ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

NNBF Short Course: Benefits, Co-Benefits and Costs

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*(and credits to **Borja G. Reguero**, UCSC & **Michael W. Beck**, The Nature Conservancy / UCSC)*

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Coastal Planning and Engineering, Jacobs

Visiting Professor, University of Southampton




NNBF Benefits

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What Do We Mean By Benefits for NNBFs?

PROVISIONING

- Food
- Timber
- Firewood

REGULATING

- Air quality
- Water quality
- Flood protection

CULTURAL

- Heritage
- Recreation
- Tourism
- Education

SUPPORTING

- Nutrient Recycling
- Water Recycling
- Photosynthesis
- Habitat Provision

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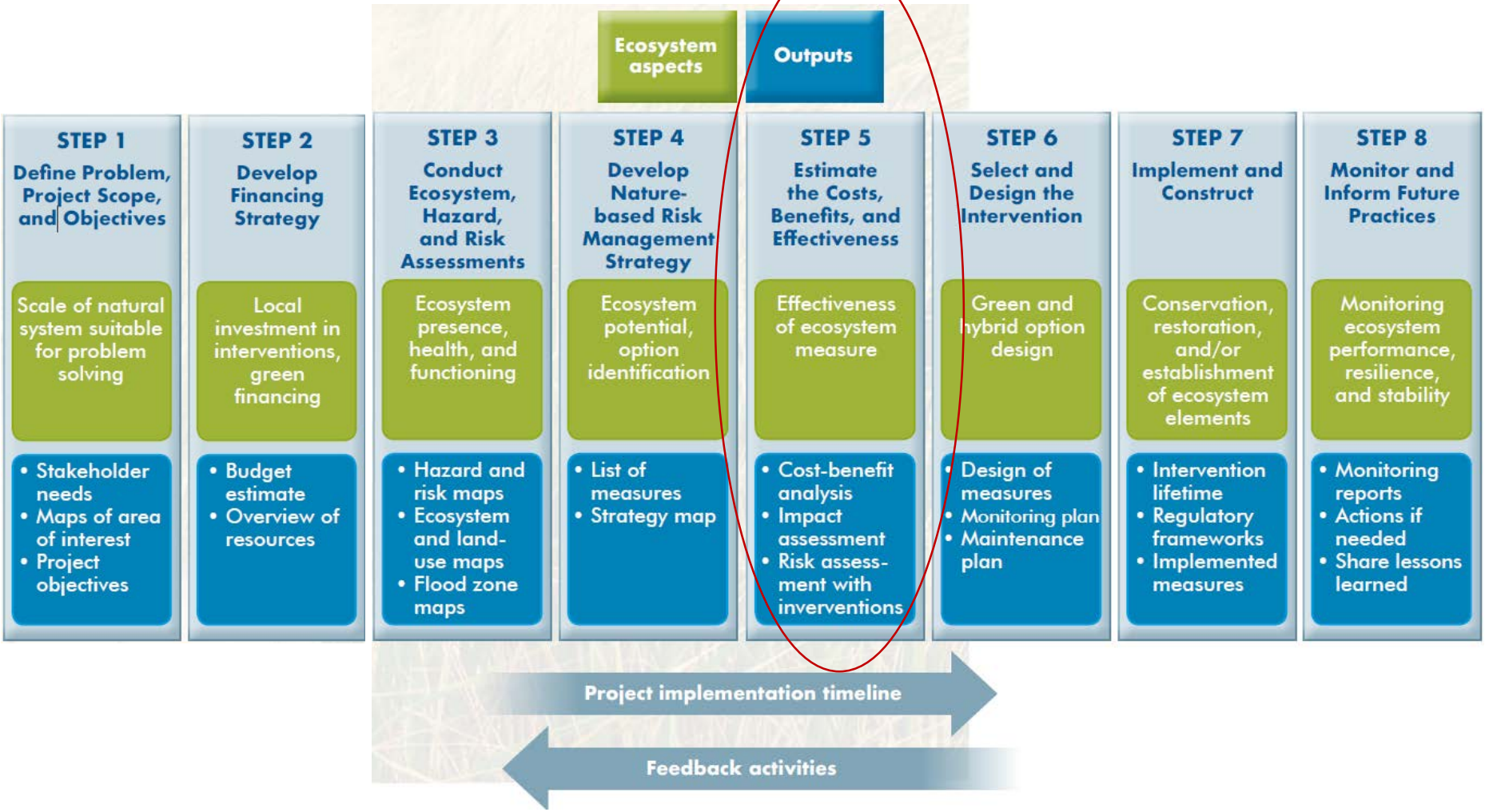
Why Report NNBF Benefits?

World Bank. 2017. Implementing nature-based flood protection: Principles and implementation guidance. Washington, DC: World Bank.



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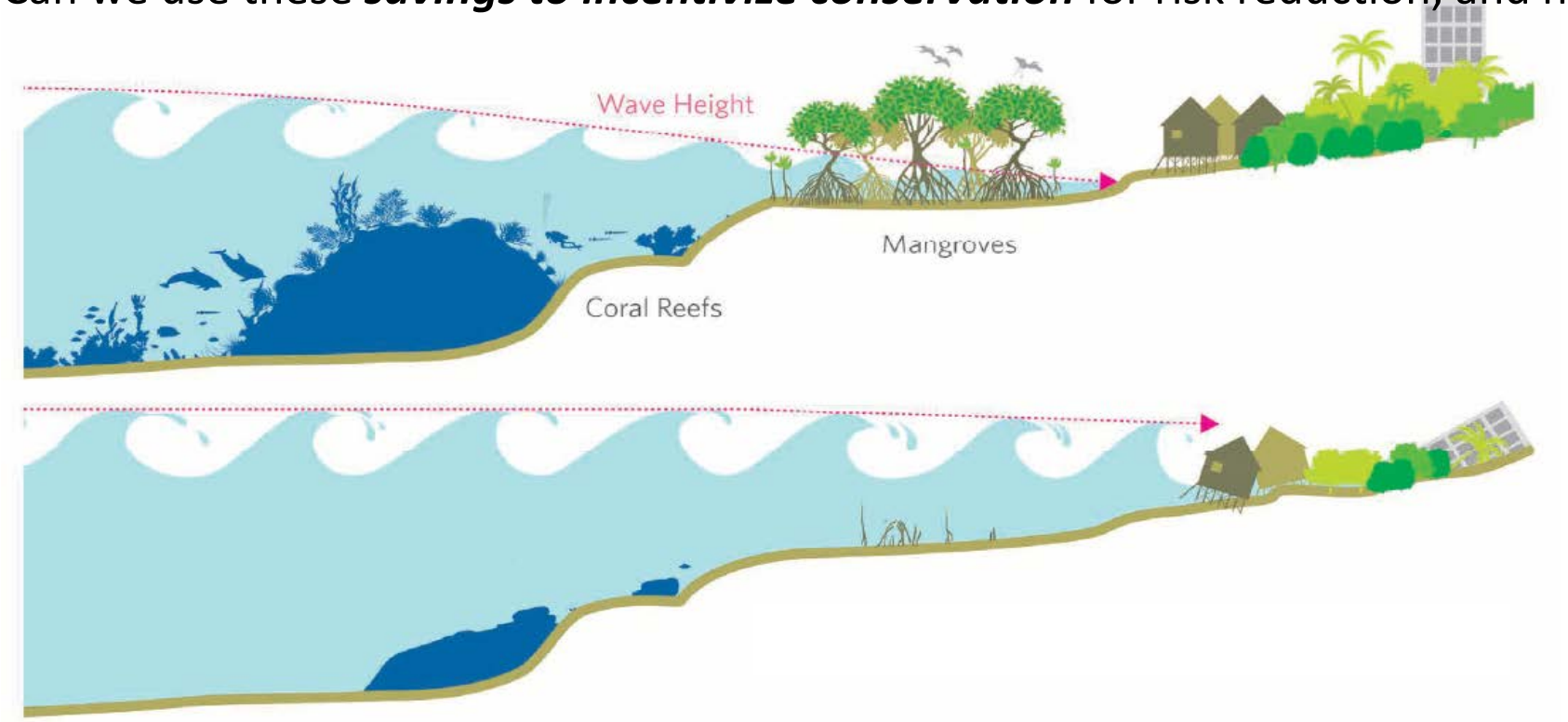
Why Report NNBF Benefits?

- Can coastal ecosystems ***reduce damages to people and property*** from hazards?
- When and where do these ***reductions translate to savings*** in property damages?
- Can we use these ***savings to incentivize conservation*** for risk reduction, and how?



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Observed Benefits of NNBF Projects

From Narayan et al., 2016

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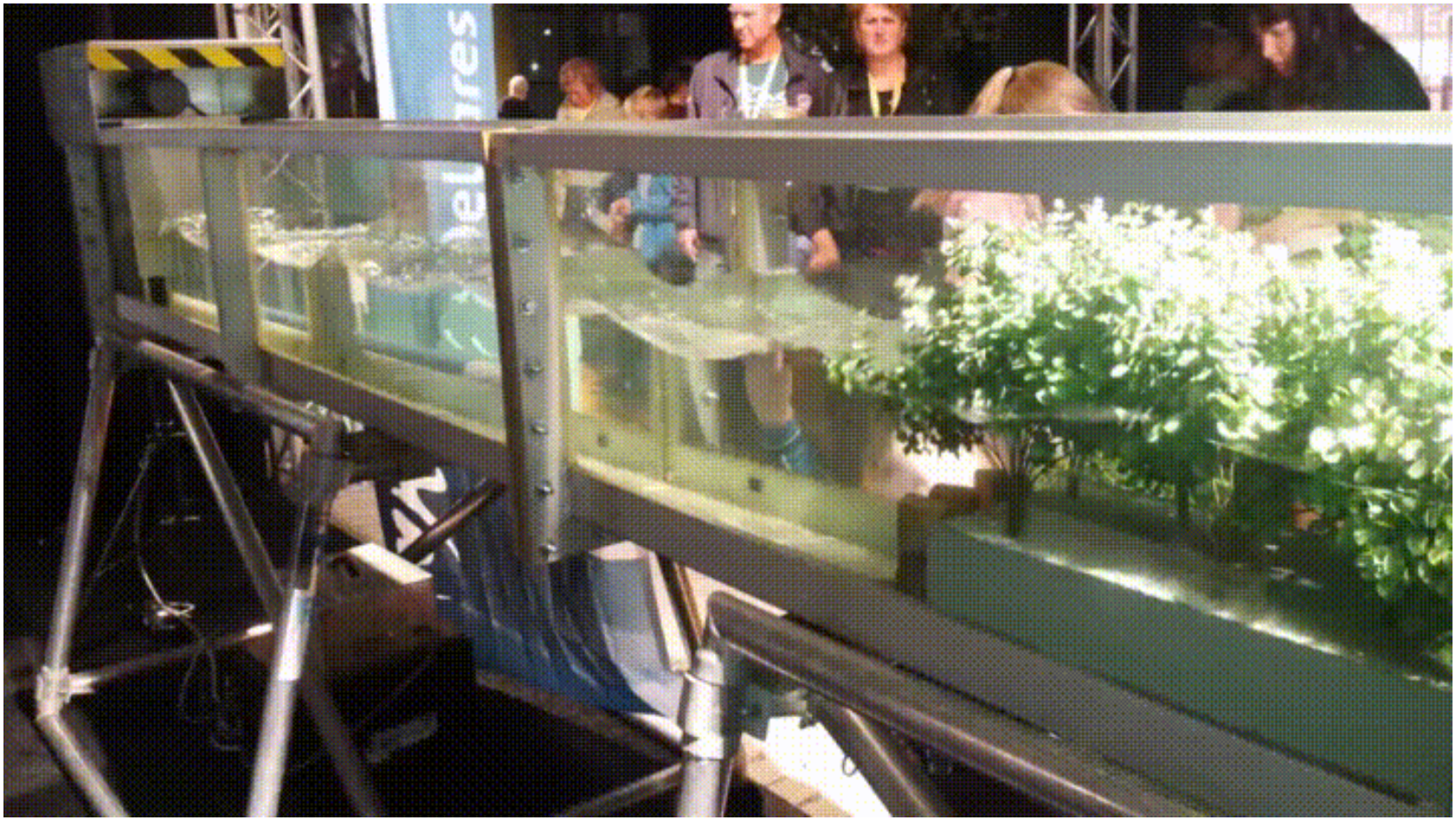
Measured Benefits of NNBF Projects – Experimental Models



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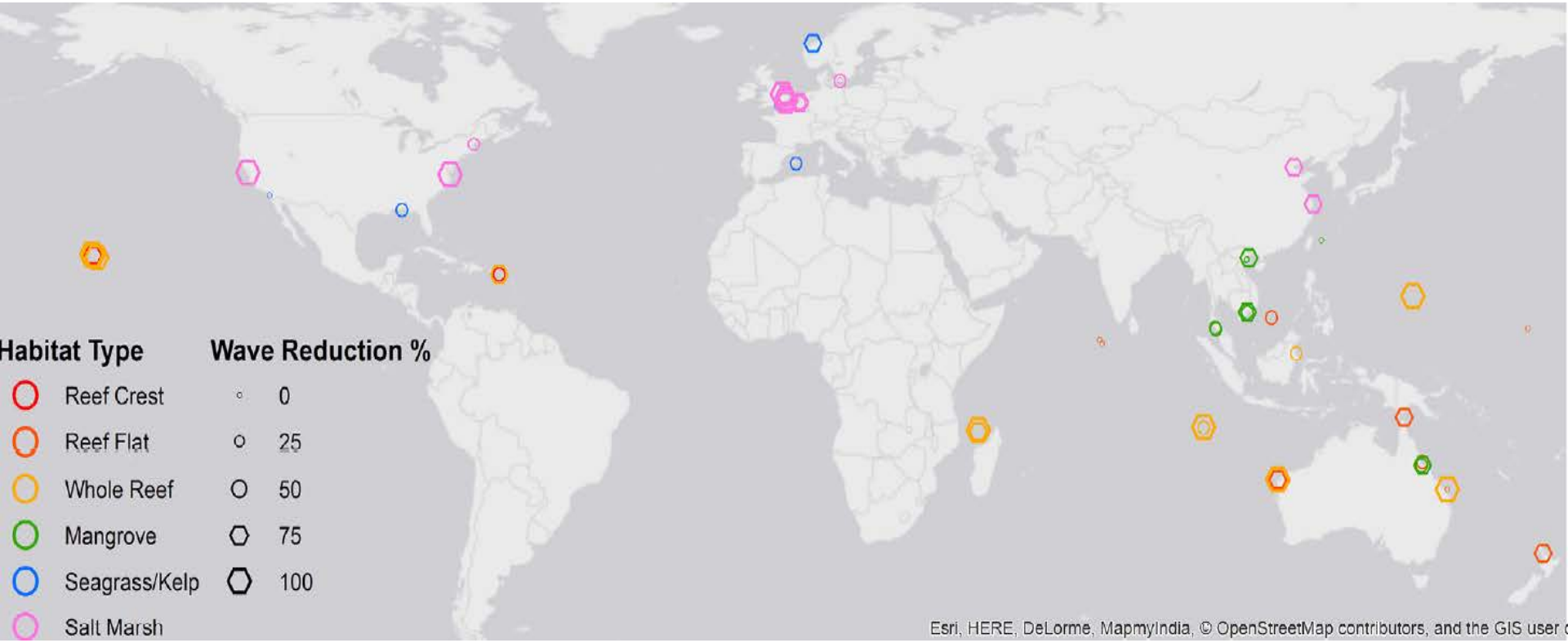
Measured Benefits of NNBF Projects – Field Measurements



From Narayan et al., 2016

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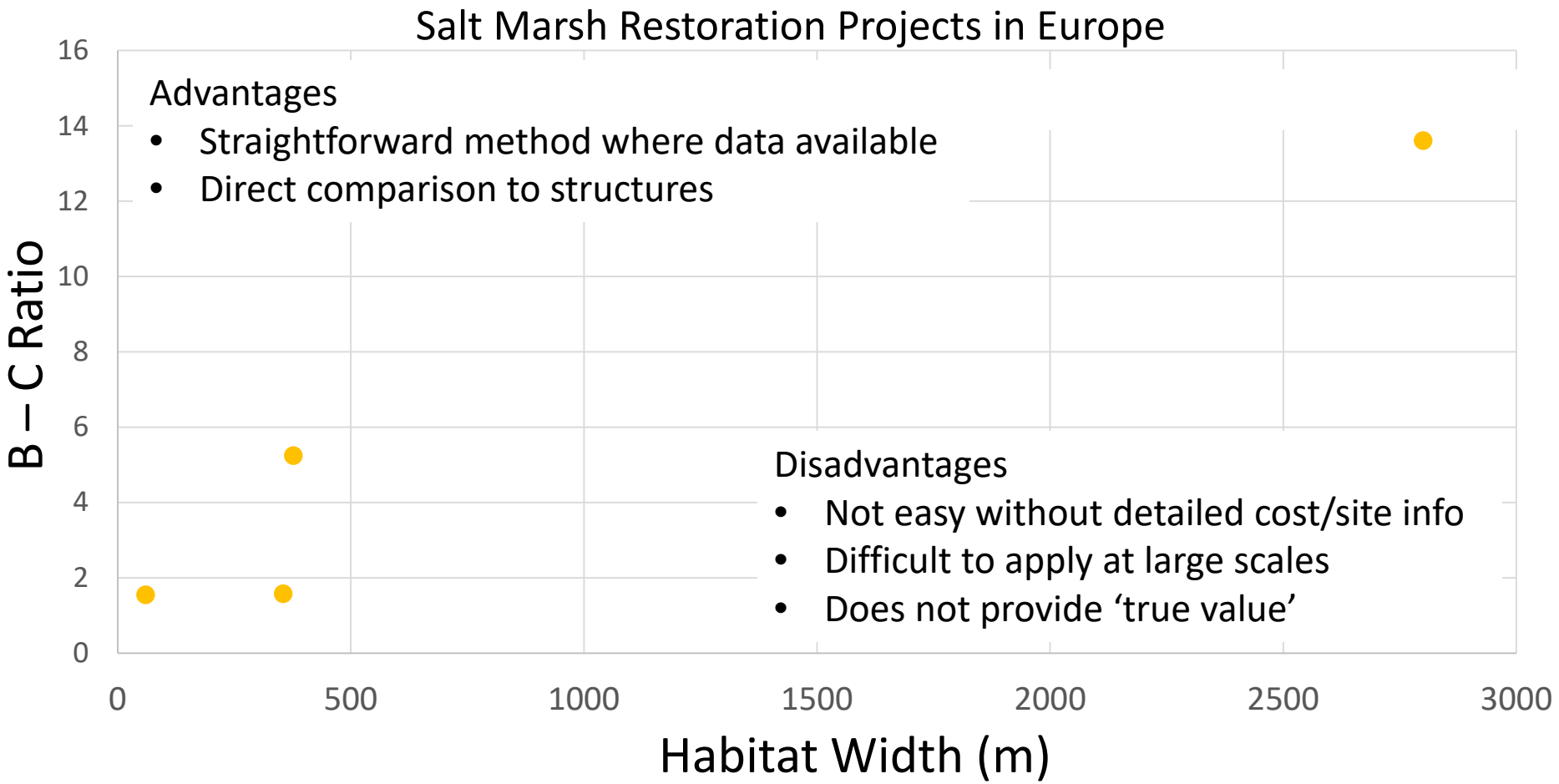
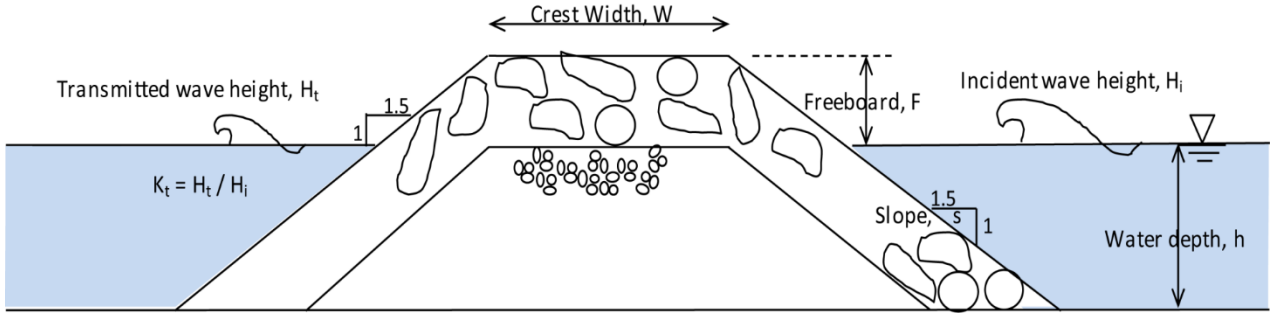
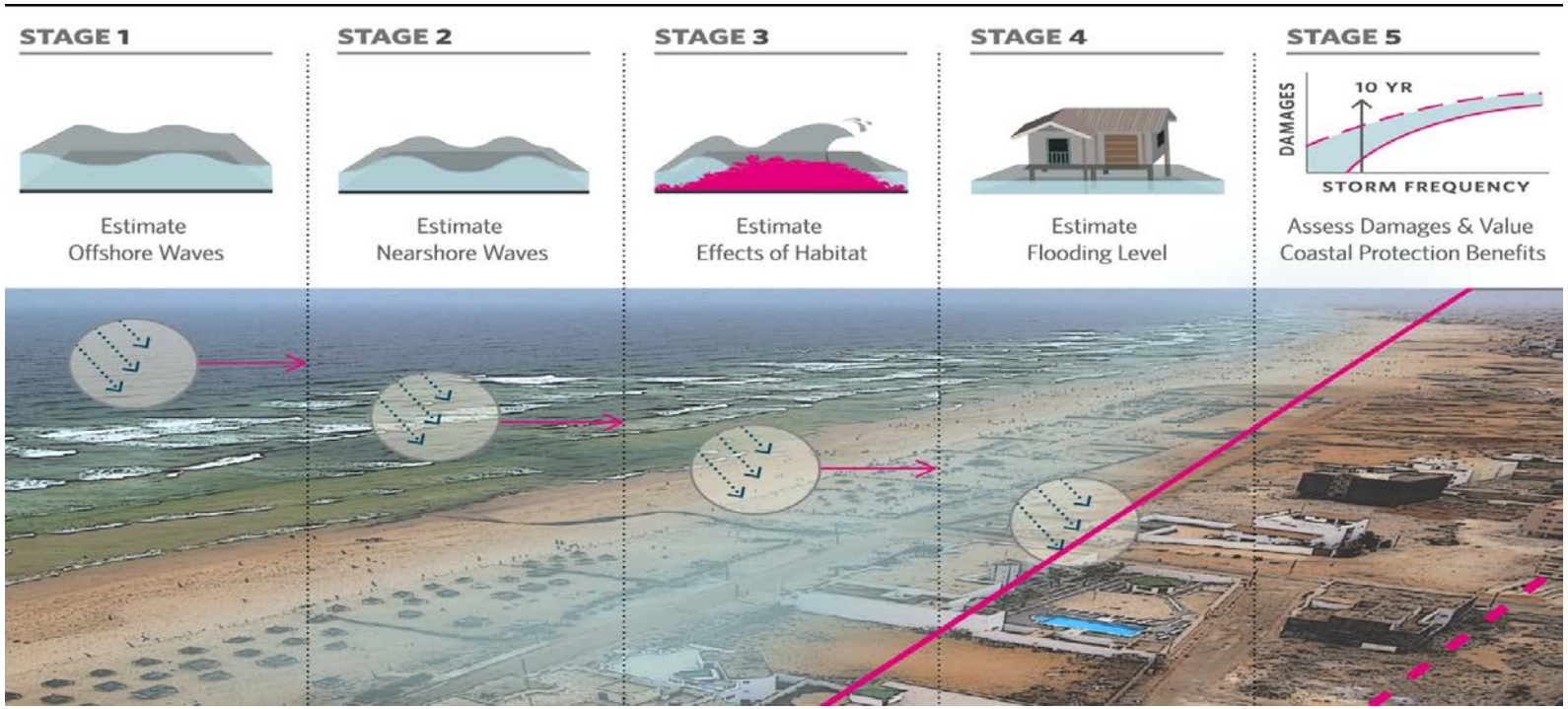
Reporting Benefits As Replacement Costs: Marshes





Reporting Benefits As Avoided Damages

- Direct quantitative estimation of ecosystem benefits for different coastal hazards
- Can be applied over large spatial scales (even globally)
- Reflects ‘true’ value and can be included in larger (national) accounting systems



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Global Annual Avoided Flood Damages from Mangroves

Losada et al., 2018

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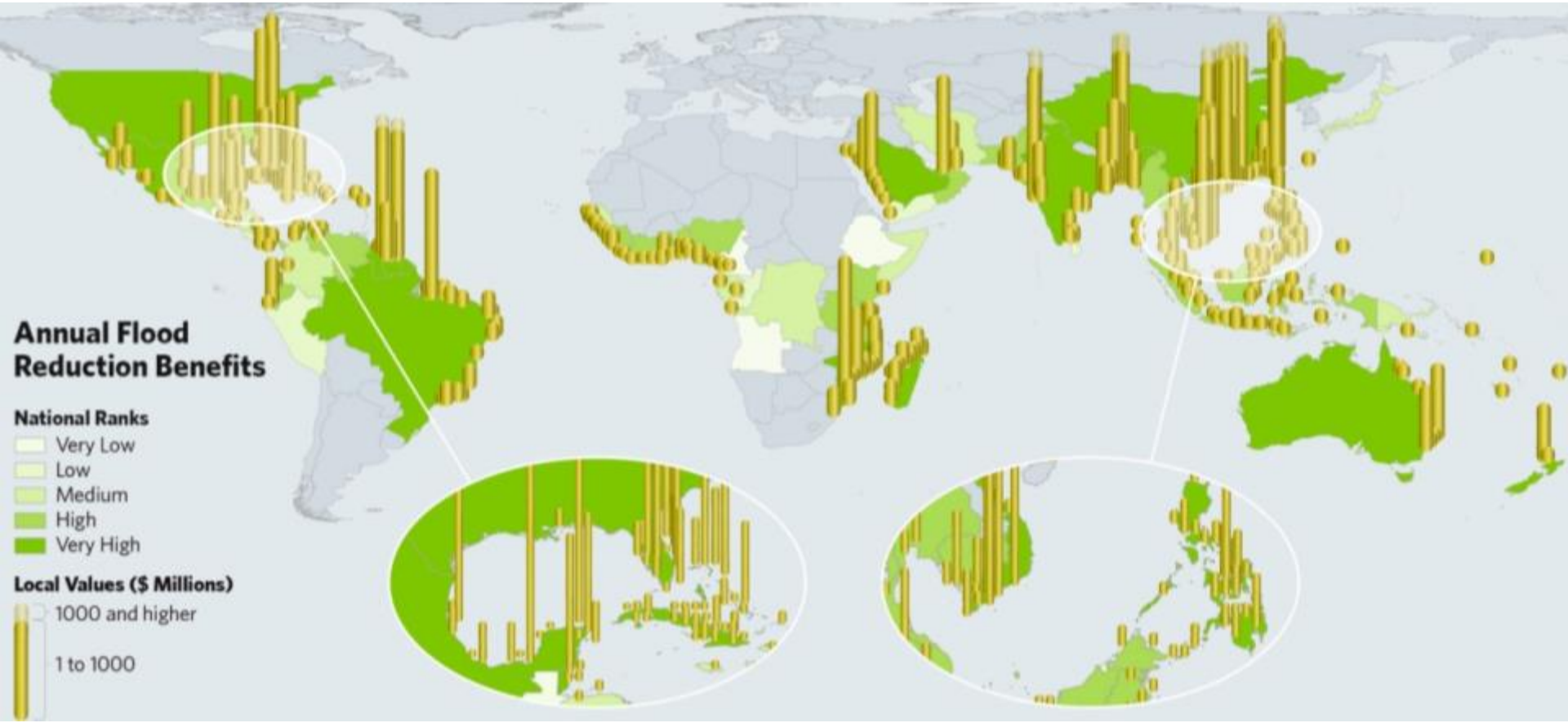
Global Annual Avoided Flood Damages from Mangroves



Losada et al., 2018

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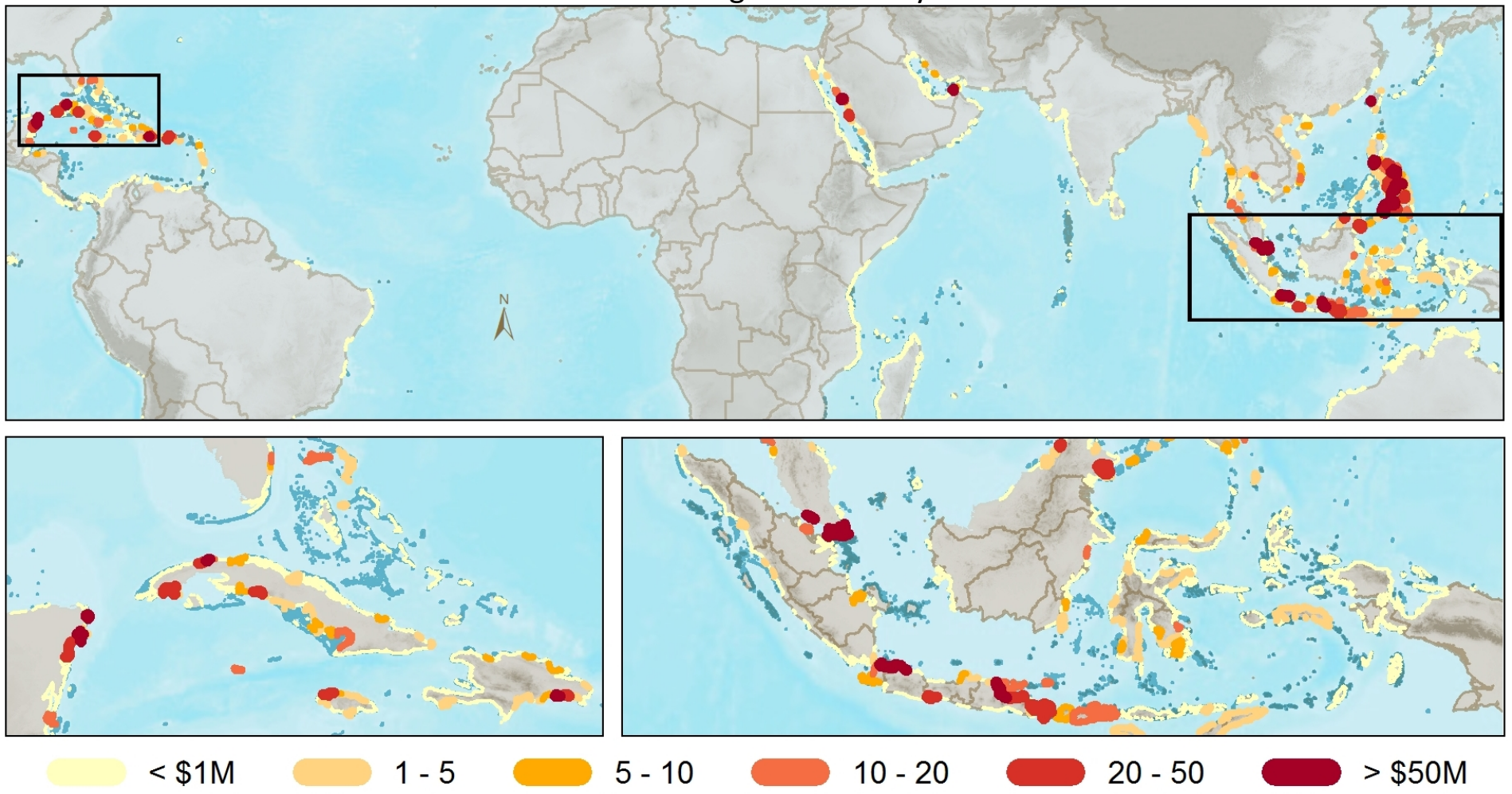
Global Annual Avoided Flood Damages from Coral Reefs

Beck et al. 2018. The Global Flood Protection Savings Provided by Coral Reefs. *Nature Communications*.



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National Avoided Damages From Mangroves in The Philippines

		TOTAL DAMAGE (Annual Expected Damage)
POPULATION (nº people)	Historical	2,253,954
	Current	2,521,004
	No Mangrove	3,134,465
POPULATION BELOW POVERTY (nº people)	Historical	558,009
	Current	619,488
	No Mangrove	761,915
RESIDENTIAL STOCK (millions US $ 2014)	Historical	1,816
	Current	2,073
	No Mangrove	2,637
INDUSTRIAL STOCK (millions US $ 2014)	Historical	1,308
	Current	1,503
	No Mangrove	1,940
TOTAL STOCK	Historical	3,124
	Current	3,577
	No Mangrove	4,577
ROADS (Km)	Historical	2,784
	Current	2,990
	No Mangrove	3,757

Losada et al., 2018

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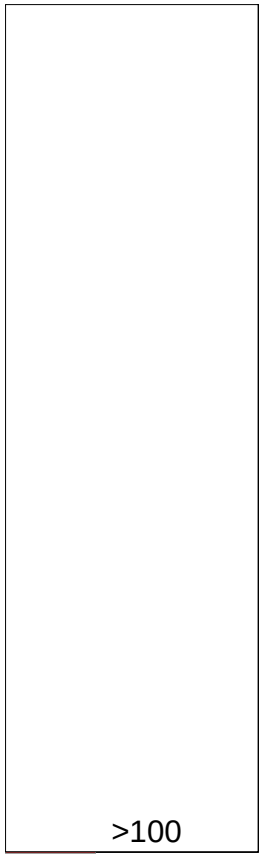
Regional Avoided Damages From Marsh Wetlands - Hurricane Sandy

Change in Sandy Flood Damages Due to Total Wetland Loss

- 625 Million US$
- 12 States



Narayan et al., 2017

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NNBF Costs

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Why Report NNBF Costs?

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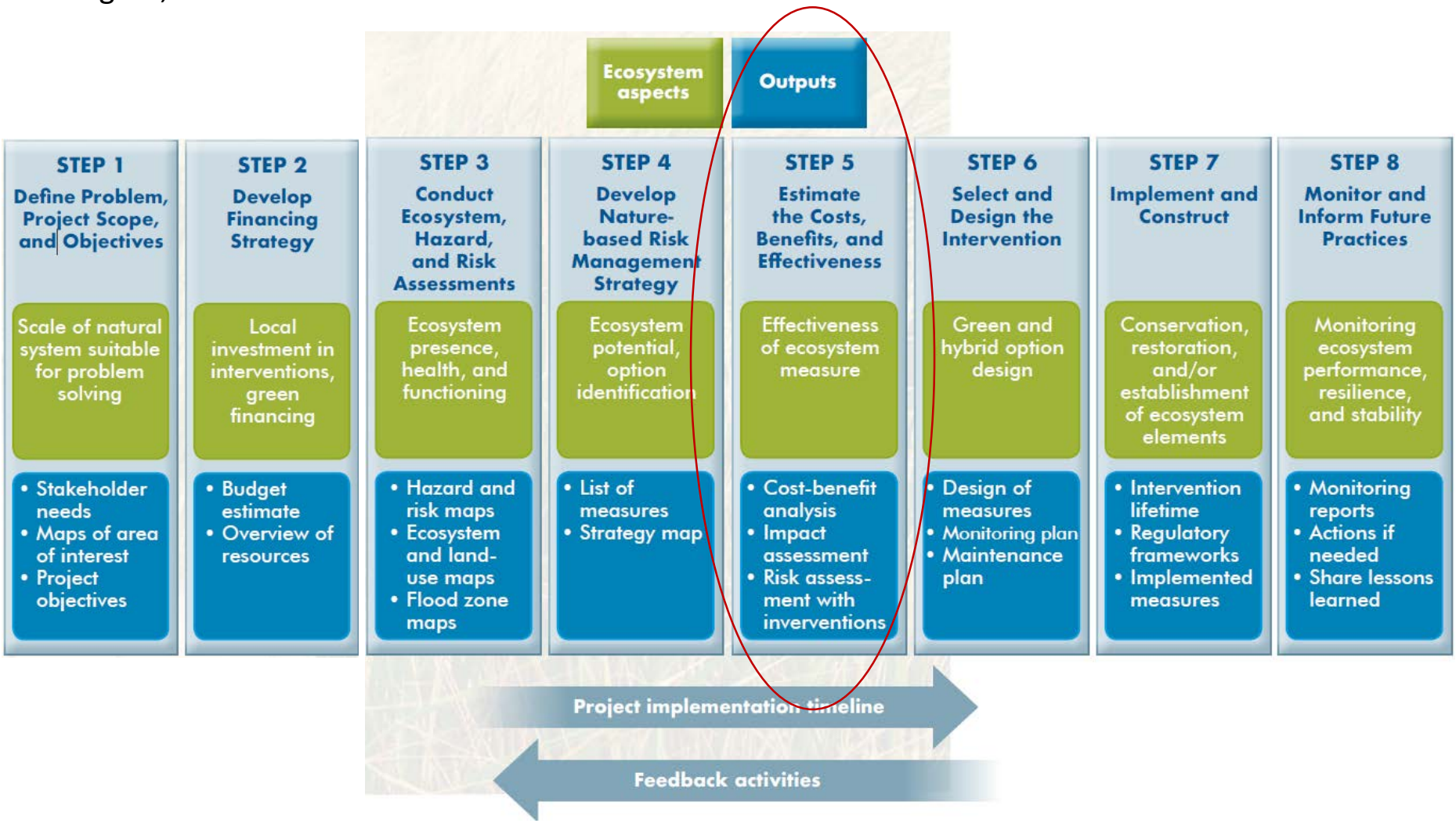

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Costs of NNBF Restoration By Habitat Type

Narayan et al., 2016
Also see Bayraktarov et al., 2017

Habitat	Reported Restoration Project Costs^ as US $ Per m^2: Median (Range)	Estimated Replacement Cost Ratios*: Average (*95% CI*)
Coral Reefs (*n = 19*)	115.62 (2–7490)	NA
Oyster Reefs (*n = 4*)	135.63 (107–316)	NA
Salt-Marshes (*n = 17*)	1.11 (0.01–33)	2 (0.95–3.01)
Mangroves (*n = 12*)	0.1 (0.05–6.43)	5 (3.1–6.9)

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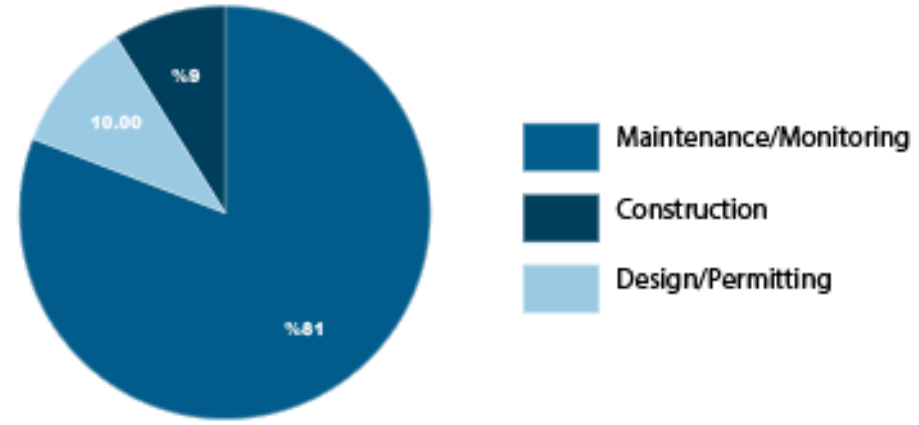
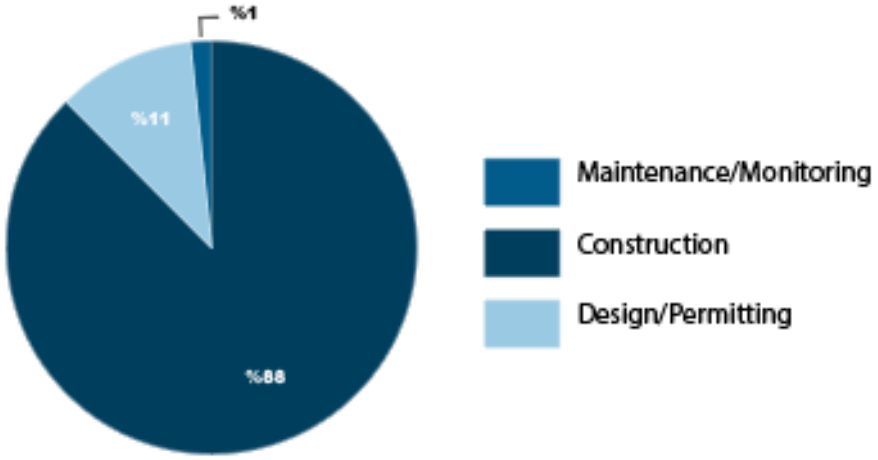
Key Gaps: Data on Factors Affecting NNBF Costs



San Diego Bay Project Costs



Hamilton Wetland Restoration Project Costs

Jones, Narayan et al., in prep

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NNBF Case Studies

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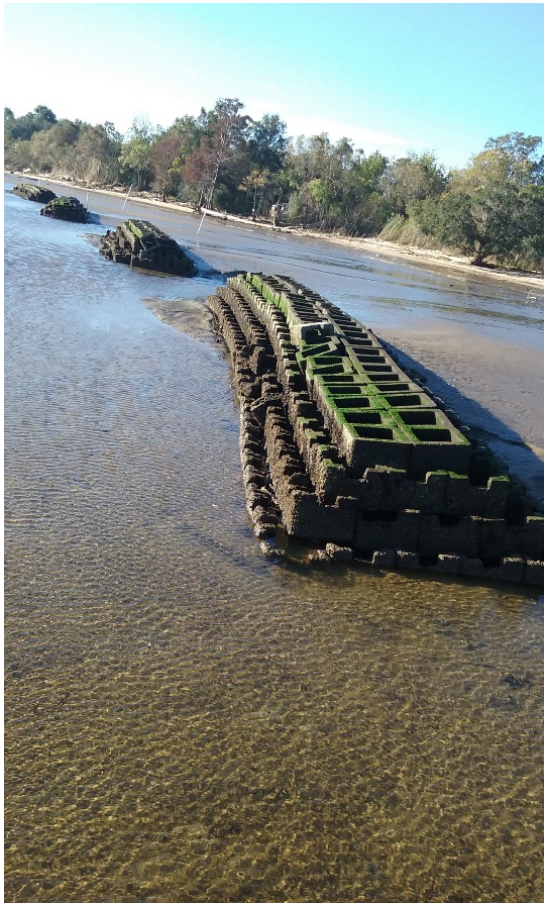
Arlington Cove Living Shoreline, Mobile, Alabama

- Client: TNC
- 5 small hand built reefs
- Provide beach stability
- Allow for marsh regrowth
- Promote aquatic habitat
- Provide educational opportunities and civic involvement



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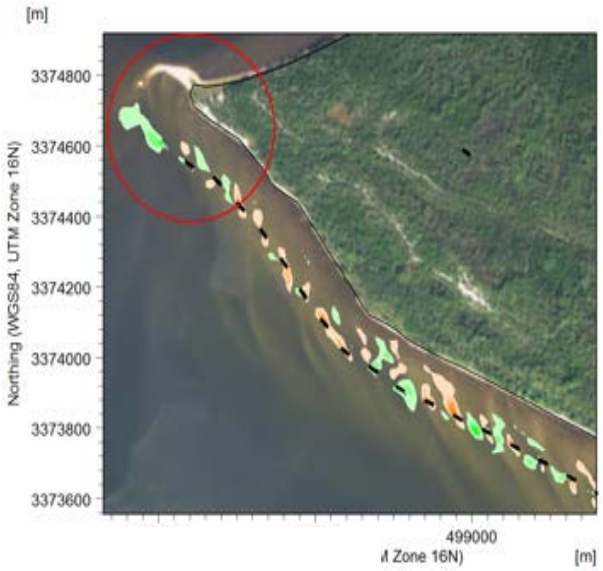
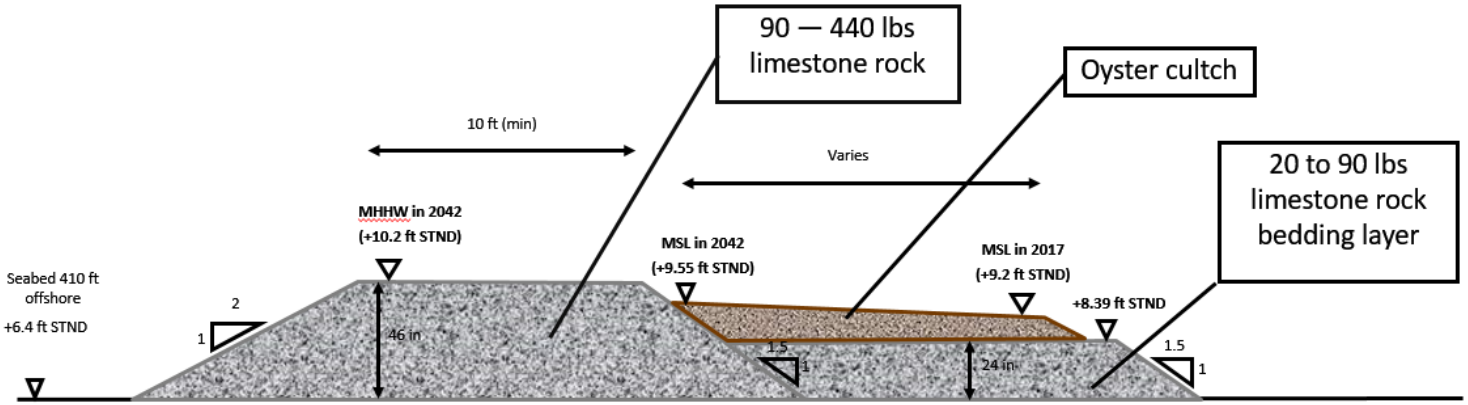
Pensacola Bay Oyster Reef, Florida

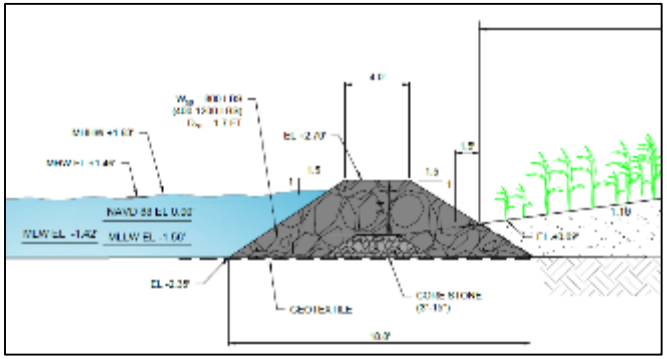
- Client: TNC
- Project aims to deliver habitat enhancement, with secondary benefit of shoreline protection and marsh accretion.
- Planning, permitting, and engineering design of a 6-mile-long oyster habitat restoration and living shoreline project in the eastern Pensacola Bay area in Florida.





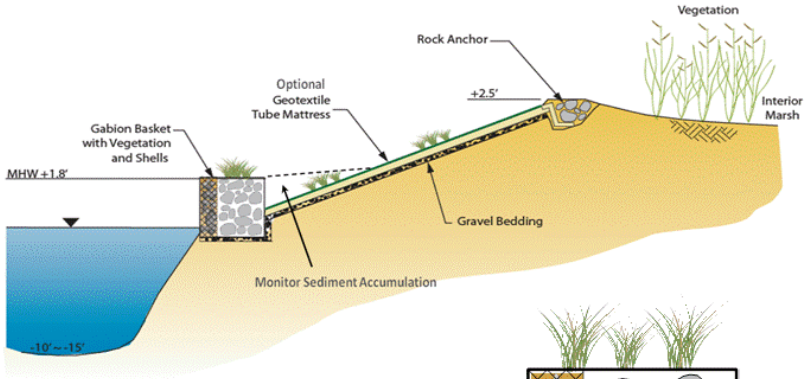
Monmouth Dune and Tidal Wetland Living Shoreline, New Jersey

- The Borough of Monmouth Beach, NJ, was severely impacted by Superstorm Sandy which inundated Borough streets significantly damaging homes and the Borough's infrastructure.
- Main elements
  - A large 1-mile long dune system along the Atlantic Ocean, beneficially reusing 50,000 cubic yards of dredged material provided by the USACE to help absorb and dissipate the ocean's wave energy during storms.
  - A breakwater tombolo living shoreline to protect several marsh islands located in the Shrewsbury River that when restored, will increase habitat for wading and roosting birds while reducing the wave run-up on the bayside residential properties and important infrastructure.

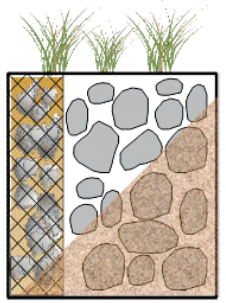


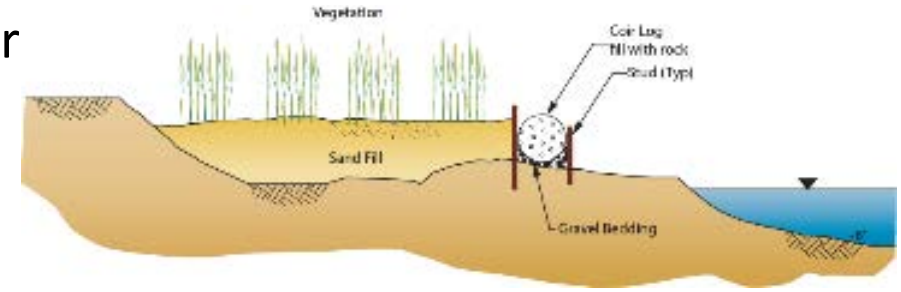
Shell Ship Shoal Pipeline Erosion Control, Louisiana

- Client: Shell Pipeline Corp. & TNC
- Range of solutions:
  - Coir logs
  - Shell filled gabions
  - Permeable concrete mattresses with planted vegetation
  - Vegetated embankments
  - Sediment fill
- Solutions tailored to local context: bathymetry, sediment supply, oyster recruitment constraints and hydrodynamics.

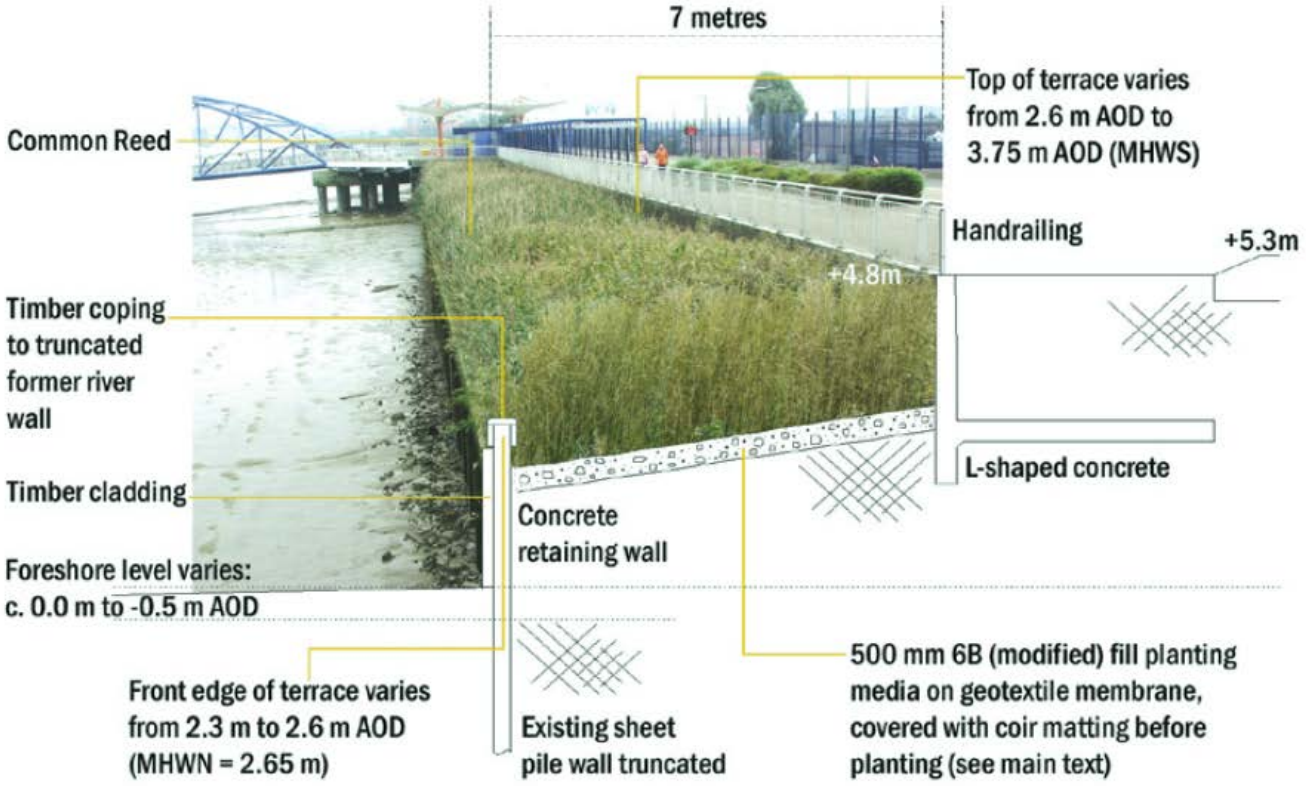


Conceptual cross-section of paired oyster-marsh-erosion control treatments with respect to the tidal frame. In some cases, gabions can have a mixture of rock and soil for plantings. Oyster shell panels have configuration flexibility. Some sites will experience infiltration of sediments, but elevation control of the gabion is a primary design consideration to create optimal vertical substrate for oyster settlement.





River terraces, Thames, London



Eastern wall, Greenwich Peninsula, London: Site 2 north end, six years after implementation (autumn)

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Exercise: Factors Influencing NNBF Costs

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Exercise: Factors Affecting NNBF Costs

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Exercise: Factors Affecting NNBF Costs

- Location and Site Accessibility
- Habitat Type and Restorability
- Land
- Size
- Restoration Techniques
  - Hydrological
  - Thin-spreading
- Permitting Costs
- Material Costs
  - Material for initial habitat protection
  - Material for Structures in case of Hybrid
- Labour
  - Volunteer Hours

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Thank You

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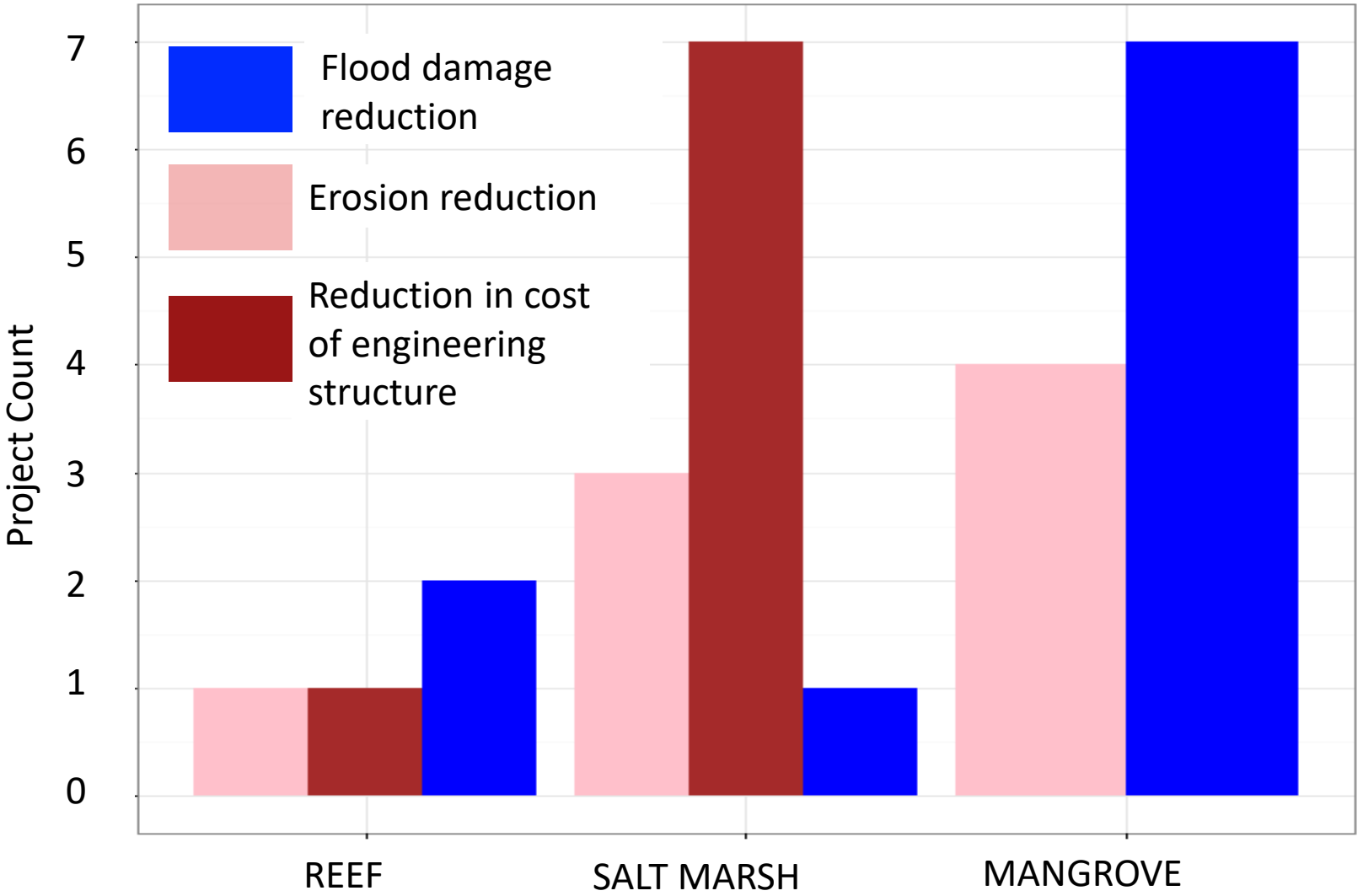
Middle Township, NJ

Photo credit: Metthea Yepsen, TNC

Also Thanks To

Observed Benefits of NNBF Projects



From Narayan et al., 2016

Measured Benefits of NNBF Projects – Numerical Models

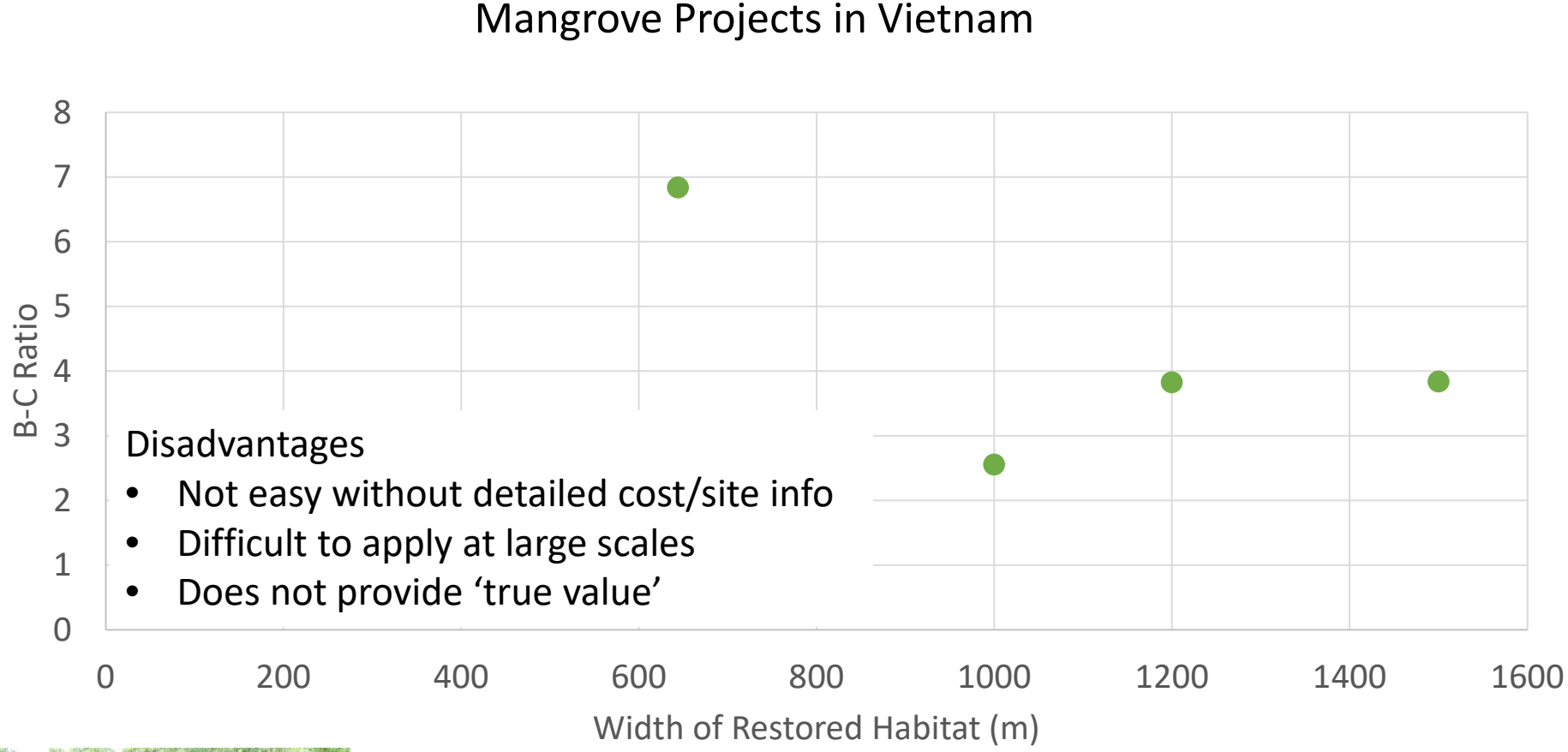
Estimated wetland impacts on attenuating maximum storm surge levels (S)		Estimated marginal values of wetlands in terms of avoiding damages to residential property	
	Change in storm surge		**Marginal value**
1% change in W_L per segment	−8.4% to −11.2%	0.1 increase in W_L per m	$99.29 to $132.87
1% change in W_R per segment	−15.4% to −28.1%	0.001 increase in W_R per m	$23.72 to $43.24
9.4 to 12.6 km change in W_A	−1 m	0.1 increase in W_L per segment	$591,886 to $792,082
		0.001 increase in W_R per segment	$141,399 to $257,762

W_L is represented by the wetland/water ratio ranging from open water ($W_L = 0$) to solid marsh ($W_L = 1$).
W_R is represented by Manning's n for bottom friction caused by degree of wetland vegetation ranging from no vegetation ($W_R = 0.02$) to high density vegetation ($W_R = 0.045$).

Barbier et al., 2013. The Value of Wetlands in Protecting Southeast Louisiana from Hurricane Storm Surges

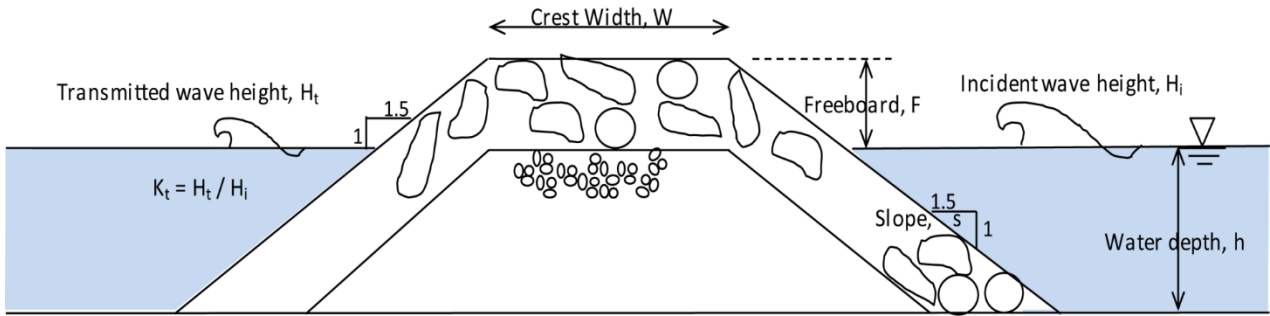
From Narayan et al., 2016

Reporting Benefits As Replacement Costs: Mangroves



Disadvantages

- Not easy without detailed cost/site info
- Difficult to apply at large scales
- Does not provide 'true value'



Global Estimates of the Coastal Protection Value of Mangroves Today

Iñigo Losada, Michael W. Beck, Pelayo Menéndez, Siddharth Narayan, Borja Reguero

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WAVES
Wealth Accounting and Valuation of Ecosystem Services

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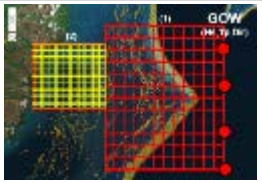
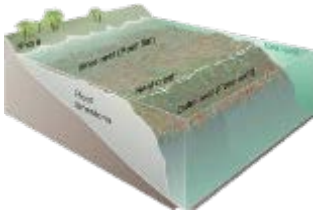
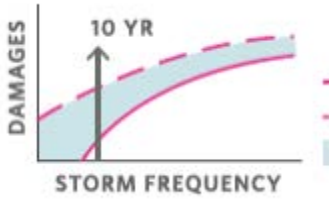
OFFSHORE DYNAMICS → NEARSHORE DYNAMICS → HABITAT → IMPACTS → CONSEQUENCES







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

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

With vegetation
Without vegetation

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

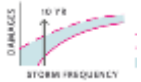
FLOODING
Historical
Future scenarios

CONSEQUENCES

Flow *Assets*

Exposure
- *Land use*
- *Poverty index*
- *Wealth*
- *Population*
- *GDP*
- *Built Capital*

Damage and loss Functions



Annual Expected Benefits

UNCERTAINTIES