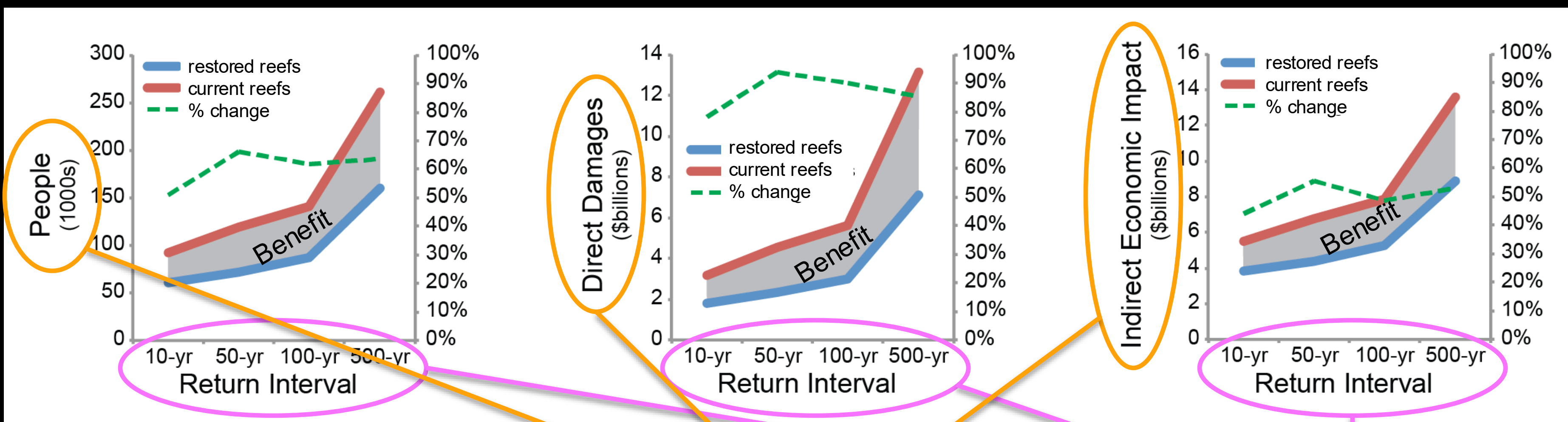
10 m^2 resolution

= 100 year floodplain with current reefs
= $1,000,000 in property protected
= $2,000,000 in property protected
= $3,000,000 in property protected
= $4,000,000 in property protected
= $5,000,000 in property protected
= coral reefs

Storlazzi et al., 2025, *Science Advances*

Risk Valuation Framework

How does the insurance industry, US Federal Emergency Management Agency, and the US Army Corps Engineers calculate annual risk reduction benefits?



Annual Risk Reduction Benefit = Magnitude of Impact X Probability of Occurrence

Reguero et al., 2021, *Nature Sustainability*

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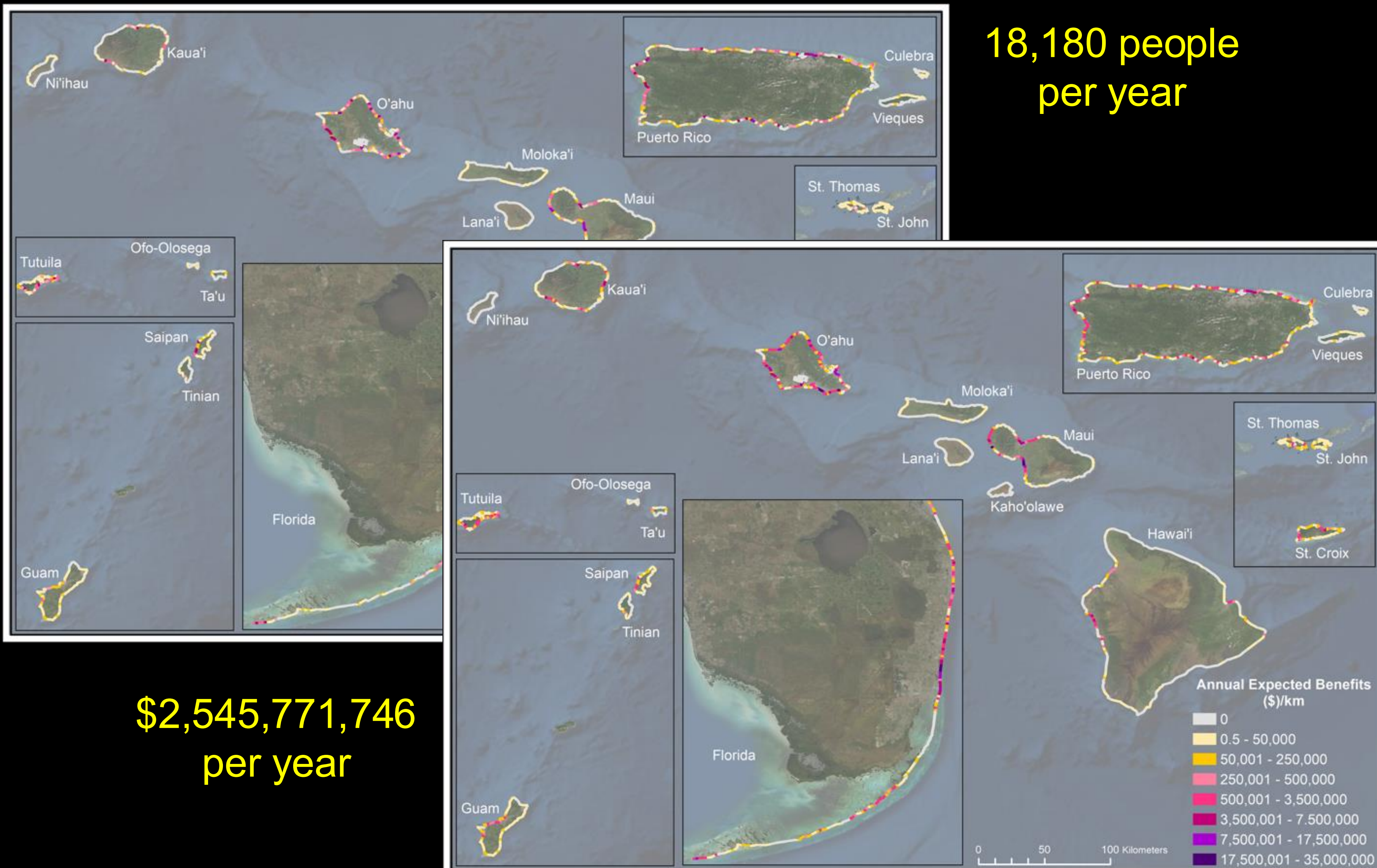
National Evaluation of Risk Reduction

18,180 people per year



$2,545,771,746 per year

Reguero et al., 2021, *Nature Sustainability*

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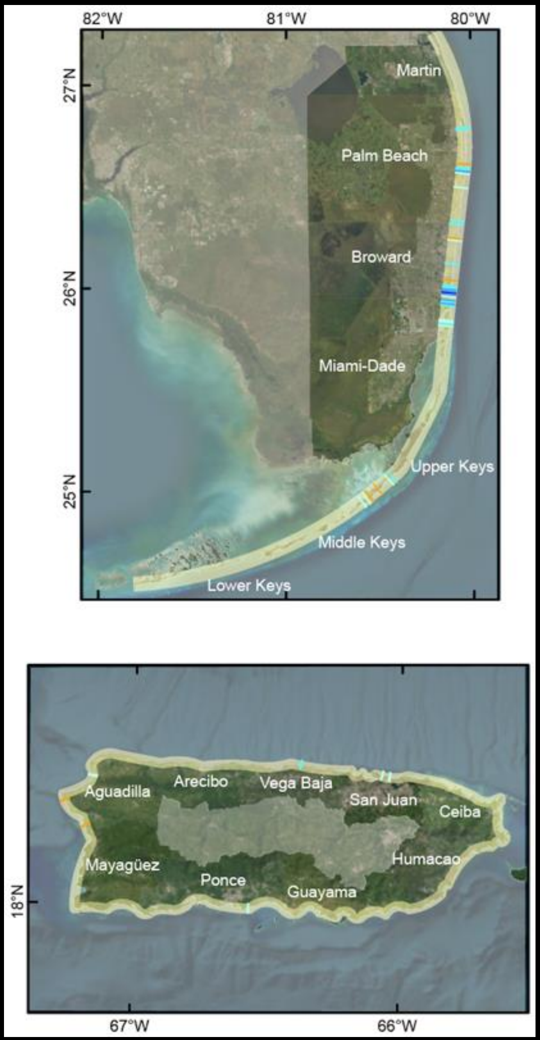
Cost : Benefit Analyses

Assuming coral reef restoration and 30 years maintenance cost = $3,000,000 per kilometer



Immediate return on investment

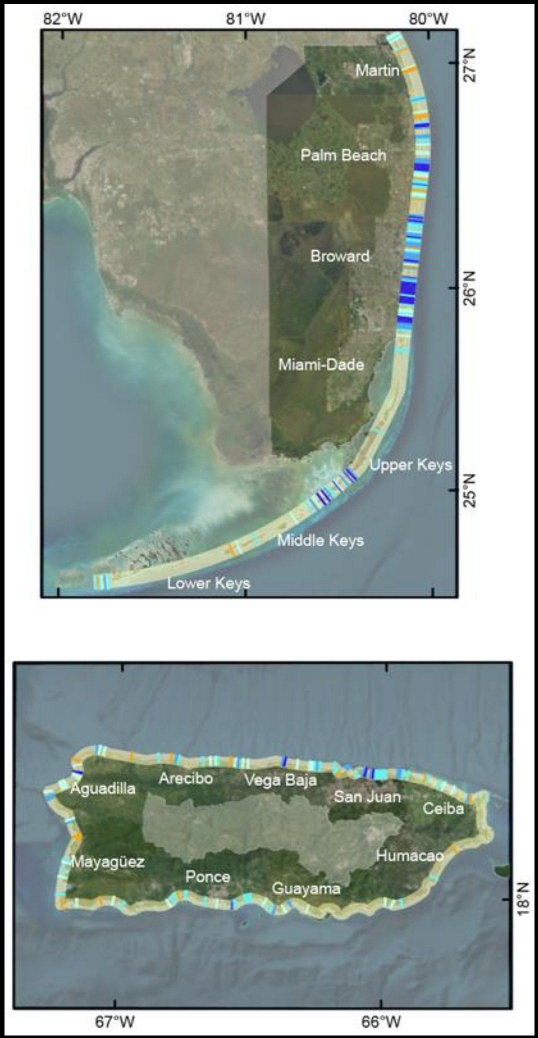
~2%

If benefits > cost, then the project has a positive return on investment

Paid for over 30 years at 7% discount rate

~20%

Most benefits occur where communities, infrastructure, and economic activity are located



Storlazzi et al., 2025, *Science Advances*

So What?

All of the tools used to fund

gray infrastructure
(seawalls, breakwaters, etc)

can be used to fund

green infrastructure
(ecosystem restoration)

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

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

WHO PAYS / **WHO BENEFITS**

Who pays: PUBLIC — Who benefits: PUBLIC

Funds are provided by general taxes, benefits cannot be assigned to any specific beneficiary.

Pre-Disaster Funding

Globally
- Infrastructure spending (e.g. transportation, energy, water) may include flood protection

In the United States
- 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

In Europe
- Natural Capital Financing Facility

In Developing Countries
- World Bank Green Climate Fund
- Global Environmental Facility Small Grants
- Mexico Fund for Disaster Prevention

Post-Disaster Funding

In the United States
- FEMA Flood Mitigation Assistance Program

In Developing Countries
- 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

Who pays: PRIVATE — Who benefits: PUBLIC

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.
- Pre and Post Disaster Funding
- Green Bonds

Who pays: PRIVATE — Who benefits: PRIVATE

Private funds provide benefits to a narrow group.

Infrastructure Finance

In the United States
- Special Purpose Districts
- Flood Control Districts
- Storm water Districts
- Tax Increment Financing Districts

Globally
- Public-Private Infrastructure Partnerships

Insurance – Pre-Disaster

In the United States
- FEMA Community Rating System

Insurance – Post-Disaster

Globally
- Insurance and Reinsurance Payouts
- Catastrophe Bonds
- Resilience Bonds

Who pays: PUBLIC — Who benefits: PRIVATE

Public expenditures, either directly or through tax subsidies, provide benefits to a narrow group.
- 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*

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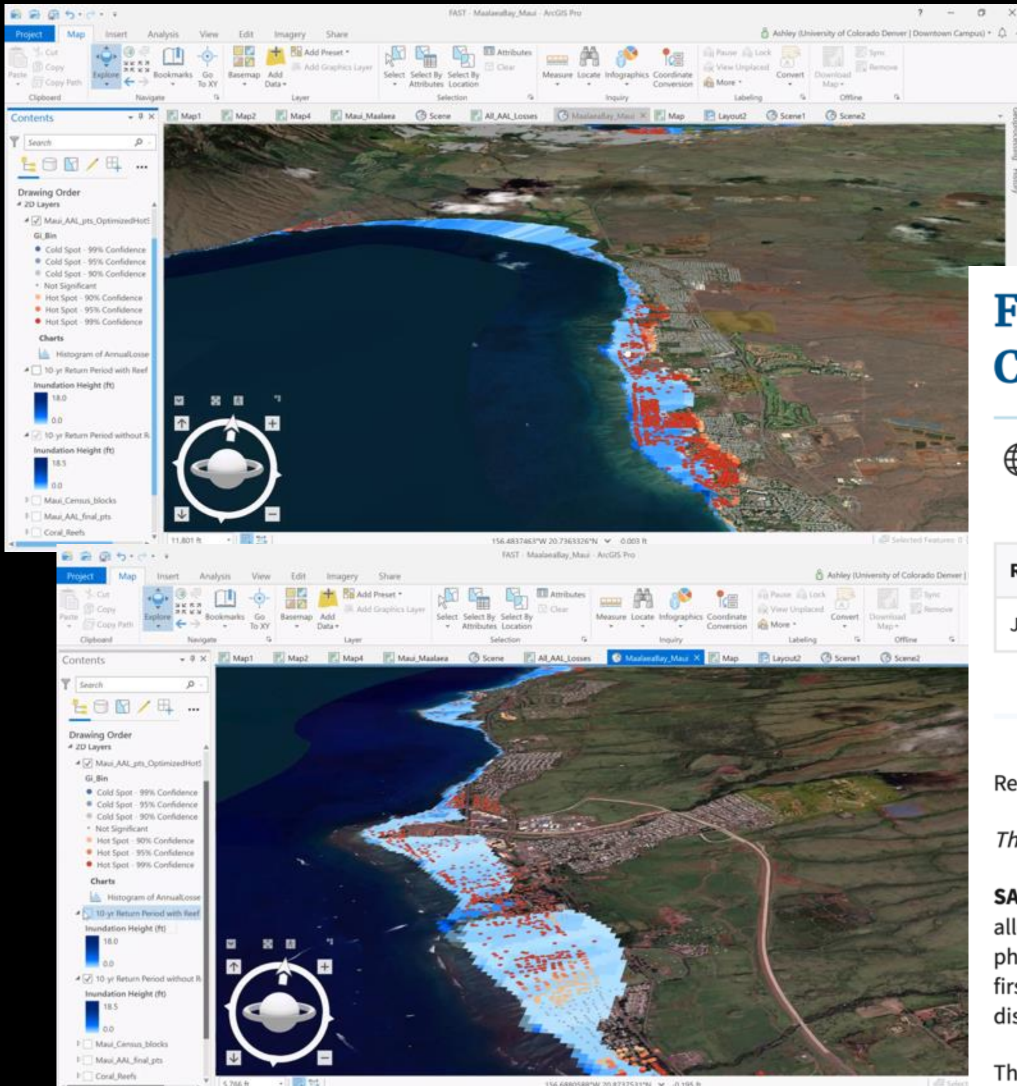
First Successes: Public Sector



US Federal Emergency Management Agency's
Flood Assessment Structure Tool (FAST)

US Federal Emergency Management Agency's first successful Hazard Mitigation Grant Program award to restore coral reefs for hazard risk reduction
(7 kilometers to protect Puerto Rico's capital and international airport)

FEMA Allocates Millions to Restore Coral Reefs in the Coast of San Juan

English Español

Release Date	Release Number
June 12, 2023	NR 572

Release Date: June 12, 2023

This is the first allocation of the federal agency for this type of project

SAN JUAN, Puerto Rico – The Federal Emergency Management Agency (FEMA) allocated $3 million under the Hazard Mitigation Grant Program (HMGP) for the first phase of restoration for the coral reef barrier located in the San Juan Bay. This is the first allocation under HGMP to restore a natural resource to protect survivors after a disaster.

The project seeks to reduce flooding and protect some 800 structures surrounding the communities of Escambrón, Condado, Ocean Park and Puntas Las Marías. The initiative consists of two phases, for a total of approximately $38.6 million.

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First Successes: Public Sector

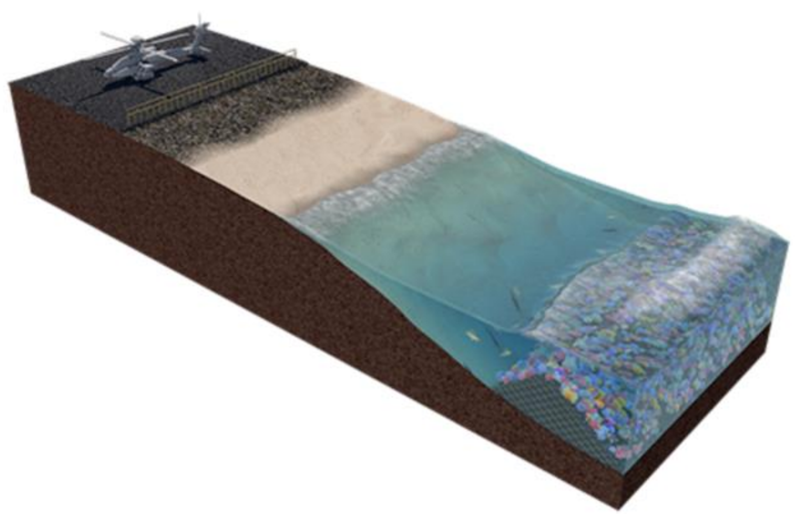
US Department of Defense Advancing Coral Reef Restoration for Coastal Protection

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

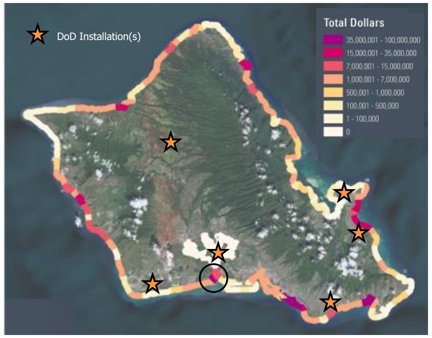
DARPA Launches Program to Mitigate Coastal Flooding, Erosion and Storm Damage

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

OUTREACH@DARPA.MIL
12/17/2020



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



The top 1 m of Reef can protect infrastructure

Table 1 | Length of coastline with high risk reduction economic savings provided by US coral reefs

Region	Location	Annual expected benefit: Length of reef-lined coast (km) with benefit ≥US$0.25 million $km^{-1} yr^{-1}$	Length of reef-lined coast (km) with benefit ≥US$1 million $km^{-1} yr^{-1}$	Length of reef-lined coast (km) with benefit ≥US$10 million $km^{-1} yr^{-1}$
Hawaii	Kauai	32	10	-
	Maui	62	38	12
	Oahu	158	112	12
	Hawaii	38	28	-
Florida	Peninsula	116	70	12
	FL Keys	46	36	-
Puerto Rico	Puerto Rico	104	26	-
American Samoa	Tutuila	30	1	-
Guam, CNMI	Guam	36	4	-
	Saipan	18	6	-
	Tinian	2	2	-
USVI	St. Thomas	16	4	-
	St. John	6	2	-
	St. Croix	22	6	-
Total		686	325	36

[illegible]

- 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

1

~$70 million program to develop make hybrid coral reefs grow faster and be more resilient to cost-effectively protect tropical coastal military bases from storm-driven flooding

First Successes: Private Sector

Insurance, Re-insurance, Catastrophe and Resilience Bonds

Key Points

- There is a large and growing pool of mechanisms to fund natural infrastructure for flood risk reduction.
- Promising new mechanisms include reinsurance, catastrophe & resilience bonds, and green bonds.
- Key local factors determine the best financing approaches for natural infrastructure.
- The biggest opportunities for developing new funding are in redirecting post-disaster recovery towards risk-reducing investments.

Financing Natural Infrastructure

A new report identifies opportunities for investing in natural infrastructure for coastal defense

Coastal development and climate change are increasing the risks to people and property from flooding. In the past 10 years, insurers have paid out more than US $200 billion for coastal damages from storms globally.

Coastal wetlands act as natural defenses that protect coastlines by reducing waves, storm surge and flooding. However, we spend thirty times more on building and maintaining gray infrastructure, such as seawalls, than we do on building and restoring natural infrastructure such as reefs and wetlands.

A new report – "*Financing Natural Infrastructure for Coastal Flood Damage Reduction*"- reviews the existing and potential funding avenues for natural infrastructure, examines the barriers that prevent the broader use of these natural solutions, and proposes a framework to identify when and where natural infrastructure financing may be most relevant.

The good news is that there is a large and growing pool of financial tools that could fund natural infrastructure, with wins for both flood risk reduction and conservation. In many cases, the same tools that fund gray infrastructure could also support natural solutions. While government programs for post-disaster funding are well-known, forward looking policies have begun to encourage pre-disaster spending that explicitly supports the use of natural infrastructure for risk reduction.

The report highlights the important role of the insurance industry in both preventative and recovery efforts and in driving innovation towards new solutions. With the development of new financial tools, including catastrophe and resilience bonds, and with a growing community of practice and many project examples, many of the existing barriers to natural infrastructure can be overcome.

Key local factors that help determine when and where natural infrastructure financing may be most relevant.

- **Geography**- The spatial relationship between development and ecosystems.
- **Ecosystems**- The types and conditions of ecosystems present.
- **Known flood risks**- The frequency and severity of floods, and the exposure of people and assets to these risks.
- **Existing natural infrastructure funding**- The financial mechanisms that may be readily deployed in a particular area.
- **Financing system capabilities**- The capacity of the banking, public finance, and insurance sectors.
- **Institutional and socioeconomic capacity**- The financial ability of the community to contribute towards funding risk reduction measures.

Find the report at
www.lloyds.com/coastalresilience

Natural habitats, such as coral reefs, mangrove swamps and salt marshes, can reduce insurance loss frequency by around a half in coastal flood cases caused by higher frequency-lower severity storms, a Swiss Re Institute study of Florida coastal areas shows.

Florida, coastal floods and natural protection

Florida has the most coastal property exposed to storm surge of any US state[1] and has been the focus of a recent data analysis by Swiss Re Institute.

We examined flood insurance losses (claims[2] and policies[3]) in Florida over the period 2009–22, sourced from the OpenFEMA data of the National Flood Insurance Program (NFIP). Over this study period, nearly 40% of NFIP claims in coastal areas were attributed to lower severity events (up to category 3 hurricanes). This represented USD 1.15 billion in paid insurance losses. Our analysis focused on this segment of overall claims.

We cross referenced the claims data with geospatial insights from the Coastal Protection layer used in our Swiss Re Institute *Biodiversity and Ecosystem Services* (BES) Index.[4] This layer represents the modelled coastal risk reduction due to the presence of coastal habitats, namely coral reefs, mangroves, salt marshes and seagrass meadows. We isolated coastal areas with high BES protection and compared claims frequency to those with less protection.

The benefits of natural protection

Our results were striking. Areas with high BES coastal protection saw on average 1% of insurance policies report a claim in a month with a flood event, compared to 2.8% in areas with less coastal protection. Even when accounting for other flood risk factors, the mitigating effect of coastal habitats remained significant. We consistently observed a reduction in loss frequency of between 42% and 65% in areas with high BES coastal protection. We conclude that for the data analysed, **the presence of coastal habitats reduces the frequency of insured flood losses from lower severity storms in Florida by around a half.**

Storm surge and coastal protection

Our empirical findings are supported by a wider body of academic research for all storm types. Detailed studies have been undertaken on the effects of mangrove forests,[5] salt marshes[6] and coral reefs[7] on wave attenuation during storm surges. The size, area and form of these natural barriers can all contribute to reducing storm surge impact.

The effectiveness and benefits of natural barriers can be quantified using modelled estimates. One study of a salt marsh on the New York state coast projects a reduction of structural losses from storm surge by 11–12% annually until 2050, even allowing for climate change.[8] Another study estimates that 325 kilometres of coral reefs provide the US with the equivalent annual value of USD 5.3 billion of flood protection.[9] Mangrove swamps are calculated to have saved USD 1.5 billion in flood damage during Hurricane Irma,[10] while coastal wetlands are estimated to have prevented USD 625 million flood surge damage during Hurricane Sandy.[11]

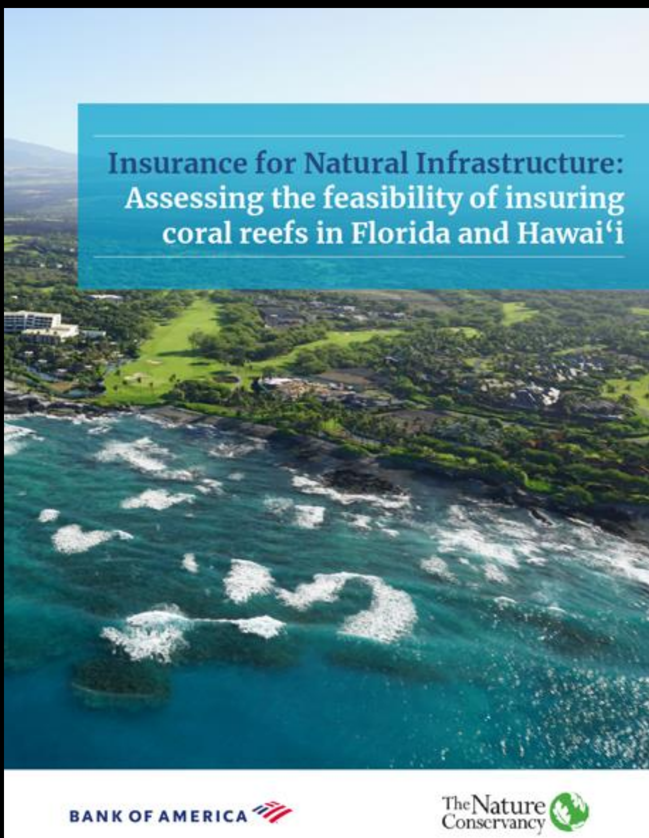
Degradation of coastal habitats reduces the protection they afford. One Florida study estimated coral reef degradation will result in increased damages from coastal flood by USD 385 million annually.[12] Degradation to habitats can be the result of one-off damages, such as storms; or systemic damages resulting from environmental changes. This is a matter of relevance for the insurance industry given their protective benefits.

Picture: USA, Florida, Aerial photograph of mangroves and sandbars along the western coastline of Tampa Bay – Getty Images

Decker et al., 2025, *Swiss Re Institute*

First Successes: Private Sector

Insuring Nature as Coastal Defense Infrastructure



The Nature Conservancy Announces First-Ever Coral Reef Insurance Policy in the U.S.

Building upon the world's first reef insurance policy covering hurricane damage in Mexico, Hawaiʻi adds tropical storms to coverage.

November 21, 2022

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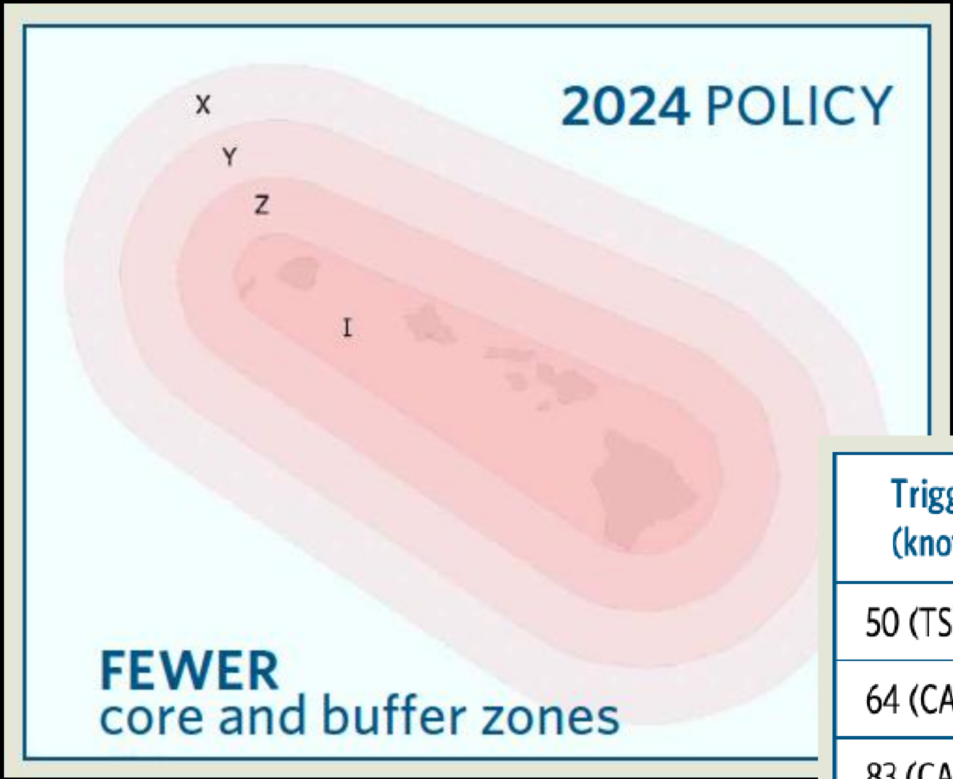
SHARE

Today, The Nature Conservancy (TNC) announces it has purchased the first-ever coral reef insurance policy in the United States. The policy will provide funding for rapid coral reef repair and restoration across Hawaiʻi immediately following hurricane or tropical storm damage.

First Successes: Private Sector

Insuring Nature as Coastal Defense Infrastructure



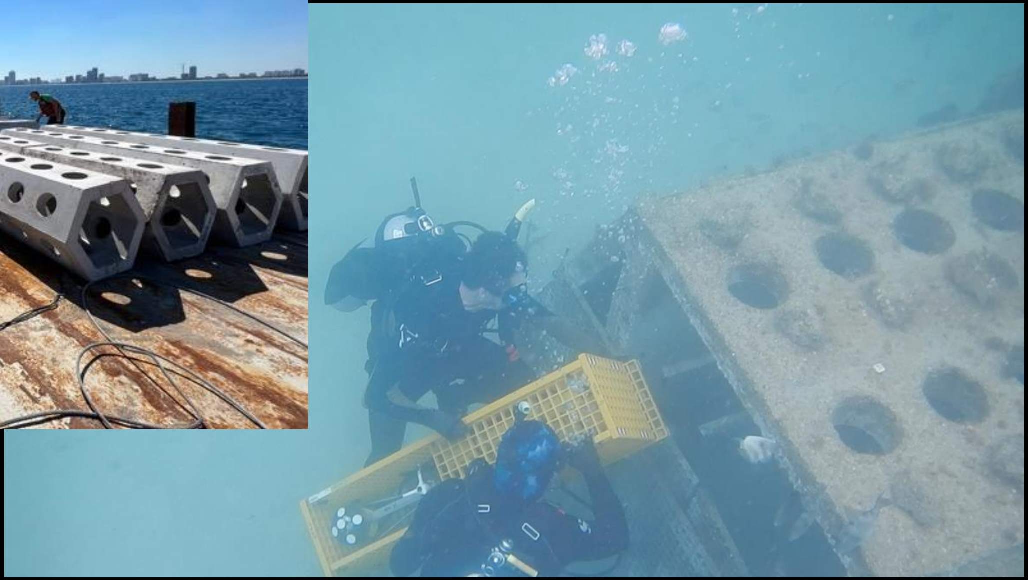
Trigger (knots)	Zone X	Zone Y	Zone Z	Zone I
50 (TS)	$0	$0	$0	$200,000
64 (CAT 1)	$0	$0	$200,000	$300,000
83 (CAT 2)	$0	$200,000	$300,000	$450,000
96 (CAT 3)	$200,000	$300,000	$450,000	$600,000
113 (CAT 4)	$300,000	$450,000	$600,000	$750,000
137 (CAT 5)	$450,000	$600,000	$750,000	$1,000,000

Next Steps

Increase Application of Corals Reefs as Nature-based Solutions by the Engineering Community

Deploy testbed structures

Determine performance



Any questions?

Thank you!