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: Reefs and Vegetation

Siddharth Narayan, PhD
Borja G. Reguero, PhD
Michael W. Beck, PhD

University of California Santa Cruz / The Nature Conservancy

Jane McKee Smith, PE, PhD
Mary Bryant, PE

US Army Engineer Research and Development Center

Coastal and Hydraulics Laboratory




Motivation

Coastal Wave Impacts:

- **Runup / Overtopping**
- **Drive nearshore currents**
- **Move sediment**
- **Damage infrastructure**

Reefs and Vegetation:

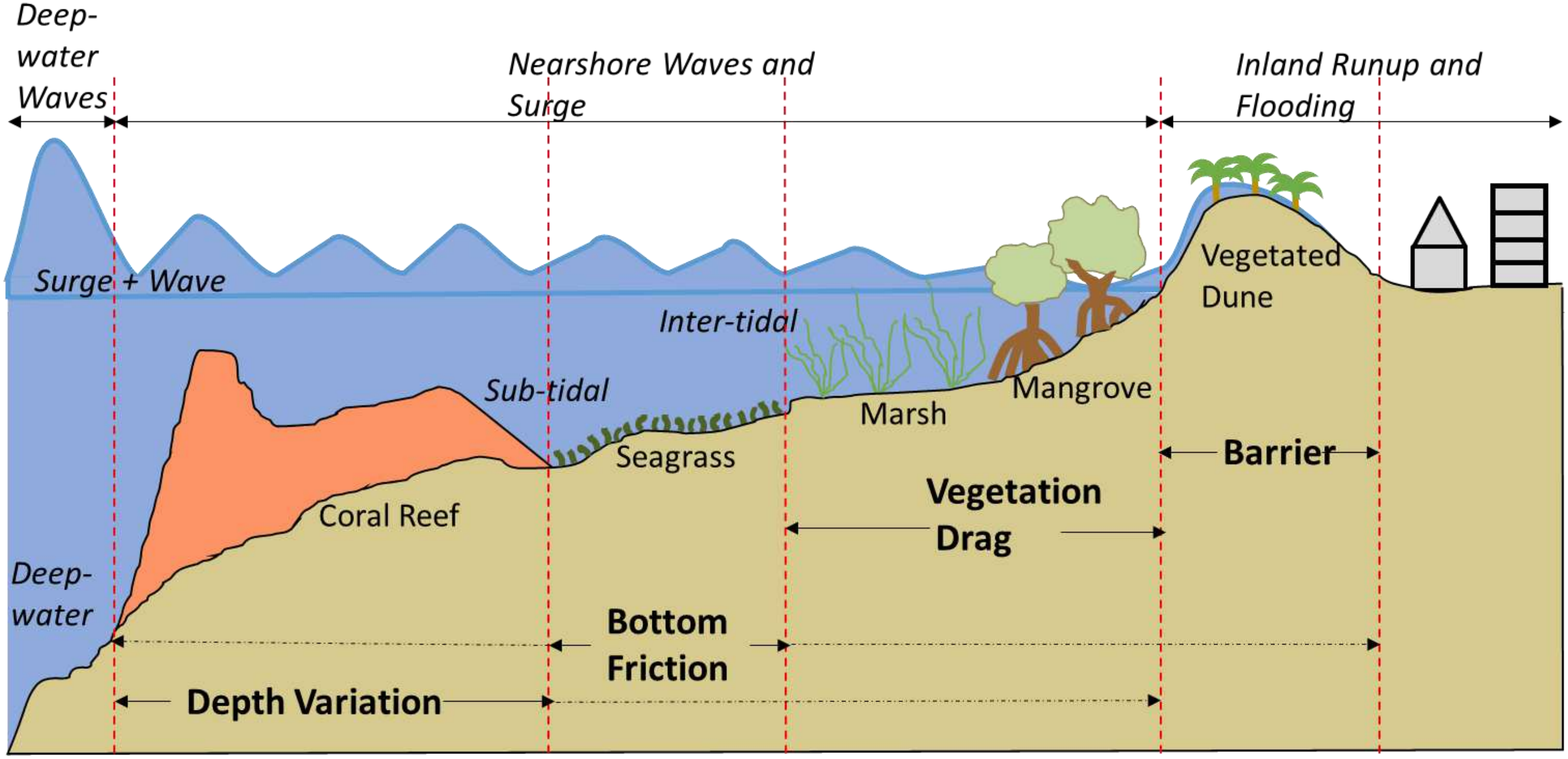
- **Attenuate waves**
- **Reduce water levels & currents**
- **Reduce coastal erosion**

Modeling Nearshore Waves

Model Features	Phase – Averaged	Phase - Resolved
Key Equations	Energy Flux	Boussinesq-type
Wave Linearity	Linear	Non-linear (3-way interactions)
Wave Breaking	Depth-limited	Empirical
Reflection & Diffraction	Neglected	Included
Dissipation & Transmission Within Reef	Neglected	Neglected
Examples	SWAN	XBEACH

Wave Height Reduction Across Coastal Habitats

$$\frac{\partial N}{\partial t} + \frac{\partial C_{g,x} N}{\partial x} = -\mathbf{D} = -(\boldsymbol{D_b} + \boldsymbol{D_f} + \boldsymbol{D_{Veg}})$$

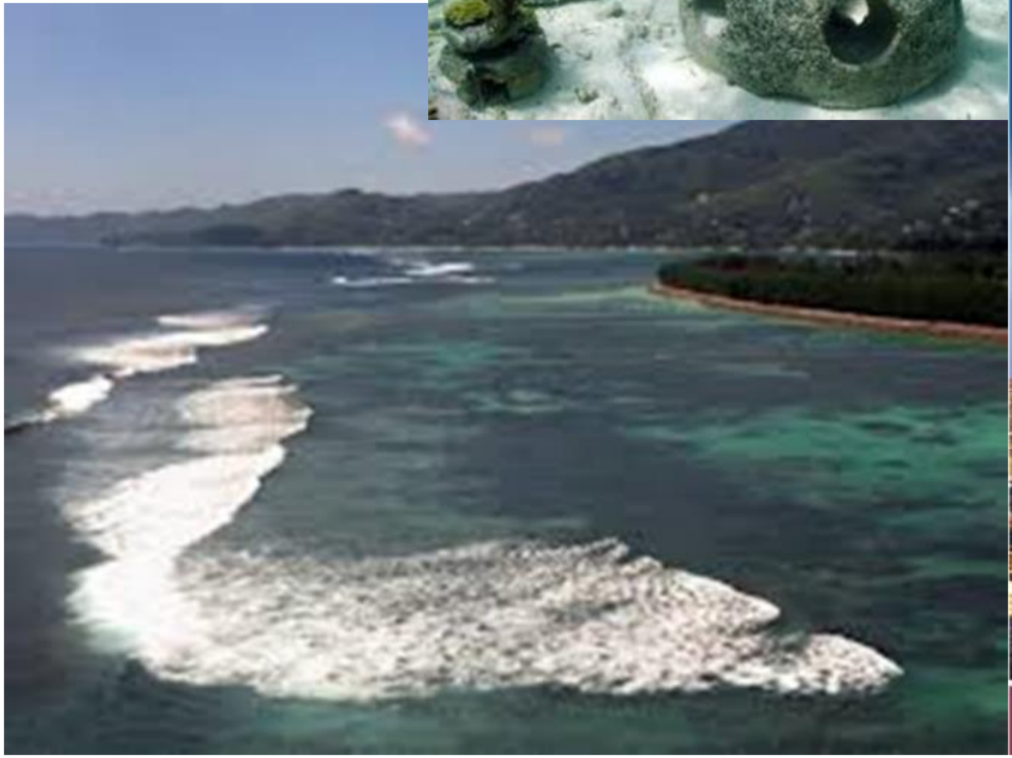


Wave Energy Proportional to H^2

From Narayan et al. 2016

Reefs

Natural and artificial reefs provide wave dissipation to reduce wave impact on the shoreline

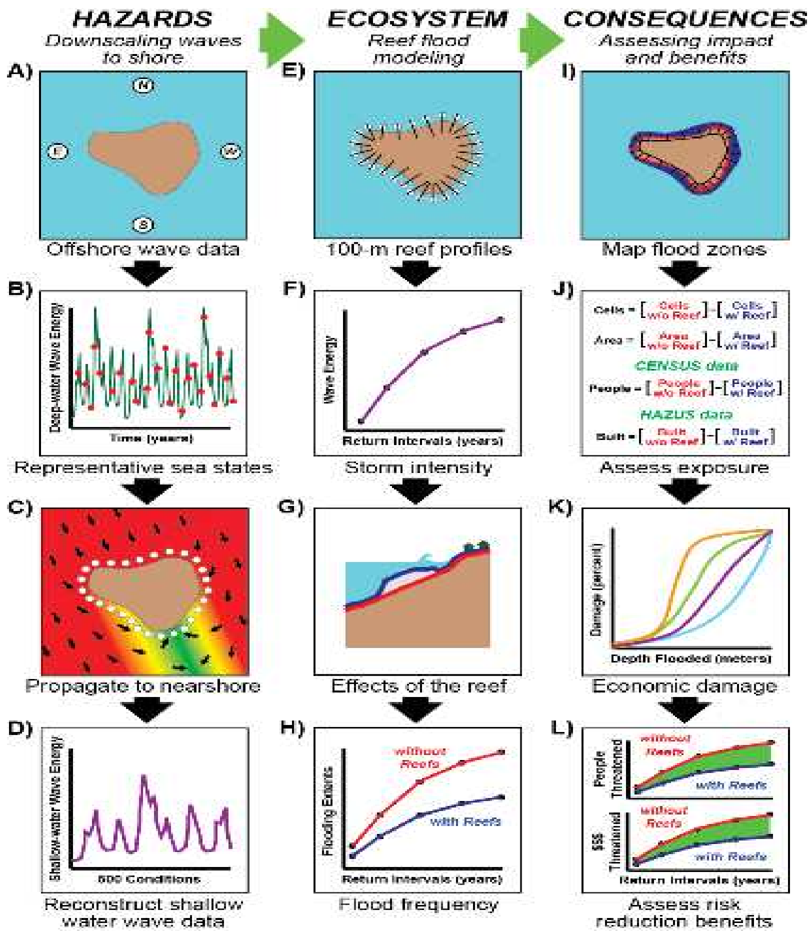


Reef Types

- Natural Reef
  - Coral
  - Rock
- Artificial Reef Structures
  - Submerged
  - Emergent
- Others
  - Oyster

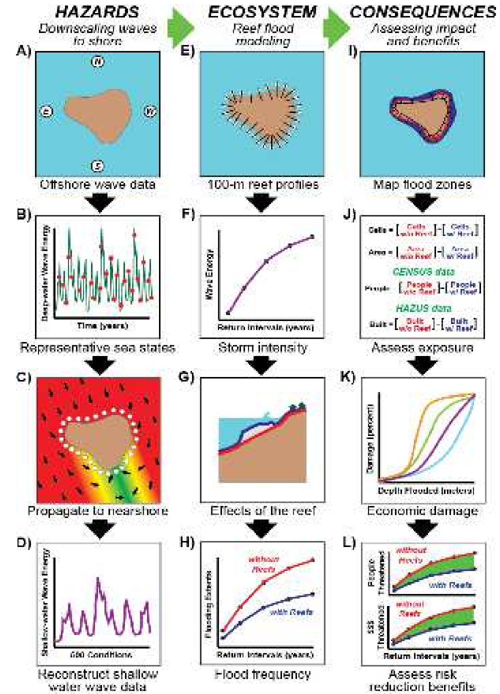
Modeling Waves on Reefs: Example From the USA

USGS
science for a changing world
Pacific Coastal and Marine Science Center



Storlazzi, Beck et al., 2017. Rigorously valuing the role of coral reefs in coastal protection: An example from Maui, Hawaii, USA. In *Coastal Dynamics 2017*

Modeling Waves on Reefs: Example From the USA



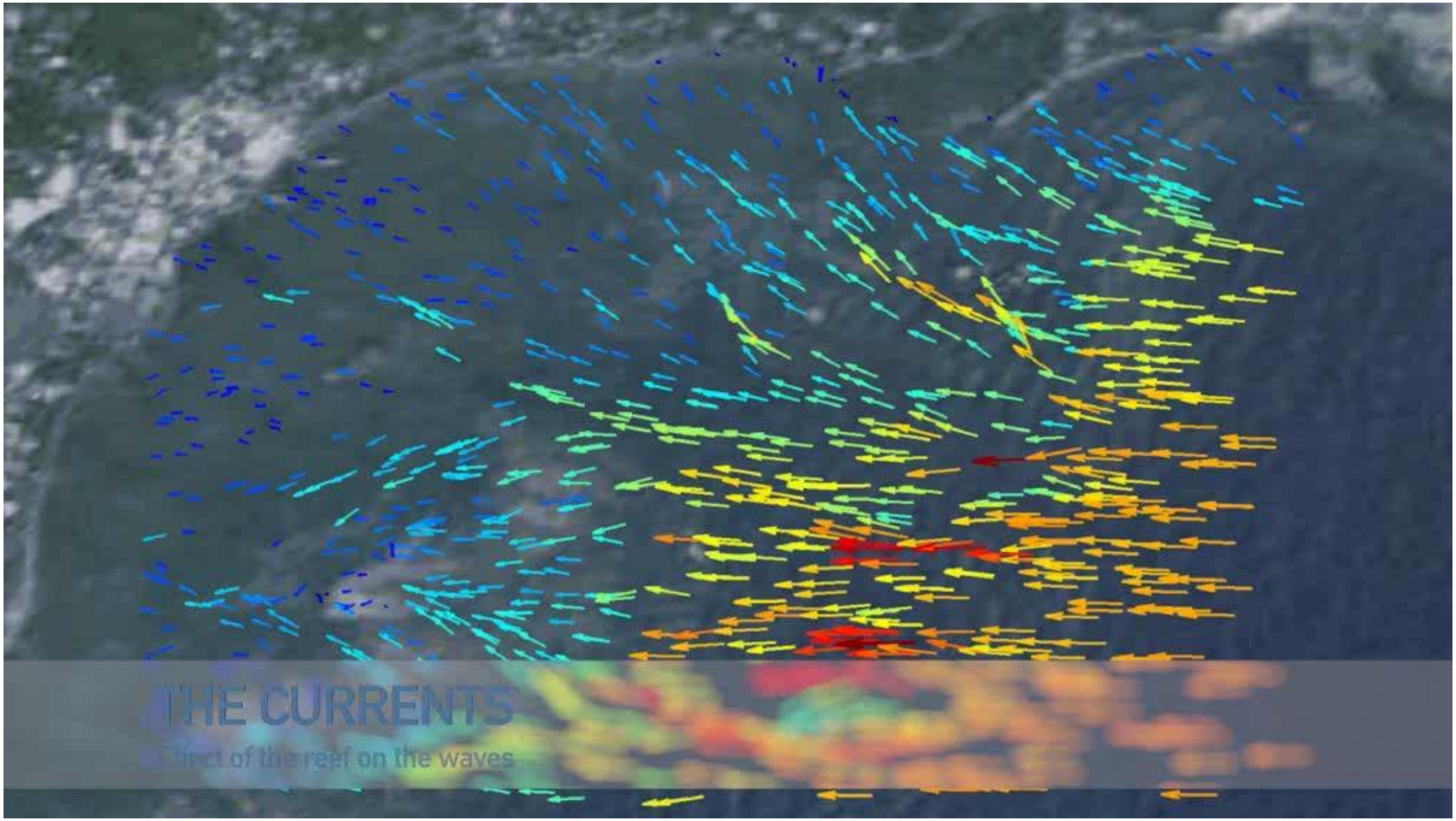
- Transects every 100 m (30,167 total)
- Non-linear wave model XBeach
  - Wave propagation
  - Long waves
  - Sediments and Currents
- Originally for sandy beaches – configured for coral reefs

Storlazzi, Beck et al., 2017. Rigorously valuing the role of coral reefs in coastal protection: An example from Maui, Hawaii, USA. In *Coastal Dynamics 2017*

A Coastal Problem Due To Reef Loss: Grenville Bay, Grenada

From Reguero, et al., 2018

Designing Reef Restoration for Coastal Resilience: Grenada



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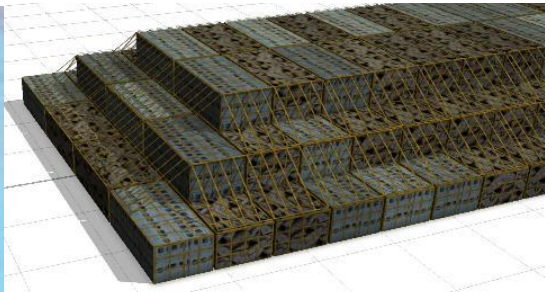
Designing Reef Restoration for Coastal Resilience: Grenada

2-tier pilot submerged breakwater structure (this one with blocks) with corals from the nursery placed along their sides



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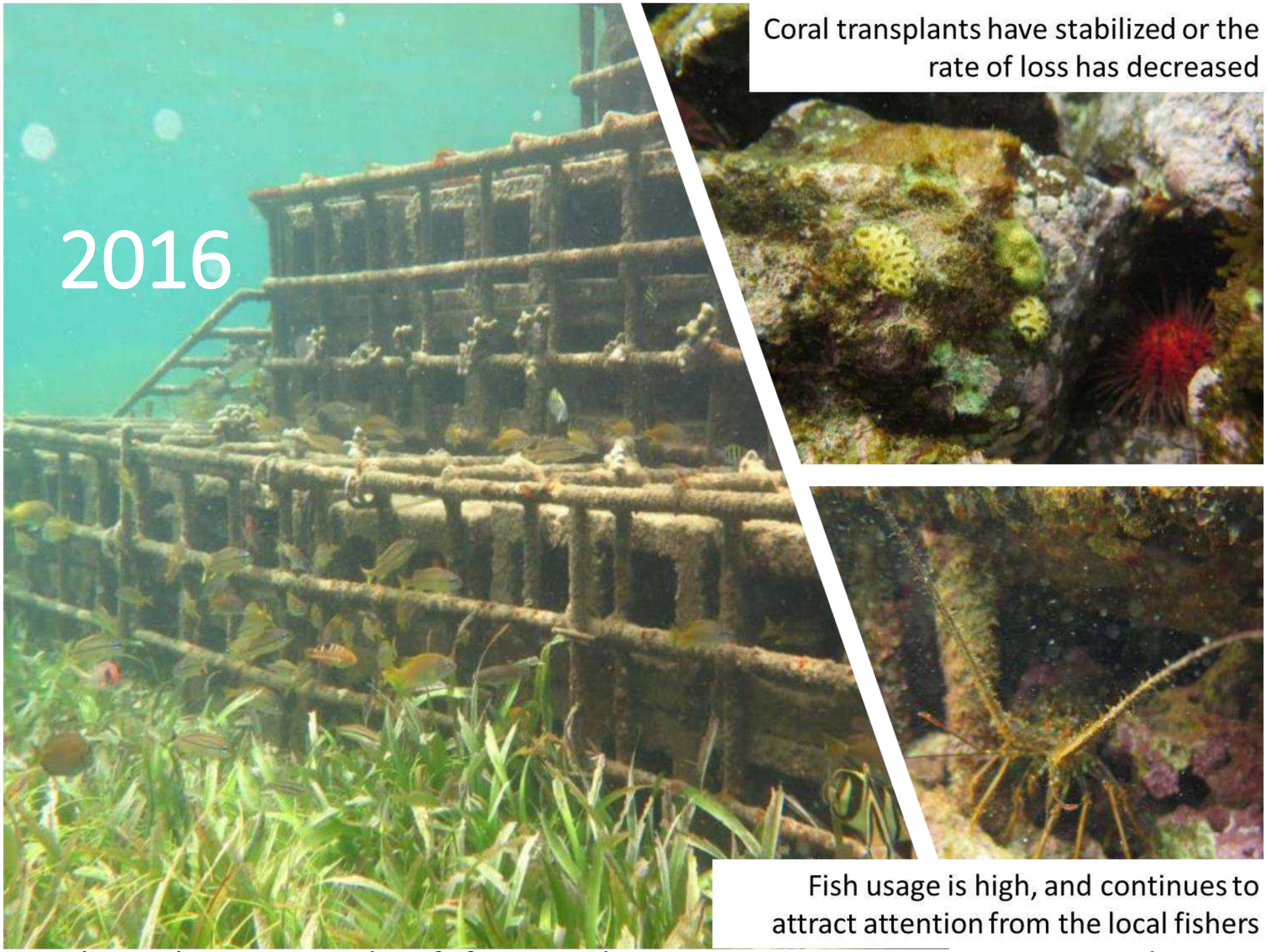
Designing Reef Restoration for Coastal Resilience: Grenada



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Oyster Reefs For Shoreline Stabilization: MacDill Air Force Base

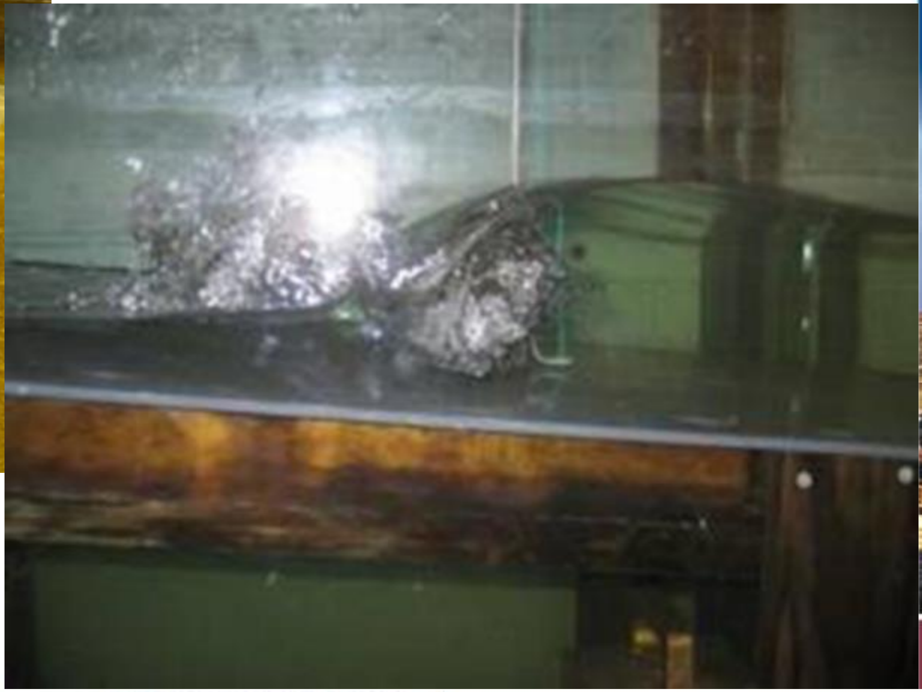
Benefit #1: Shoreline stabilization – reduce wave energy; trap sediment
Benefit #2: Water Quality Improvement
Benefit #3: Habitat Enhancement – diversity, encourages marsh /mangrove recruitment

Limitation #1: Porous, less effective than coral reefs
Limitation #2: Prefer low wave-energy environments

From Kirkpatrick, 2013.
http://www.oyster-restoration.org/wp-content/uploads/2013/02/9.-Jason-Kirkpatrick.pdf

Field Studies

Lab Studies of Waves on Reefs



Reef Summary

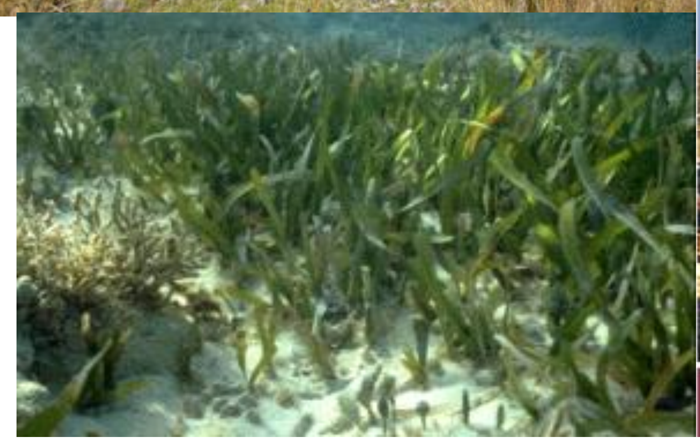
- Empirical, numerical, and lab tools to evaluate wave dissipation by reefs
- Research needs:
  - Characterize stability
  - Characterize porosity (dissipation/transmission)
  - Field and Lab Studies for Validation
  - General Parameters for Simplified Models
  - Design guidance
  - Quantify additional environmental benefits

Vegetation

Vegetation provides wave dissipation to reduce wave height as a function of:

- Stem height
- Stem diameter
- Stem density
- Length of vegetation field
- Stiffness of the vegetation
- Submergence depth
- Wave parameters
- Drag coefficient

Morison-type equation



$$D = \frac{g^2}{16\sqrt{\pi}} C_D b_v N \left(\frac{T_p}{L}\right)^3 \frac{sinh^3 k\alpha h + 3 \sinh k\alpha h}{3k cosh^3 kh} H_{rms}^3$$

Dalrymple (1984)

Mendez and Losada (2004) ~ irregular waves

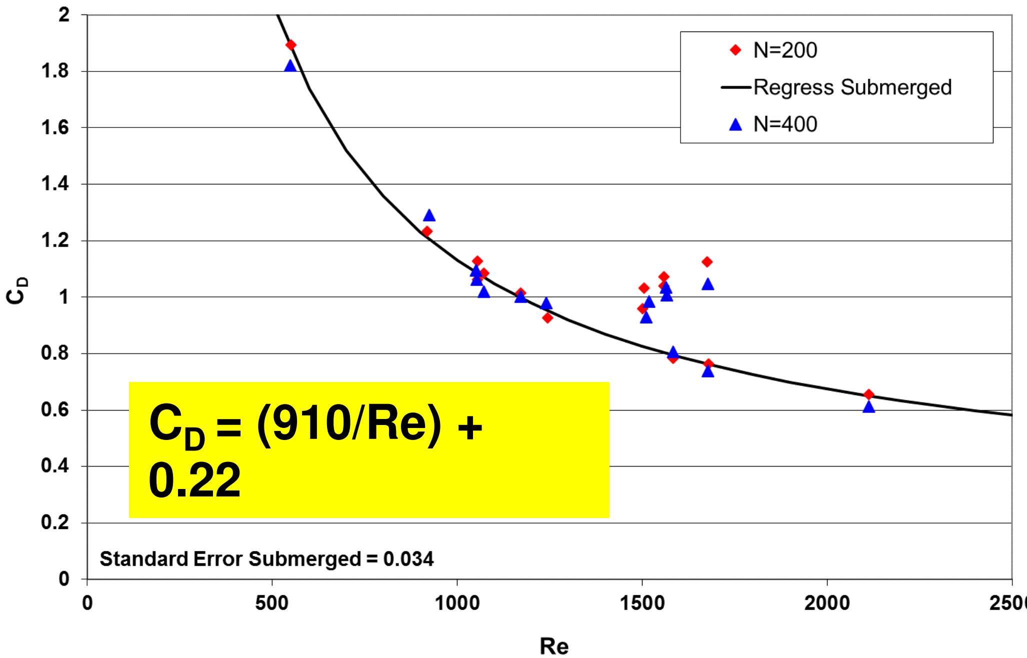
Bulk Drag Coefficient C_D

Drag coefficient parameterized based on lab or field data

- Reynolds number
- Keulegan-Carpenter number
- No comprehensive formulation for C_D
  - Vary with season
  - Vary with depth/submergence
- >70 parameterization in literature (mostly lab based)

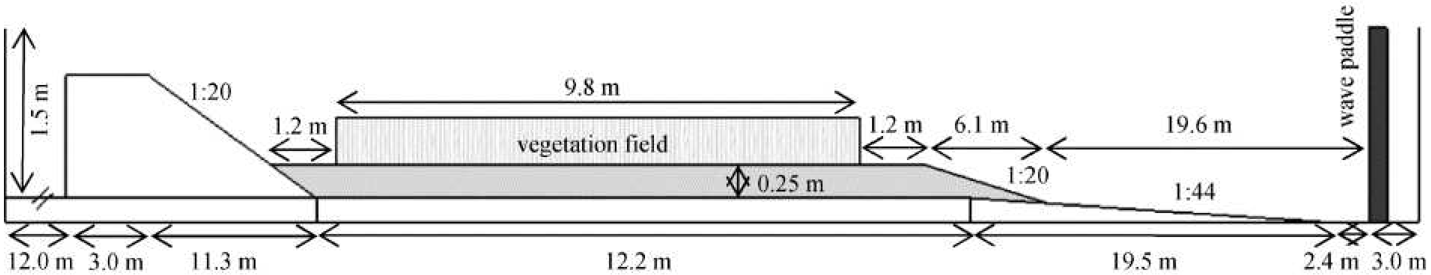
$$Re = \frac{u_c d}{\nu}$$

$$KC = \frac{u_c T_p}{b_v}$$



u_c ~ characteristic velocity, d ~ depth, ν ~ kinetic viscosity, T_p ~ peak wave period, b_v ~ stem diameter

Lab Experiments (Anderson & Smith 2014)



Three water depths (h): 30.5 cm, 45.7 cm, 53.3 cm

- ►correspond to l_s/h ratios of 1.0 (emergent), 0.91, 0.78

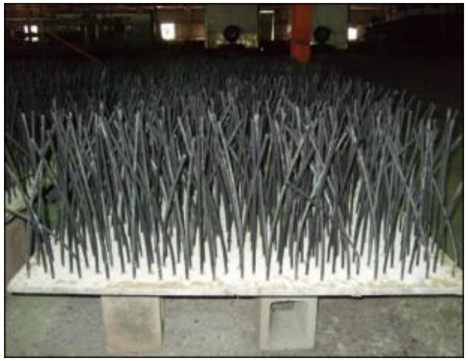
Irregular waves

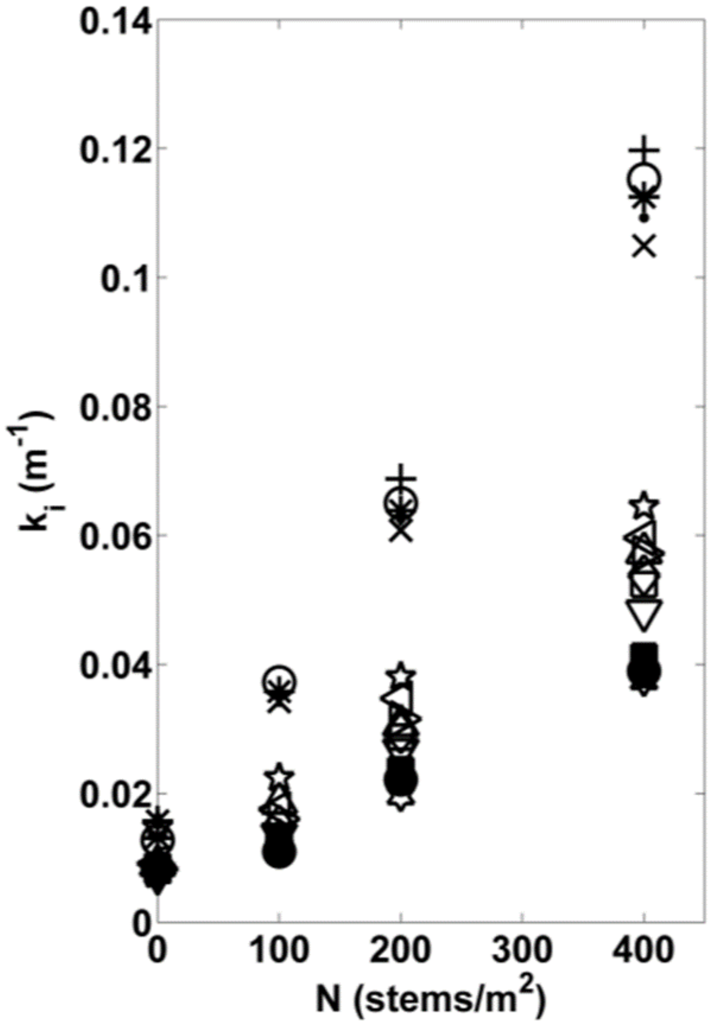
- ► T_p ~ 1.25 s to 2.25 s
- ► H_{m0} ~ ranging from 5.0 cm to 19.2 cm

Trends in Wave Attenuation

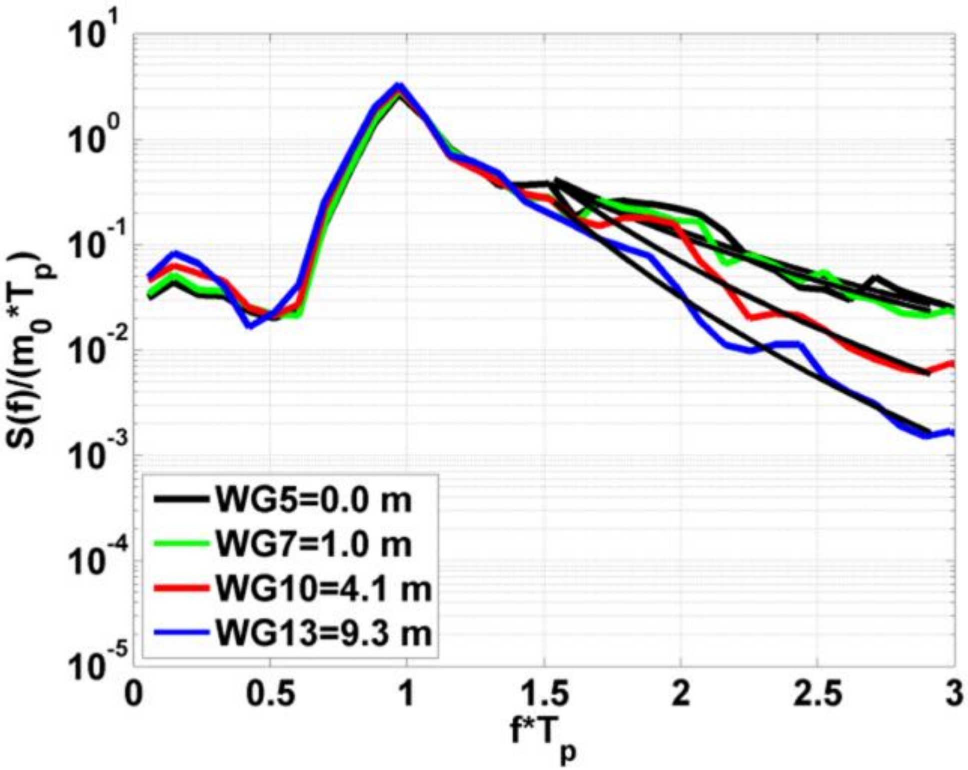
Wave attenuation was found to:

- increase with stem density
- increase with submergence ratio
- slightly increase with incident wave height
- marginally decrease with longer waves during emergent conditions



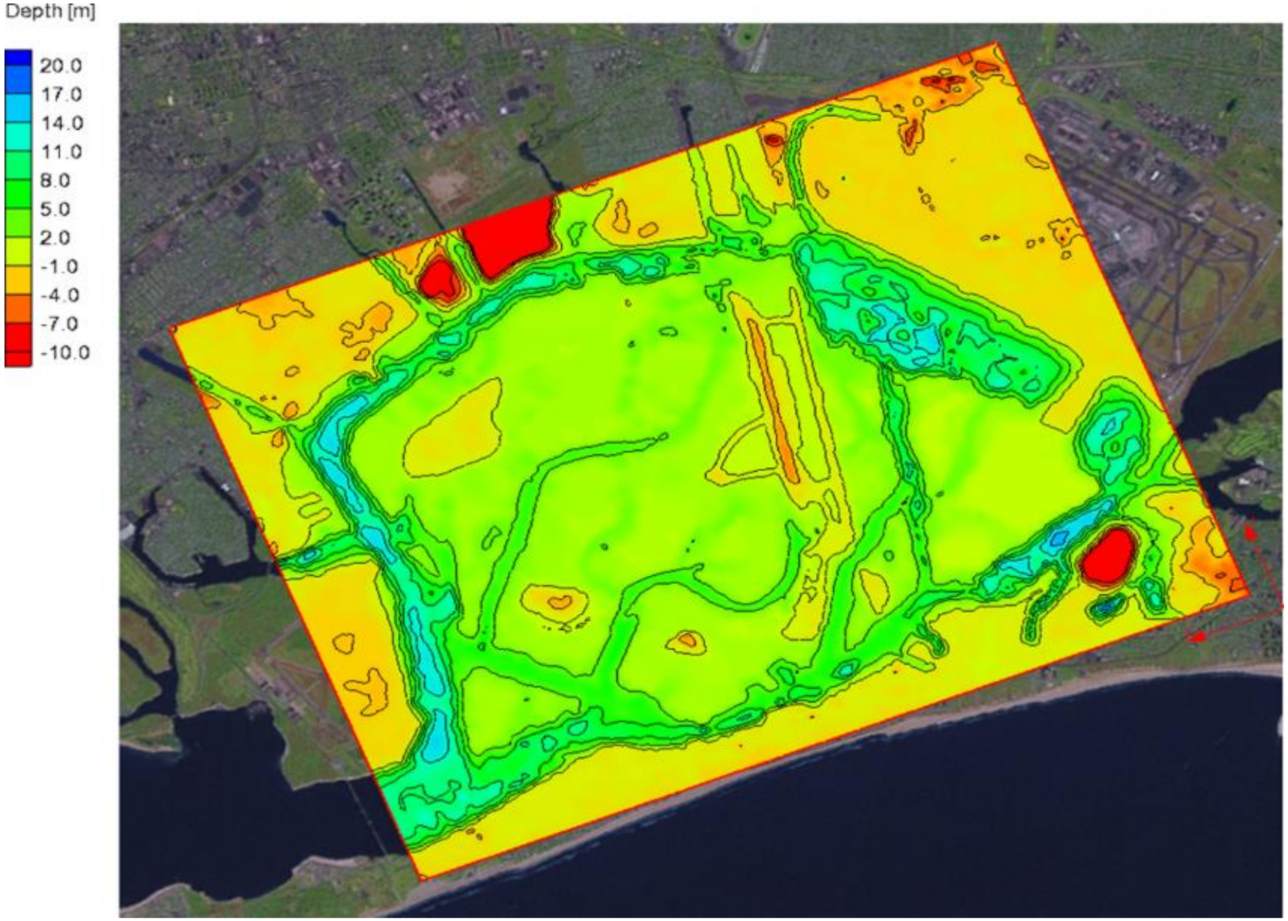


Wave Spectra



- Deviations of slope of spectral tail, 1.5f_p to 3f_p
- Preferential dissipation of higher frequencies
- dissipation of higher frequencies dependent on stem density and submergence ratio

Example: Jamaica Bay, NY



Bathymetry

Simulations with Spectral Wave Model (STWAVE)

Three wind & water level combinations

- 18.5 m/s winds, 1.3 m WL
- 22.1 m/s winds, 2.0 m WL
- 26.0 m/s winds, 2.9 m WL

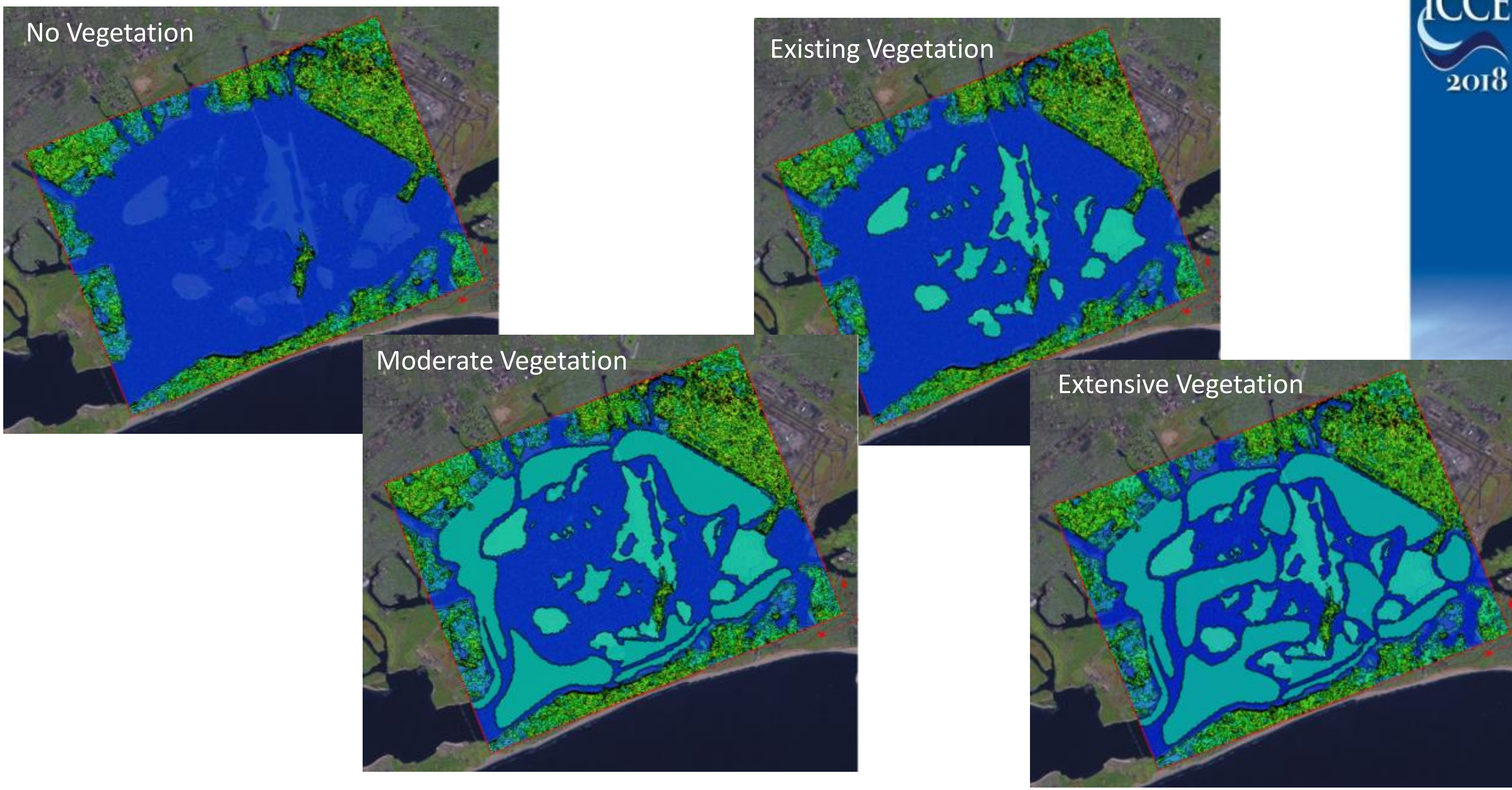
Four vegetation states

- No vegetation, existing bathymetry
- Existing vegetation and bathymetry
- Moderate vegetation w/ modified bathymetry
- Extensive vegetation w/ modified bathymetry

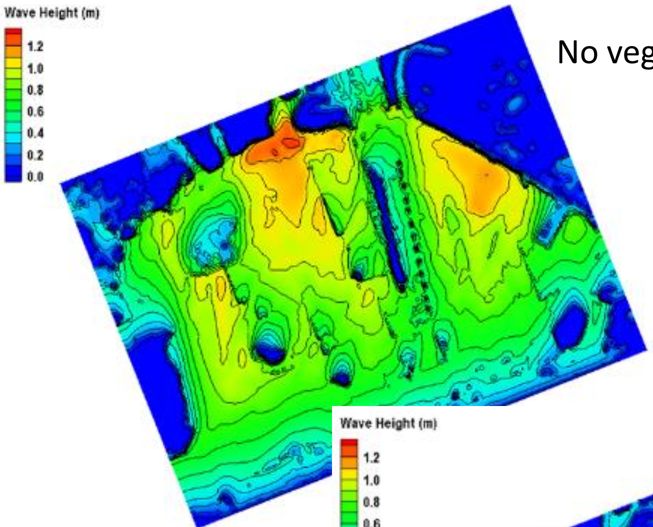
Spartina alterniflora in the low marsh, *Spartina patens* in the high marsh, and *Phragmites*

C_D ~ 0.35, N = 400, b_v=0.6 cm

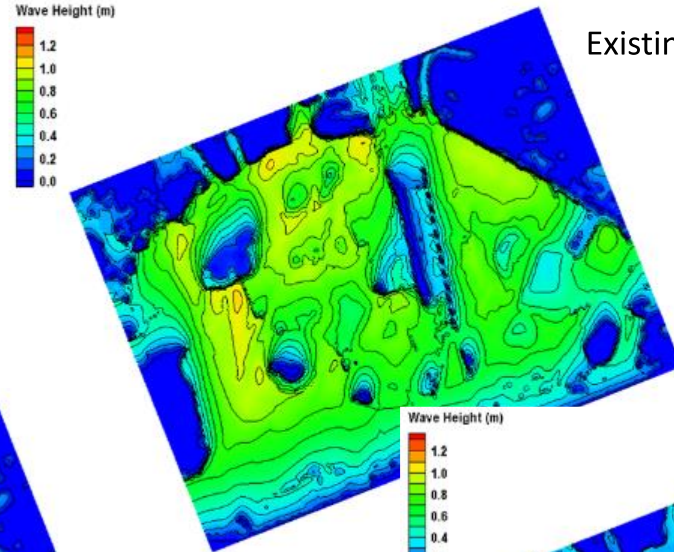
Vegetation States



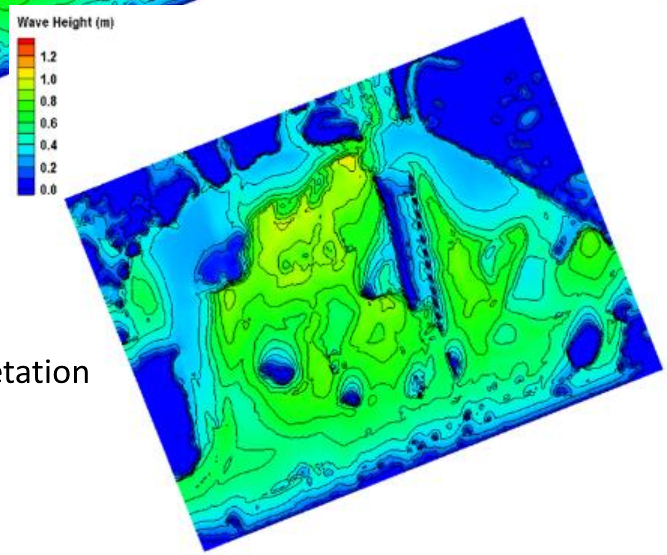
26 m/s winds, 2.9 m WL



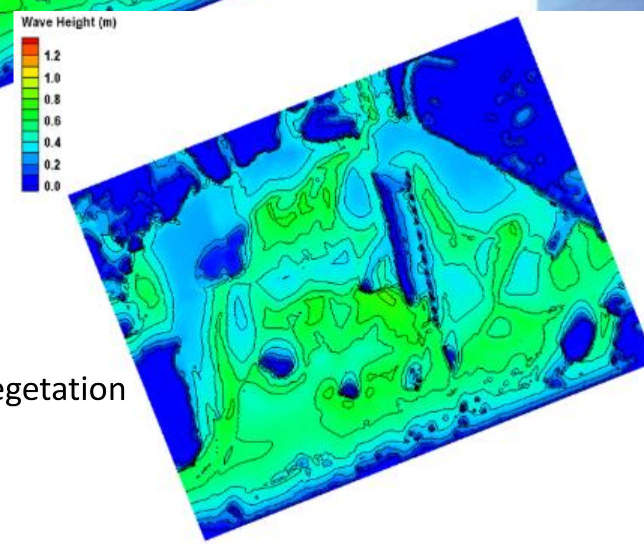
No vegetation



Existing vegetation

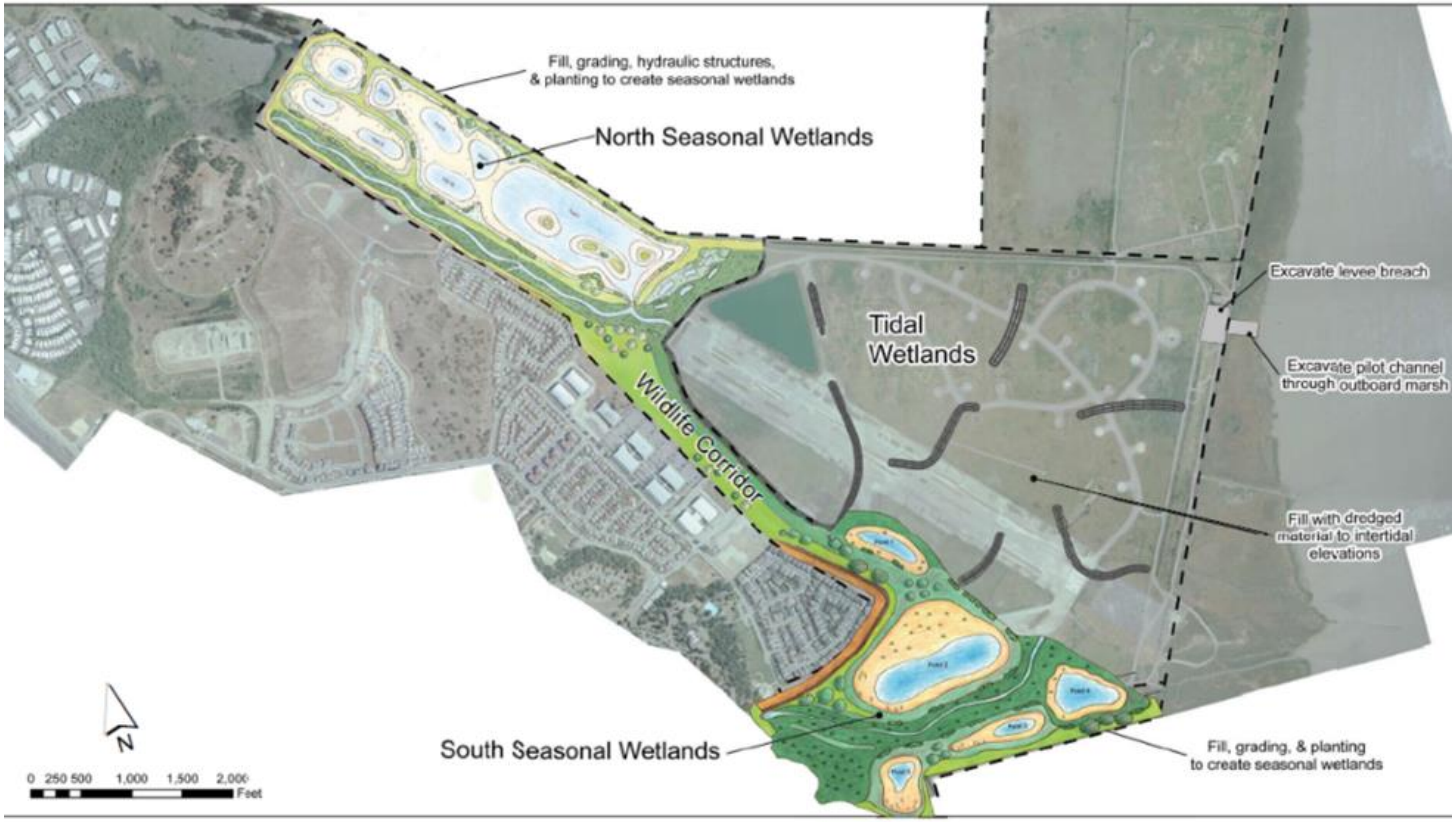


Moderate vegetation



Extensive vegetation

Example: Hamilton Wetland, California

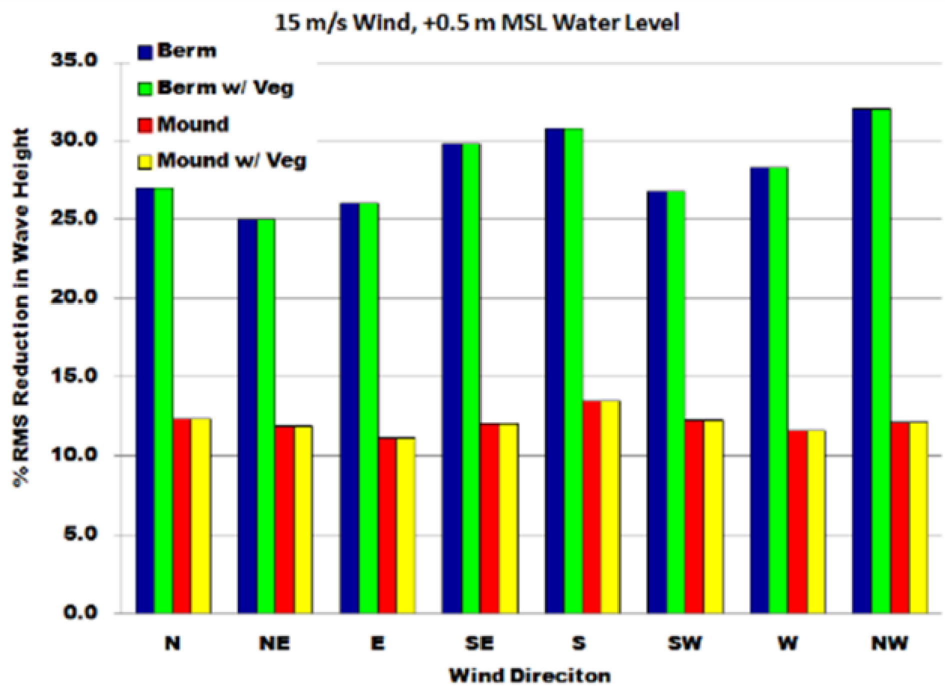


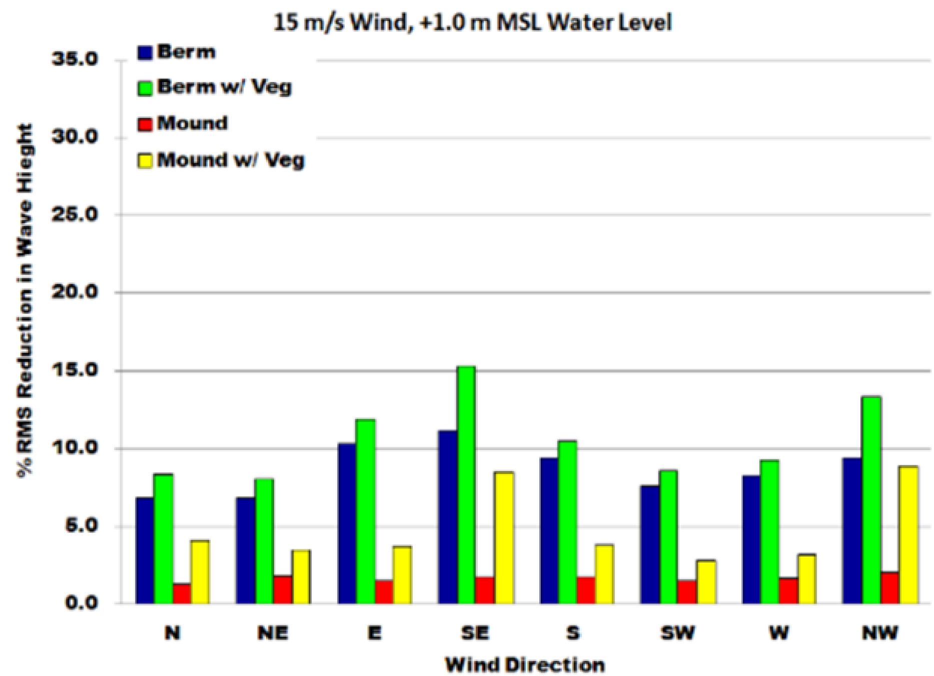
Example: Hamilton Wetland, California

Compare wave reduction for Berms (linear feature) vs. Mounds (circular feature)
Numerical simulations:

- Winds of 15 and 20 m/s (14-yr wind record at Richmond, CA)
- Water levels of + 0.5 and +1.0 MSL
- 8 wind directions (N, NE, E, SE, S, SW, W, NW)
- With and without vegetation
  - Pickleweed
  - Within depth range of +0.4-0.95 m MSL
  - C_D = 0.1, stem height=0.6 m, density = 300/m^2 diameter = 0.01 m (Northwest Hydraulic Consultants 2011)

Example: Hamilton Wetland, California





Linear berms produced a greater reduction in wave height than circular mounds:

25-32% at 0.5m MSL Berms versus 11-14% at 0.5m MSL Mounds

Wave height attenuation by berms AND mounds decreases significantly once they are submerged (75% reduction 1m v. 0.5m MSL)

Vegetation increases wave height reductions (when vegetation is submerged), vegetation impact greater for circular mounds

Vegetation Summary

- Wave dissipation is key, but other factors may come into play for reducing currents and sediment transport
- Need sufficient "space" for dissipation
- Research needs:
  - Better characterization of vegetation types and C_d
  - Understanding of resilience to storms (breakage, failure, recovery)
  - Seasonal variability
  - Validation
  - Design guidance

Thank You

Contact Details

Siddharth Narayan: sidnarayan@ucsc.edu

Jane McKee Smith: Jane.M.Smith@usace.army.mil

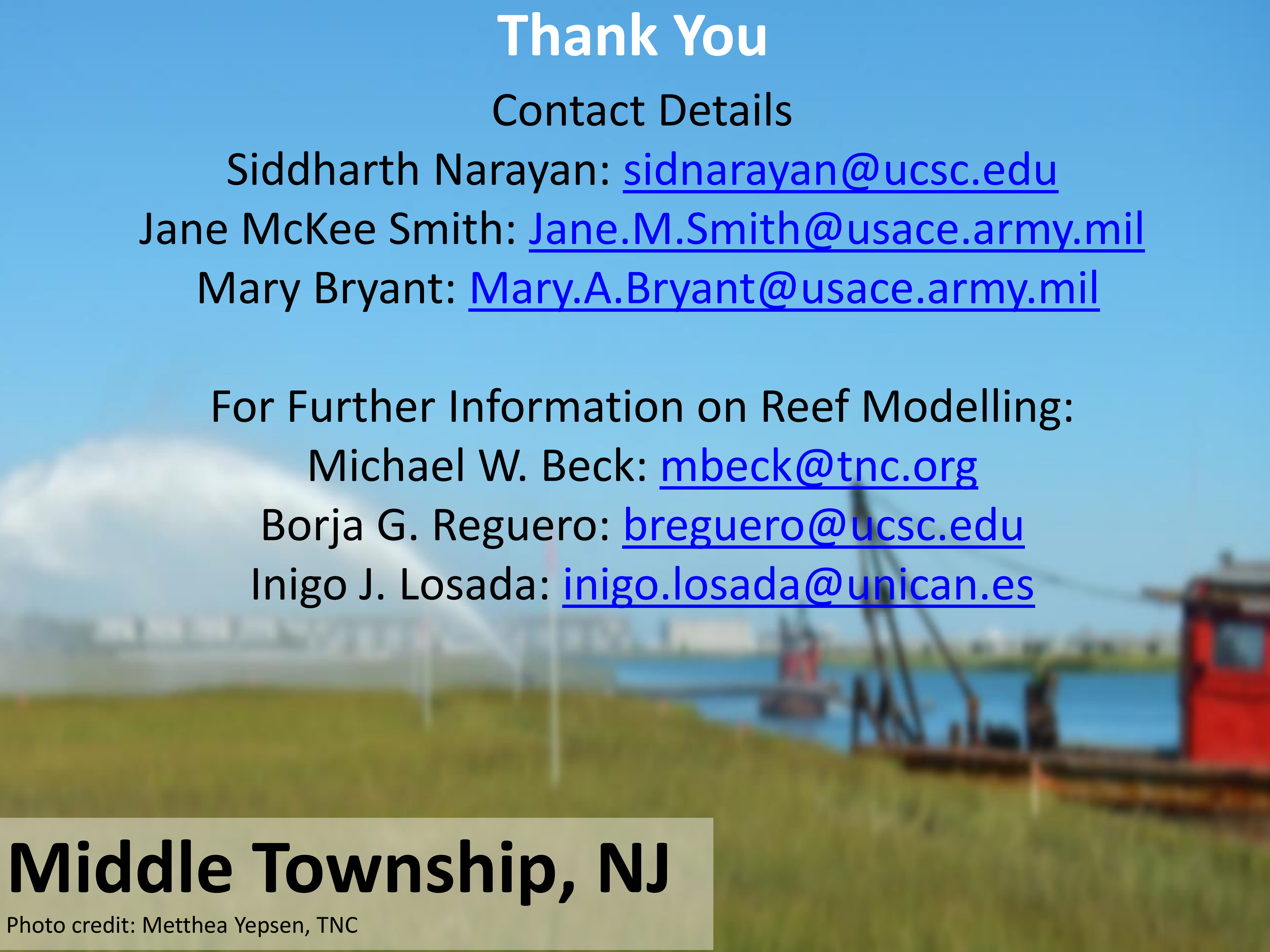
Mary Bryant: Mary.A.Bryant@usace.army.mil

For Further Information on Reef Modelling:

Michael W. Beck: mbeck@tnc.org

Borja G. Reguero: breguero@ucsc.edu

Inigo J. Losada: inigo.losada@unican.es



Middle Township, NJ

Photo credit: Metthea Yepsen, TNC