Applications of Natural Infrastructure: Context, Features, and Benefits

NASEM Workshop on Natural Infrastructure
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Outline

- **Introduction and design considerations**
  - *International Guidelines* and mangroves within the context of coastal wetland systems
- **Motivation - why mangroves?**
  - Case study: damage observations after Hurricane Irma (2017) in the FL Keys
- **Quantifying mangrove performance metrics**
  - Prototype-scale laboratory study
- **Conclusions**

NNBF

International Guidelines on Natural and Nature-Based Features for Flood Risk Management

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Coastal Wetlands and Tidal Flats

Authors: Candice D. Piercy, Nigel Pontee, Siddarth Narayan, Jenny Davis, Trevor Meckley

Key Messages

1. Coastal wetlands and tidal flats reduce flood and erosion risks in coastal environments
2. Projects can include conserving existing wetlands, restoring degraded wetlands, or constructing new wetlands
3. Performance is controlled by location, coastline geometry, vegetation morphology, and storm characteristics
4. Wave height reduction is well documented over moderate spatial scales and depends on topography, vegetation characteristics, and storm characteristics
5. Storm surge reduction requires greater spatial scales (i.e., wetland size and extents)

Coastal Wetlands and Tidal Flats

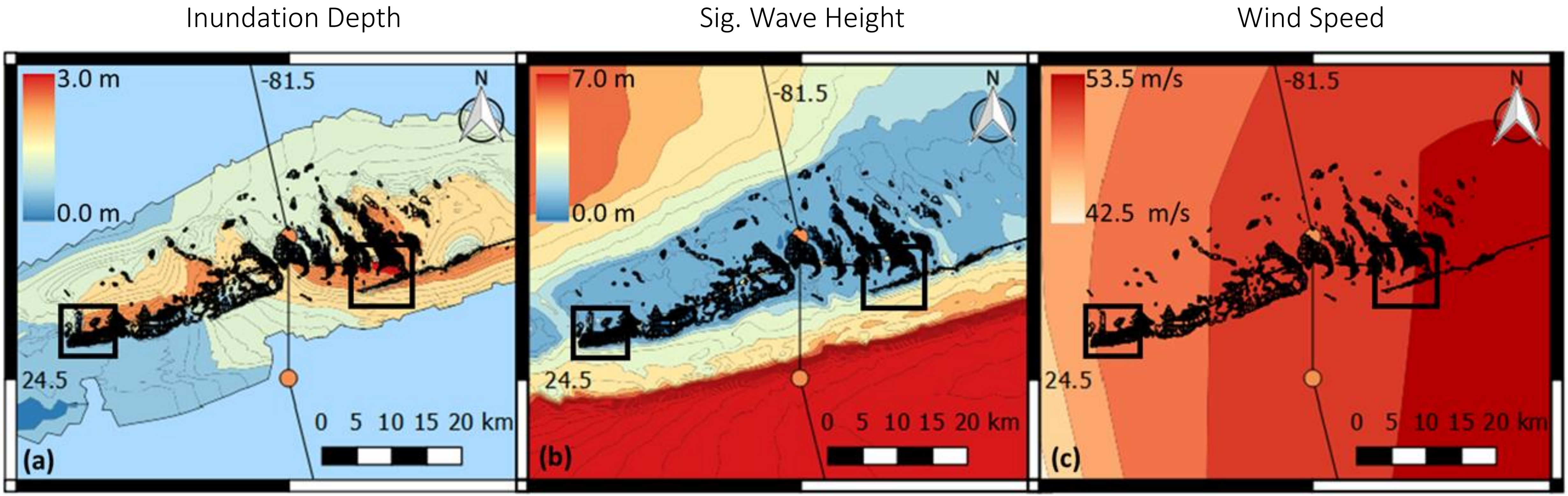
Authors: Candice D. Piercy, Nigel Pontee, Siddarth Narayan, Jenny Davis, Trevor Meckley

Key Messages (cont'd)

6. Coastal wetlands can provide flood storage; efficacy depends on location and design
7. Projects can draw upon extensive experience in marsh and mangrove restoration
8. Provided with the appropriate ecological and ambient wave energy conditions, coastal wetland NNBF can be self-maintaining over time.
9. Consider where wetland NNBF will persist now and under future climate and SLR scenarios
10. Performance of wetland NNBF will vary over time as vegetation establishes, develops, and recovers after disturbances

Coastal wetlands also provide numerous cobenefits (*e.g.*, habitat, Carbon sequestration)

Motivation for Mangroves: Damage Observations after Hurricane Irma (2017) in the Florida Keys



Tomiczek et al. (2020)

	Key West	Big Pine Key
Wind Velocity (m/s)	44.8-49.2	49.3-53.6
Inundation Depth (m)	1.23-2.14	1.53-2.75
Significant Wave Height (m)	0-1.83	0.92-2.74

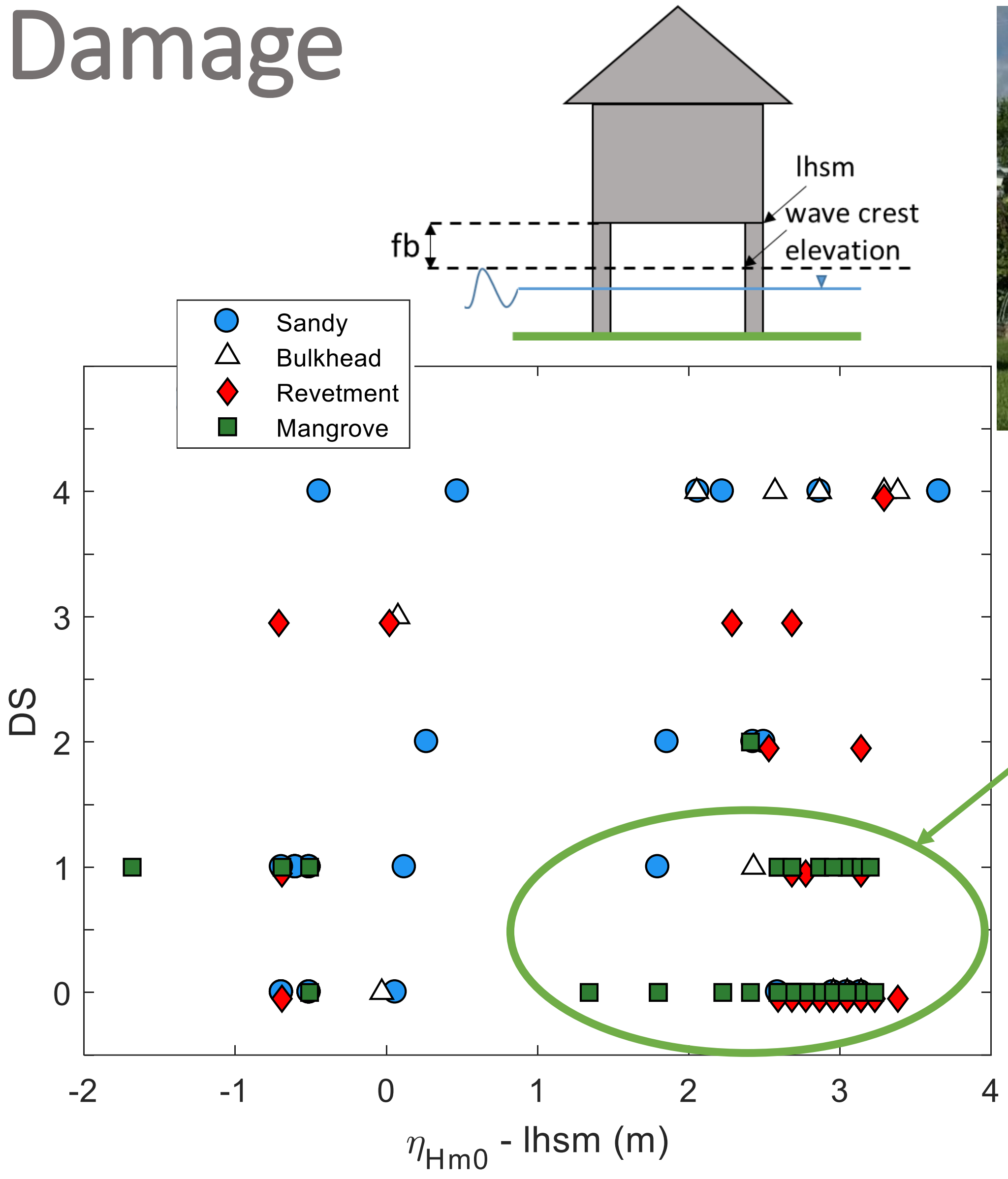
Post-Storm Damage Assessments

- NEU-USNA Collaborative Effort
  - July 2017- March, 2018
- Key West and Big Pine Key
- *Investigate relationship between shoreline resiliency, structural vulnerability, and shoreline management*
- **October Survey**: 263 residential structures, 332 shorelines

Parcel-Scale Shoreline Variability

- Shoreline archetypes based on NOAA C-CAP Classifications
- Four-point damage scale
- Mangroves show resilience

Fragility Relationships: Relate Hazard, Shoreline Type, and Damage



- Structures with mangrove shorelines: lower damage states (*DS*) for higher hazard intensities ($\eta_{Hm0} - lhsm$)
- Similar to protection noted in other studies (*e.g.* India (Danielsen et al. 2005), SW FL (Zhang et al. 2012)) for km-scale forests, but for 10-50 m cross-shore forest widths

Tomiczek, T., O'Donnell, K., Furman, K., Webbmartin, B., and Scyphers, S. (2020). Rapid Damage Assessments of Shorelines and Structures in the Florida Keys after Hurricane Irma. Nat. Haz. Rev. 21 (1) 15019006. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000349.

Need to Quantify Mangrove Performance Metrics

- **Previous Studies of wave attenuation through vegetation**
  - Anderson and Smith (2014) – *Spartina alterniflora* mimics, emergent and near-emergent
  - Ozeren et al. (2014) – idealized rigid vegetation, live wetland vegetation, emergent
  - Hu et al. (2014) – idealized rigid wetland vegetation, emergent
  - Maza et al. (2017, 2019) – *Rhizophora,* 1:12 and 1:6 geometric scales
  - Chang et al. (2019) – *Rhizophora,* 1:7 geometric scale
- **Generally quantify a drag coefficient**
  - e.g., Mendez and Losada (2004):

Vegetation Parameters

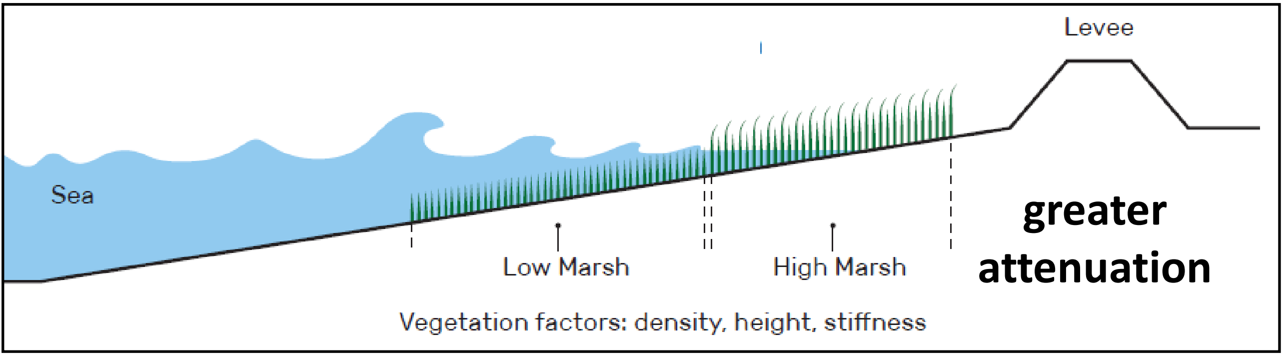
Hydrodynamic Parameters

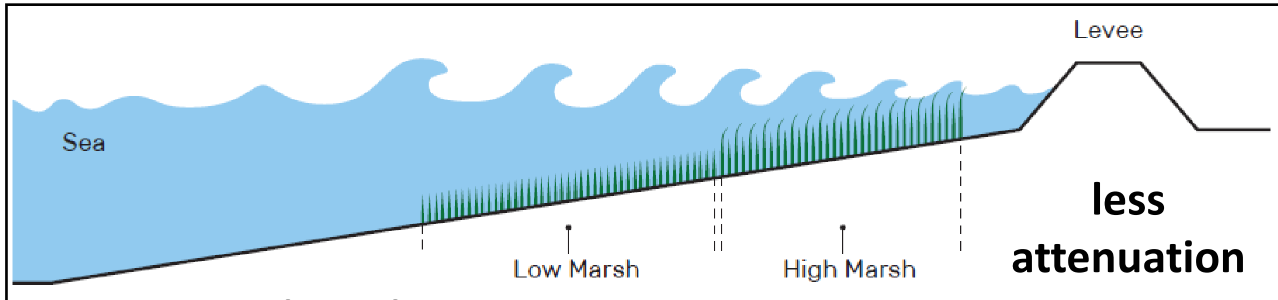
Ratio of transmitted to incident wave height

$$\frac{H_t}{H_i} = \frac{1}{1 + \tilde{\alpha} x}$$

where

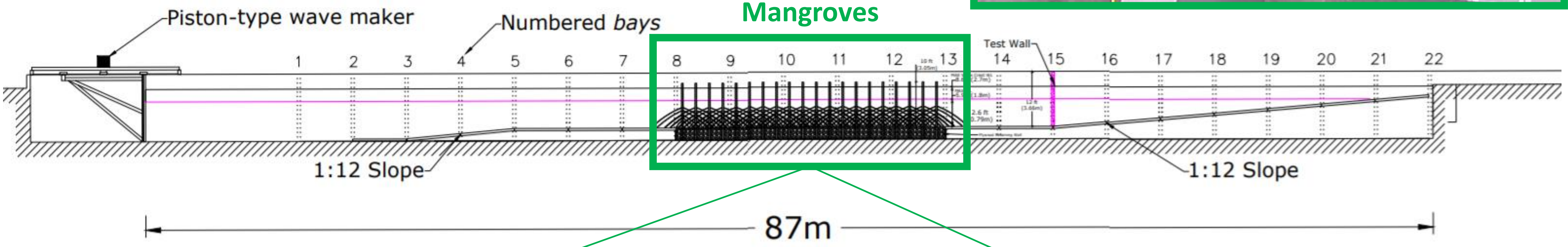
$$\tilde{\alpha} = \frac{A_t \cdot N \cdot H_{rms,i} \cdot C_D \cdot k_p}{3\sqrt{\pi}} \cdot \frac{\left(\sinh\left(k_p l_d\right)\right)^3 + 3\sinh\left(k_p l_d\right)}{\sinh\left(k_p h\right)\left[\sinh\left(2k_p h\right) + 2k_p h\right]}$$



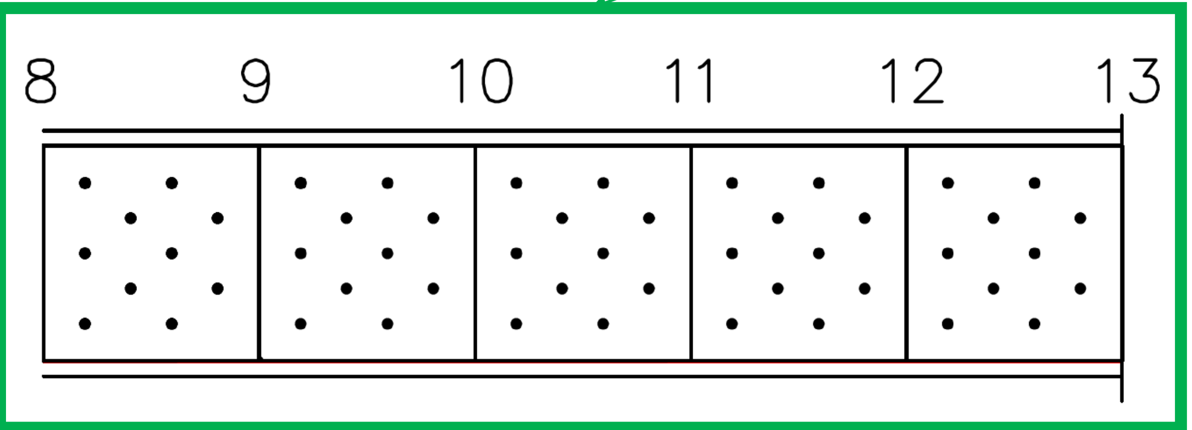


Piercy et al. (2021)

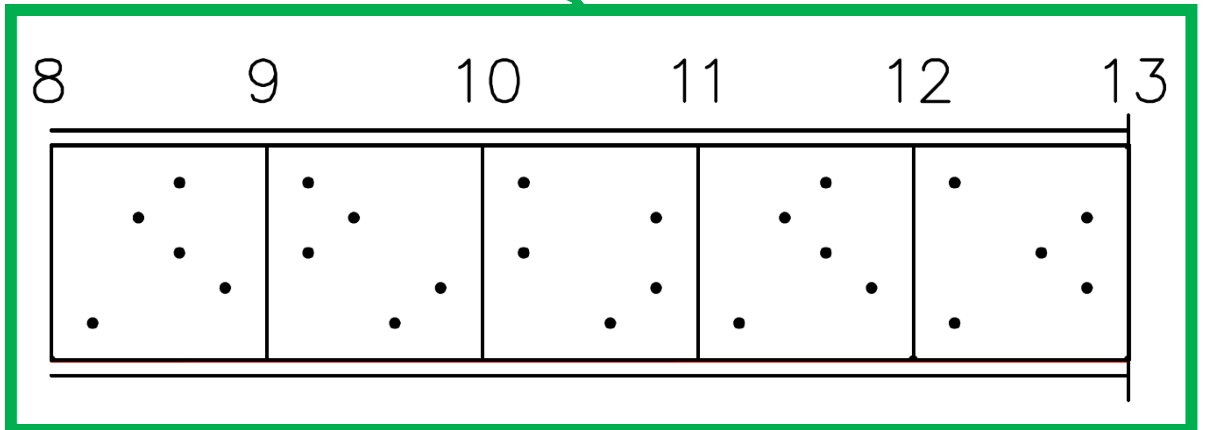
Full-Scale Physical Model of Wave Attenuation through *R. mangle*



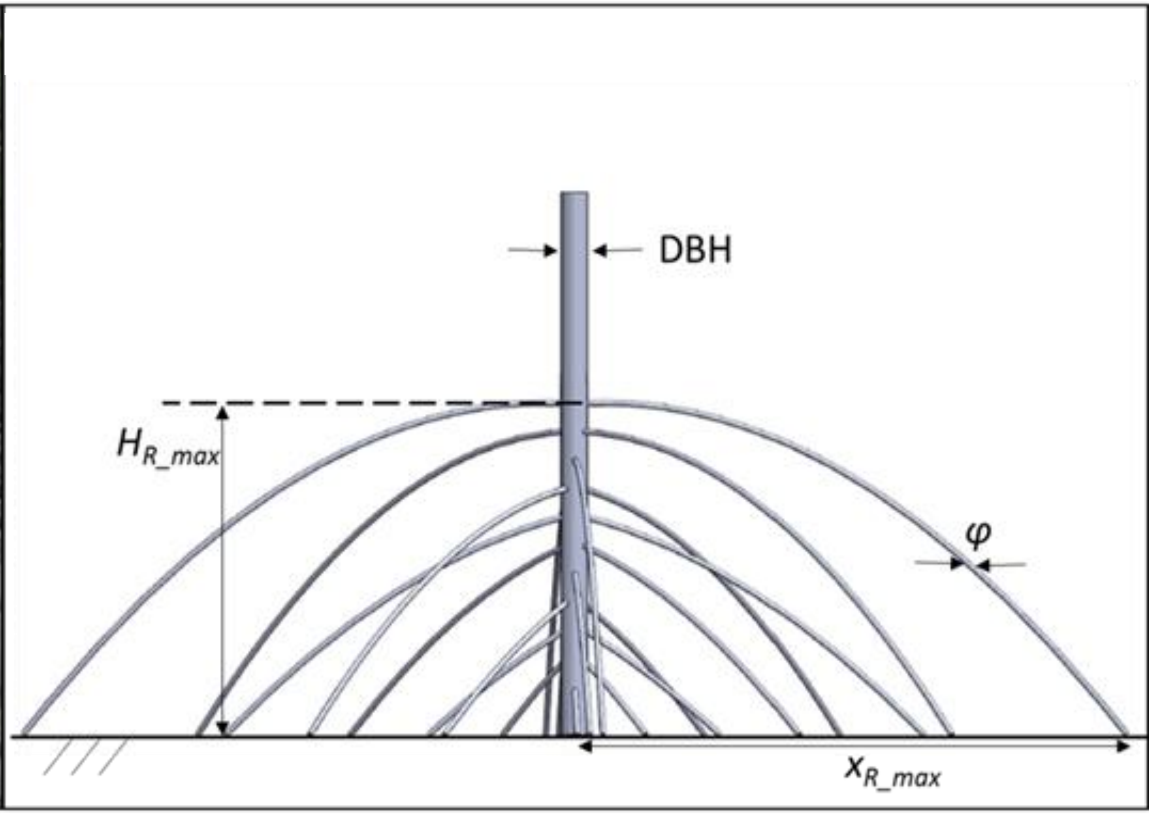
High-Density (0.75 stems/m^2)



Low-Density (0.375 stems/m^2)



Specimen Design

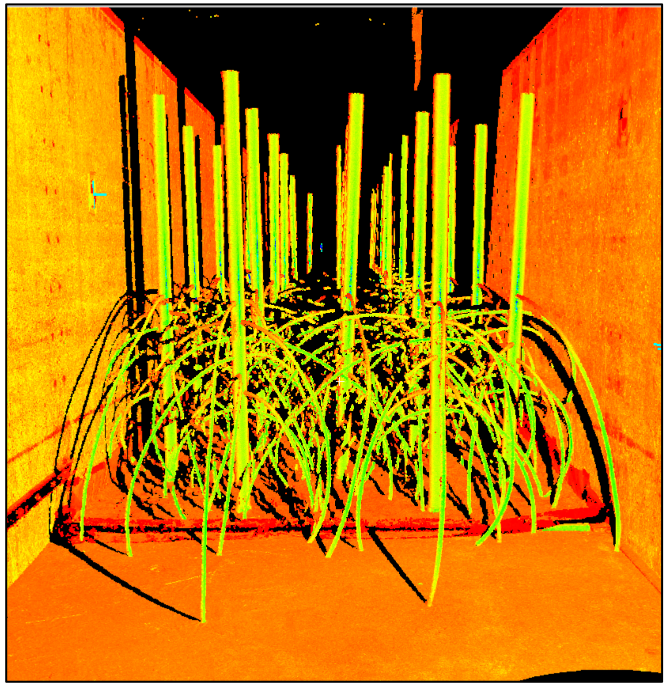


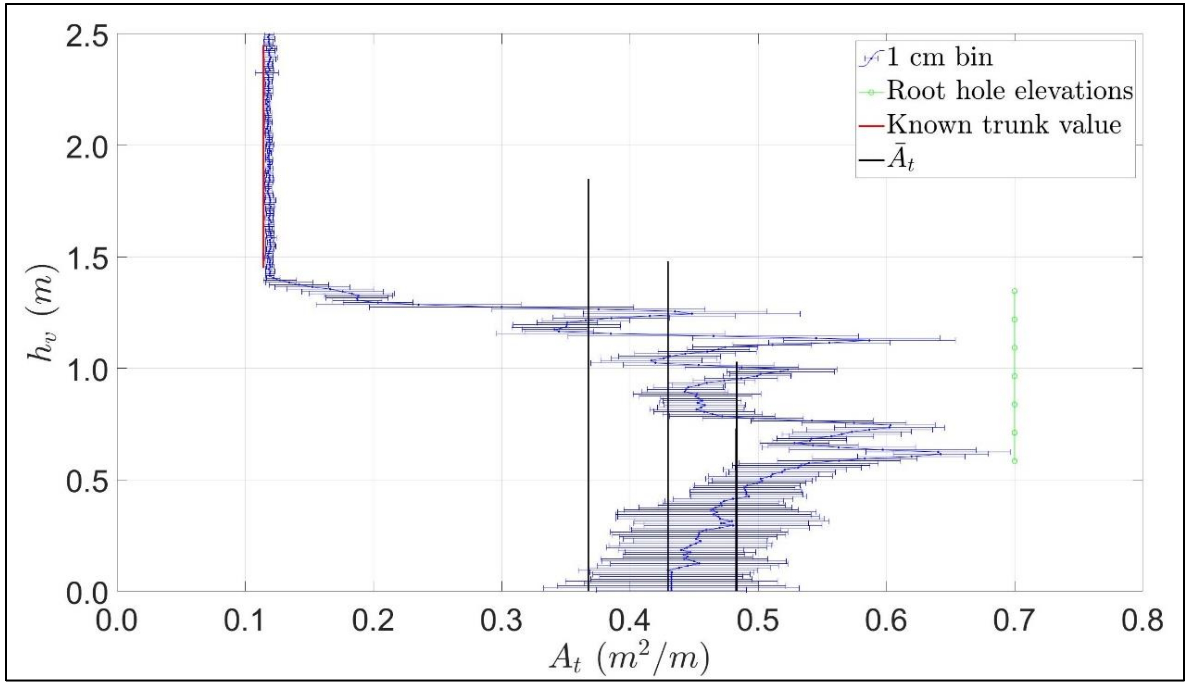
Dimension	Full Scale (m)
DBH	0.114
φ	0.029
H_{R_max}	1.445
x_{R_max}	2.58
N	14

Material	Total Length
PEX	3867 ft
PVC	625 ft

- Identical to 1:2-geometric scale specimens constructed at ERDC

LiDAR Characterizarion of Projected Area





$$\tilde{\alpha} = \frac{\overline{A_t} \cdot N \cdot H_{rms,i} \cdot C_D \cdot k_p}{3\sqrt{\pi}} \cdot \frac{\left(\sinh\left(k_p l_d\right)\right)^3 + 3\sinh\left(k_p l_d\right)}{\sinh\left(k_p h\right)\left[\sinh\left(2k_p h\right) + 2k_p h\right]}$$

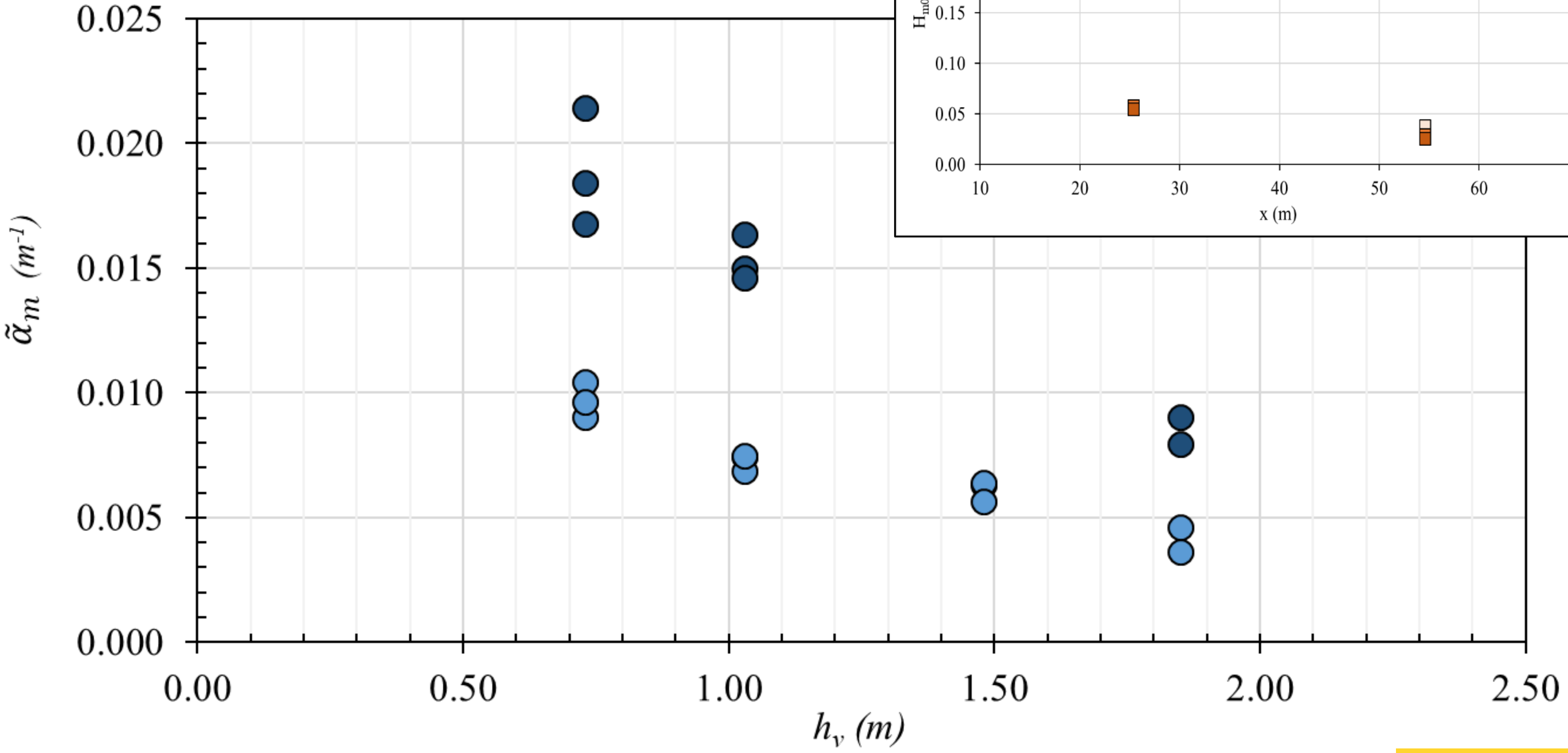
- Accurate to within 2% of known stem diameters, 10% of known root diameters
- Allows full characterization of vertical variation of projected area, uncertainty

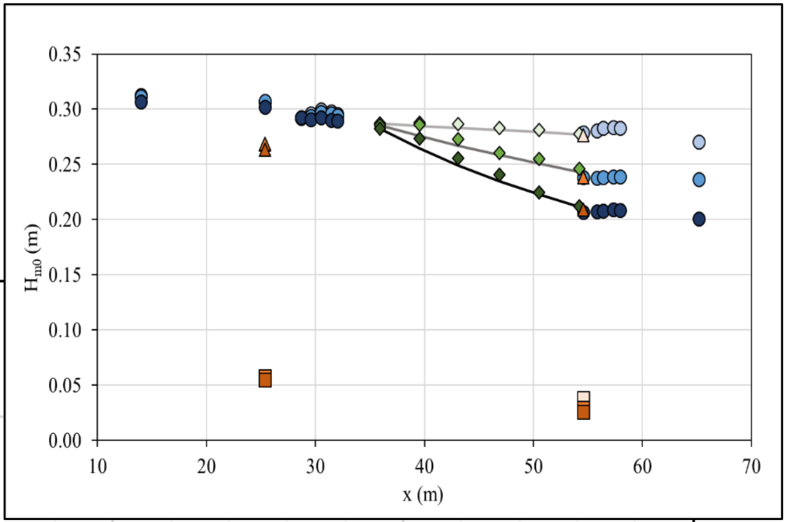
Mangrove Effects on Hydrodynamics

- 4 water depths tested
  - h_{veg} = 0.70 m to 1.82 m
- Irregular and regular wave conditions
  - $H_{i,m0}$ = 0.1 m to 0.73 m
  - T_p = 1.91 s to 7.45 s

Empirical Wave Height Decay Coefficients

$$\frac{H_t}{H_i} = \frac{1}{1 + \tilde{\alpha} x}$$

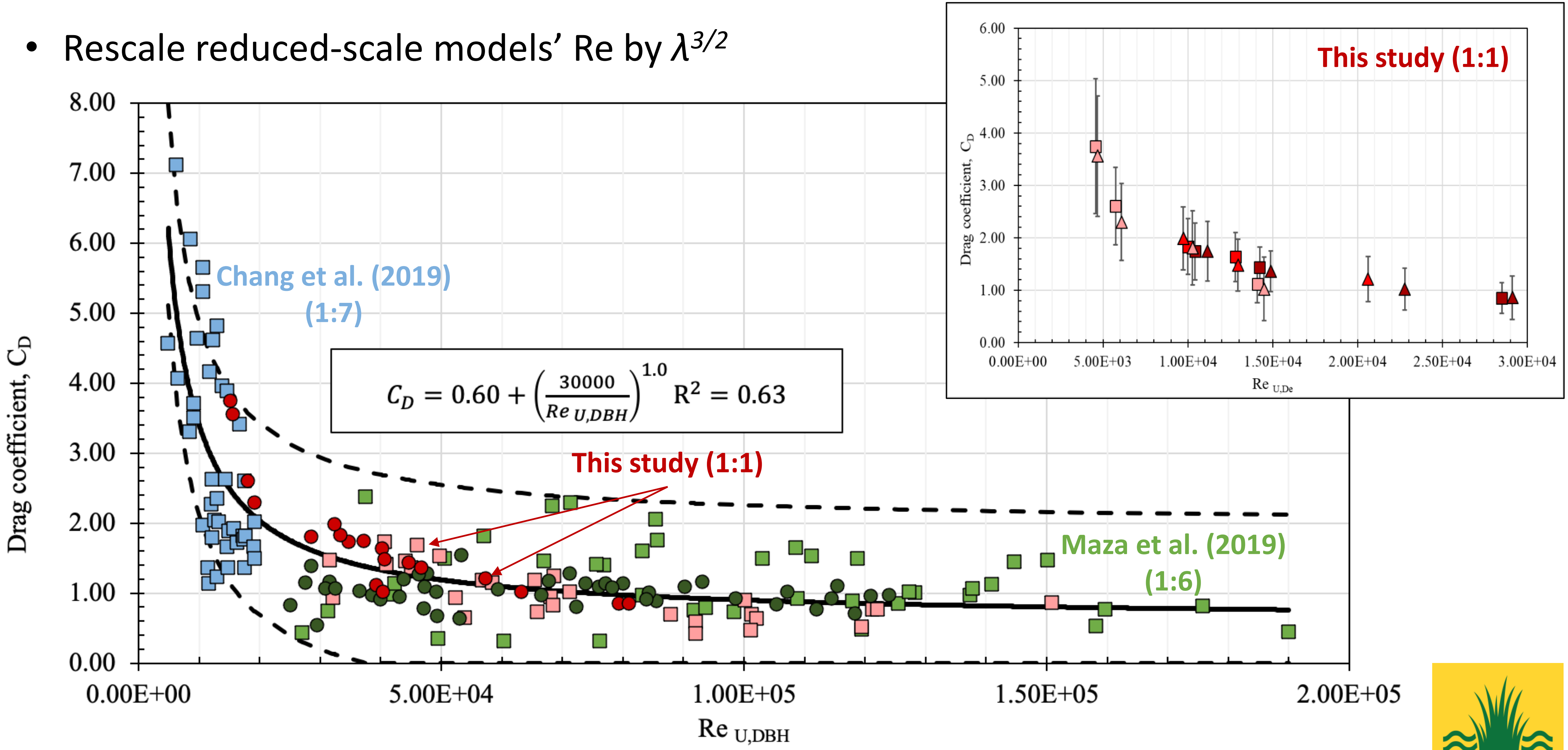




- Decay coefficients are a function of water depth
- Doubling forest density increased decay rate by factor of ~2

Drag Coefficient Including Uncertainty

- Rescale reduced-scale models' Re by $\lambda^{3/2}$



Kelty, K., Tomiczek, T., Cox, D., Lomonaco, P., and Mitchell, W. Prototype-Scale Physical Model Study of Wave Attenuation by a Mangrove Forest of Moderate Cross-shore Thickness: LiDAR-based Characterization and Reynolds Scaling for Engineering With Nature. Frontiers In Marine Science, Revisions Submitted.

Conclusions

- Field observations, reduced-scale experiments show potential of red mangroves as effective NNBF solutions for coastal protection
- Prototype-scale tests ongoing to quantify wave attenuation, load reduction, and assess scaling impacts from laboratory to field
- **Future Work:** Research, Outreach, Incorporation into design guidance

Thank you!

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