

EWN Case Study: Mangroves

The Role of Shoreline Type in Mitigating Damage due to Hurricane Irma in the Florida Keys



Tori Tomiczek, Kelsi Furman, Brittany Webbmartin, Kiera O'Donnell, Steven Scyphers

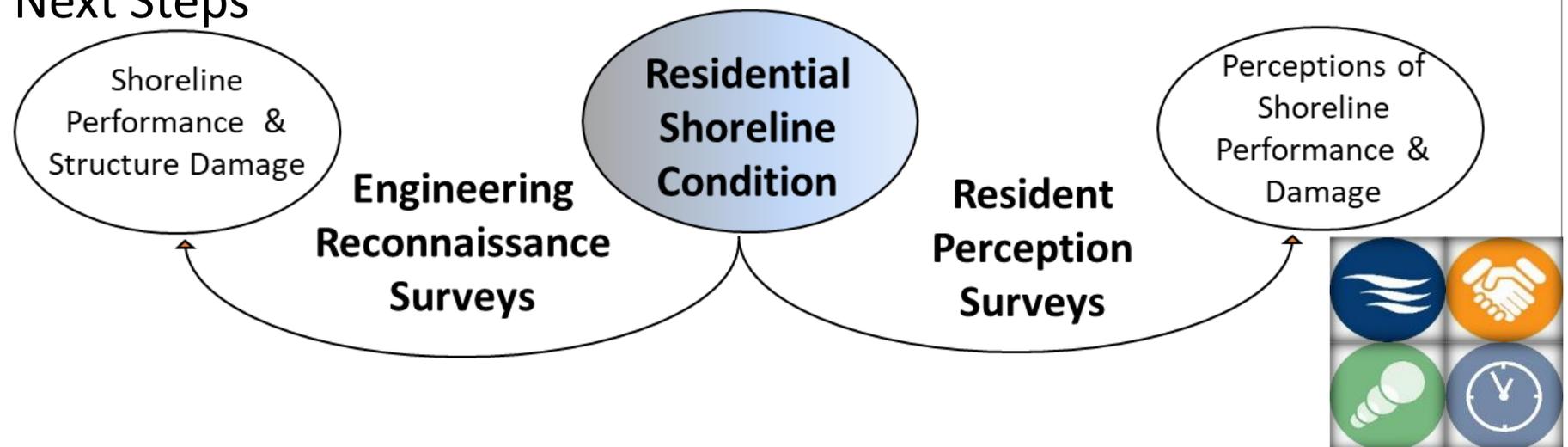
RAE 2018 Short Course: Engineering with Nature (EWN) for Sustainable Estuaries

13 December 2018

Long Beach, CA, USA

Outline

1. Introduction: The Florida Keys and Hurricane Irma
2. Post-Storm Reconnaissance
 - a. Shoreline Damage- Island and Parcel Scales
 - b. Structural Damage- Parcel Scale
4. Interconnectivities between Hazard, Shoreline Archetype, and Physical Damage
5. Homeowner Perceptions of Shoreline Performance
6. Quantifying Engineering Benefits
7. Conclusions and Next Steps



Florida Keys: Structural Consistency, Shoreline Variability



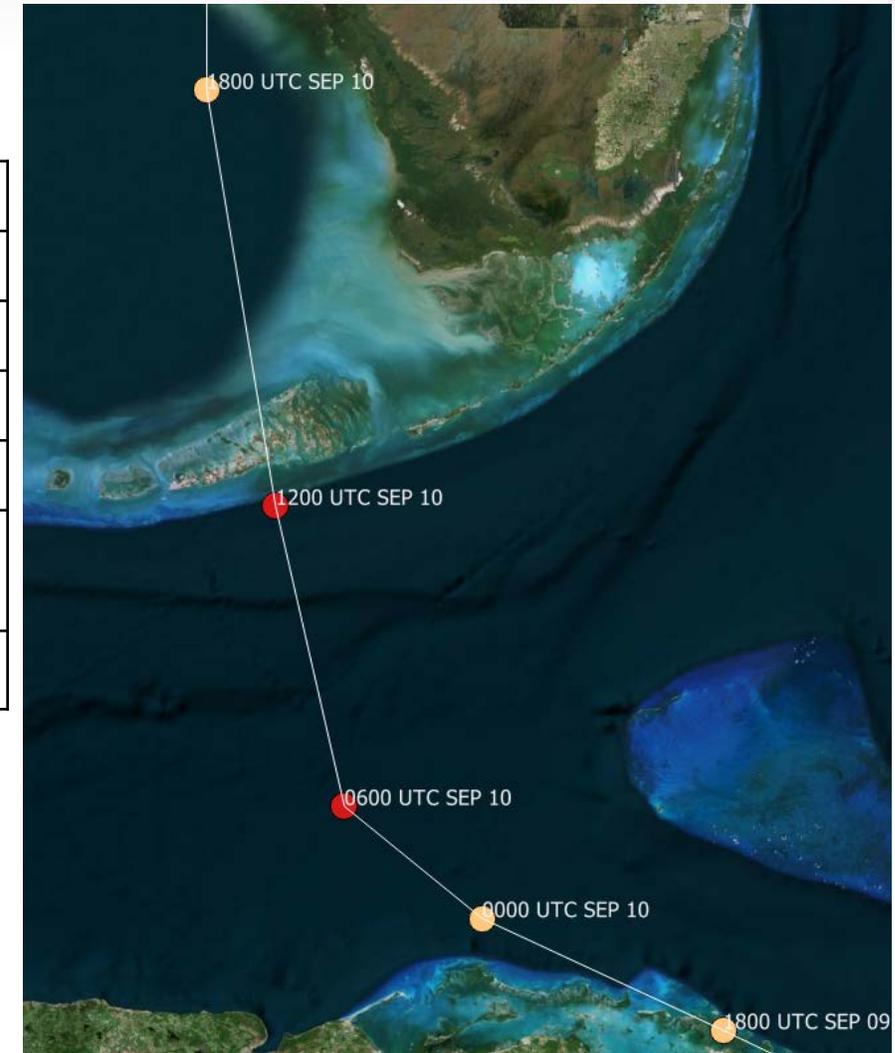
Hurricane Irma

Duration	30 August-16 September, 2017
Keys Landfall	Cudjoe Key, 10 September, 2017, 1310 UTC, Category 4
Central Pressure	914 mBar (min)*; 929 mBar (Keys landfall)
Wind Speeds	185 mph (maximum)**; 130 mph (Keys landfall)
Storm Surge	3 m (Florida Keys)
Effects	Catastrophic damage in Barbuda, USVI, Caribbean, middle Florida Keys, >146 deaths
US Property Damage	\$53.4 billion***

* 2nd most intense of 2017 (behind Hurricane Maria)

** Strongest of 2017

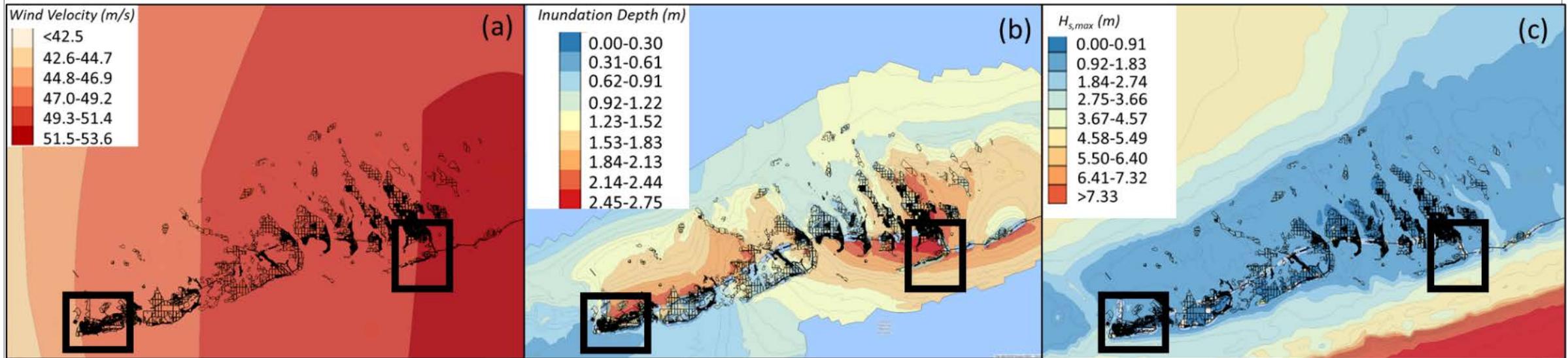
*** 5th costliest in US History



Hurricane Irma Best Track: NHC

Hurricane Irma: Hazard Intensity Measures

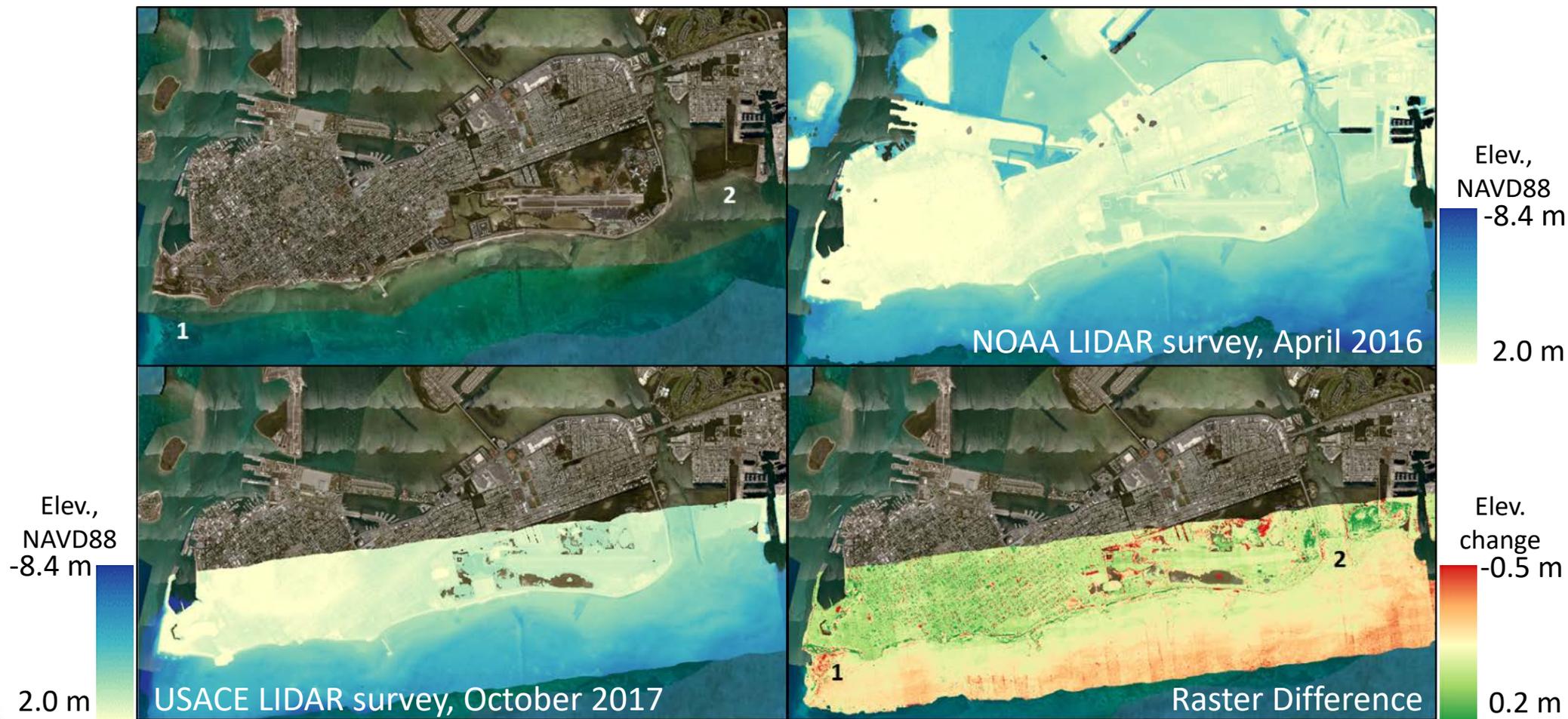
ADCIRC + SWAN storm simulation courtesy CERA (2017)



	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



Island Scale Vulnerability



Island Scale Vulnerability



Fort Zachary Taylor State Park



Roosevelt Seawall and Cow Key Mangroves



Parcel Scale Damage Assessments



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



Shoreline Archetypes

Mangrove



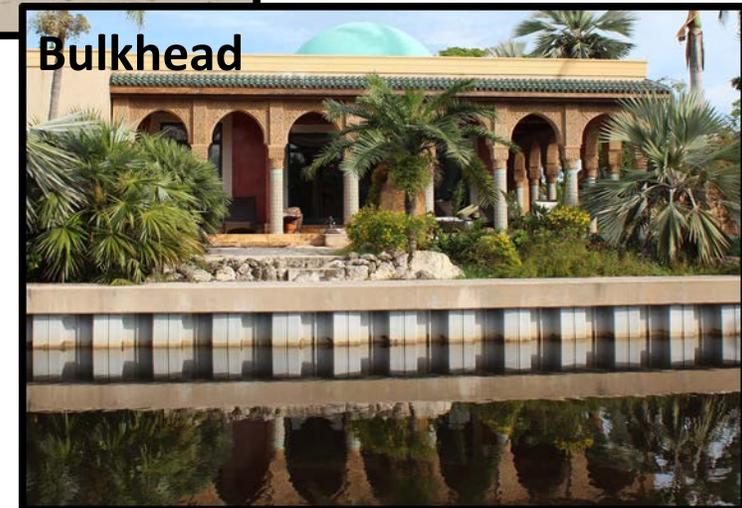
Sandy Beach



Revetment



Bulkhead



- Compiled from observations, NOAA C-CAP (2017) regional land cover classifications and USACE (1995) descriptions of shoreline structures



Shoreline Damage



Mangrove: broken branches, loss of foliage, regrowth



Sandy Beaches: erosion



Revetment: rocks displaced



Bulkhead: cracks, undercutting, structural collapse

- 4 point damage scale from 0 (no visible damage) to 3 (totally destroyed)
- Based on field observations, permitting data





Component-Based Structural Damage Assessments

Component	0	1	2	3	4
Roof	<ul style="list-style-type: none"> No visible damage 	<ul style="list-style-type: none"> Few shingles missing (<15% of roof area) Minor damage to gutters 	<ul style="list-style-type: none"> Significant amount of shingles missing 15-30% of roof area Minor damage to frame Roof interior is not exposed 	<ul style="list-style-type: none"> Holes in roof due to debris or wind- sheathing is exposed but not house interior 	<ul style="list-style-type: none"> Large parts of roof are missing or collapsed; structural damage
Walls	<ul style="list-style-type: none"> No visible damage 	<ul style="list-style-type: none"> Minor cladding removal (<10% of 1 wall) Small scratches/ aesthetic damage 	<ul style="list-style-type: none"> Cladding removed from >25% of wall surfaces Interior sheathing exposed on <25% of house but insulation and house interiors are not 	<ul style="list-style-type: none"> Minor structural wall damage, including debris caused holes or repairable damage 	<ul style="list-style-type: none"> Walls have collapsed, bent or are out of plumb, structural damage Large holes in walls major structural damage
Foundation	<ul style="list-style-type: none"> No visible damage 	<ul style="list-style-type: none"> Scour <0.5 feet around foundation Water marks around foundation Structurally sound 	<ul style="list-style-type: none"> Scour 0.5-2' deep Structurally sound foundation Evidence of weathering/minor damage on piles 	<ul style="list-style-type: none"> One pile out of plumb, or damaged Scour >2' deep Minor damage to foundation 	<ul style="list-style-type: none"> Major foundation damage Differentially settlement >1 pile is damaged House is missing
Landscaping, Attachments and Detached Structures (If Waterfront, Shoreline Condition)	<ul style="list-style-type: none"> No visible damage 	<ul style="list-style-type: none"> <2 Exterior structures damaged or removed Damage to stair, porches, detached garage, or walkways, most structures remain in tact Shoreline- aesthetic damage 	<ul style="list-style-type: none"> 2 or more exterior structures are gone or destroyed Damage/ collapse of deck, shed Landscaping damage- >50% of trees, bushes uprooted Shoreline- moderate damage 	<ul style="list-style-type: none"> Collapse of detached garage Shoreline- complete damage 	
Openings: Windows, Doors, Attached Garages	<ul style="list-style-type: none"> No visible damage 	<ul style="list-style-type: none"> 1 window or door is broken (glass only) Screens may be damaged or missing 	<ul style="list-style-type: none"> 2+ windows/doors broken or removed Damage to frames of doors and windows Attached garage door damaged or gone 		
Interior	<ul style="list-style-type: none"> No visible damage 	<ul style="list-style-type: none"> No flooding Minimal/no evidence of rain intrusion- minor water damage in corners or around windows only Minor water damage to interior furnishings 	<ul style="list-style-type: none"> Slight evidence of flooding Water marks (0-1') above floor Evidence of rain intrusion- dampness/ minor water damage on <10% of wall area or ceiling Water damage to interior furnishings No mold 	<ul style="list-style-type: none"> Water marks (1'-4') Rain/water damage to ceiling: wet spots, dripping, or sagging Dampness on >25% of wall areas and evidence of dripping or cracks on walls Mold 	<ul style="list-style-type: none"> Water marks 4' or higher Structural ceiling damage from rain- wet spots and sagging Structural damage to interior walls



Component-based Structural Damage Assessments

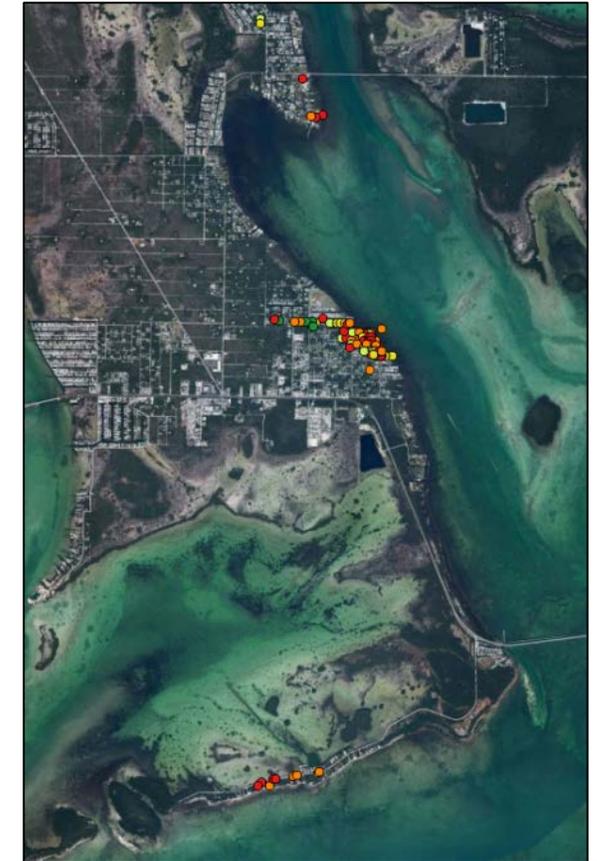
Key West

Big Pine Key

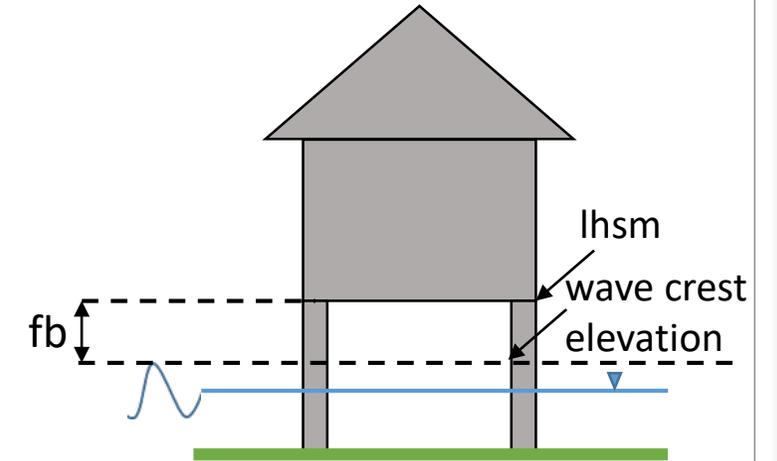
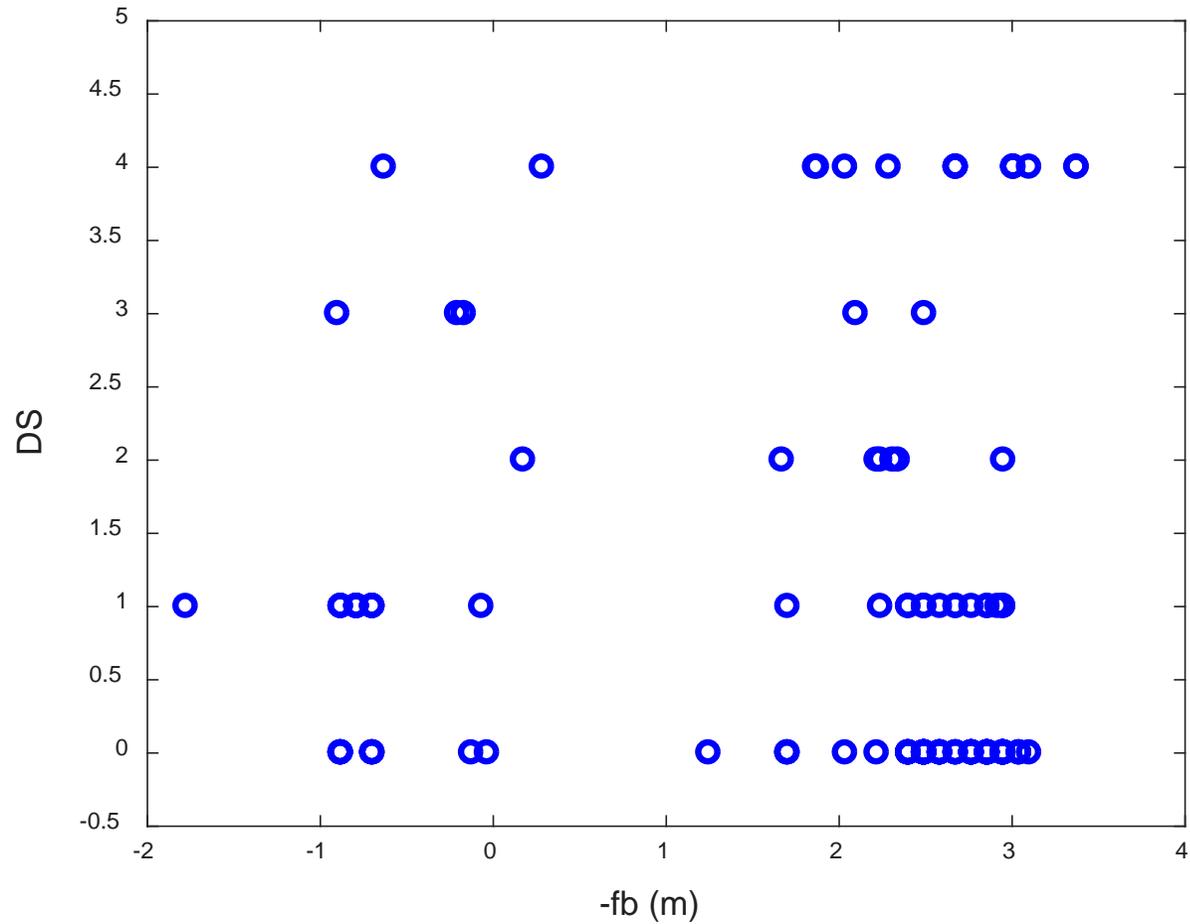
Damage

State

- 0
- 1
- 2
- 3
- 4



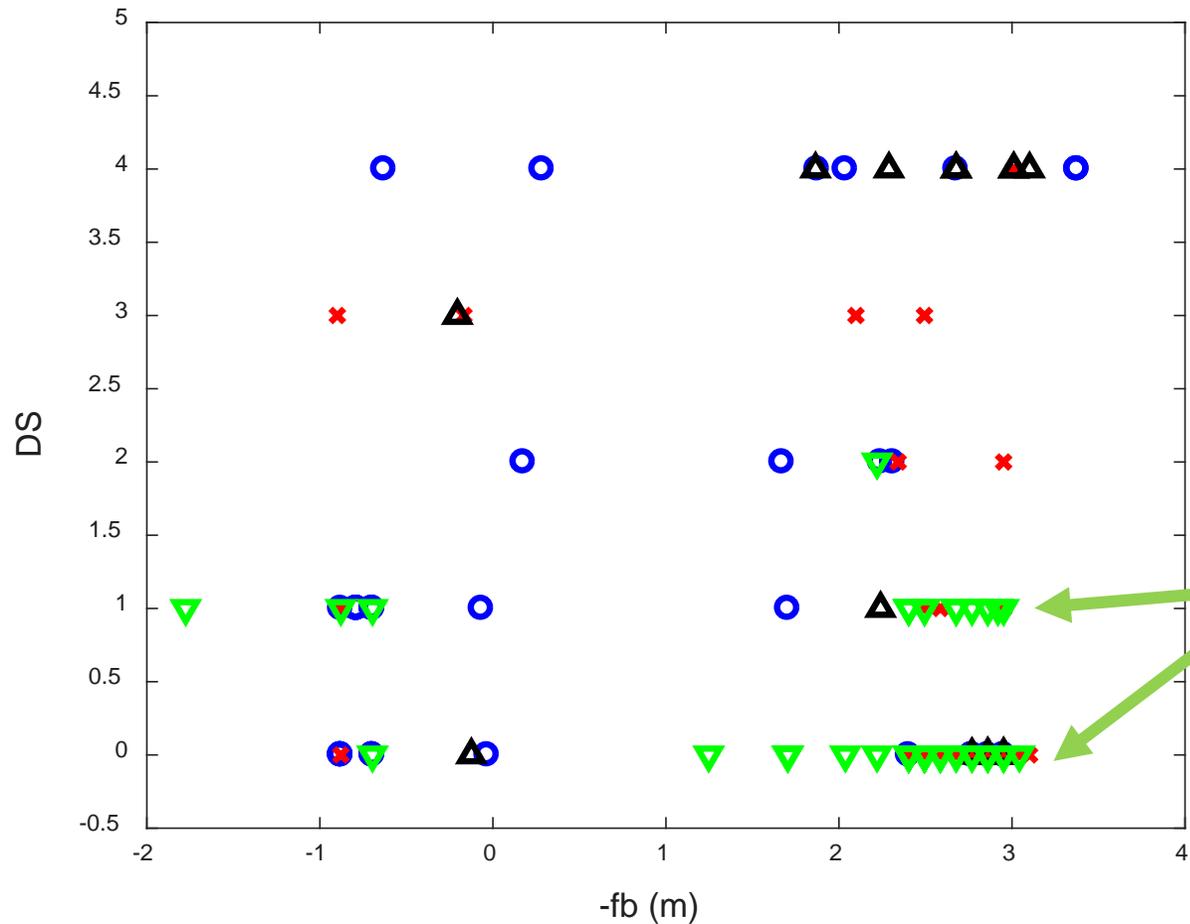
Structural Fragility: Relate Hazard, Structural Damage (?)



fb=freeboard
DS= damage state



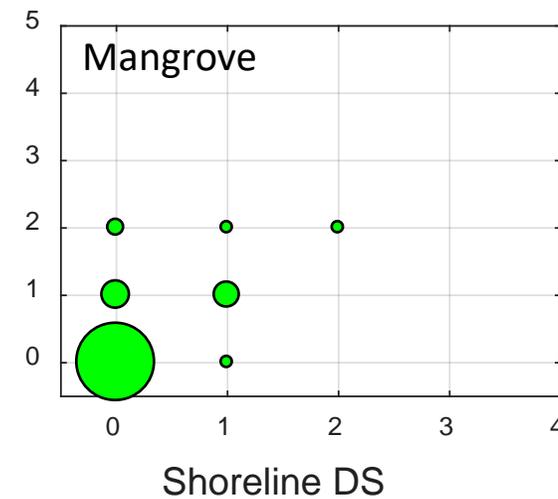
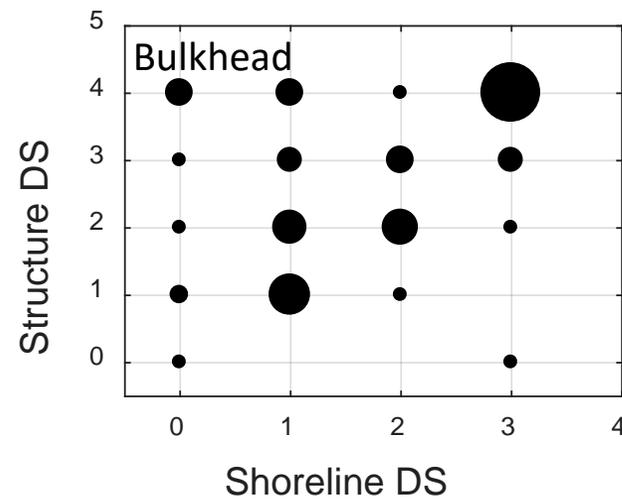
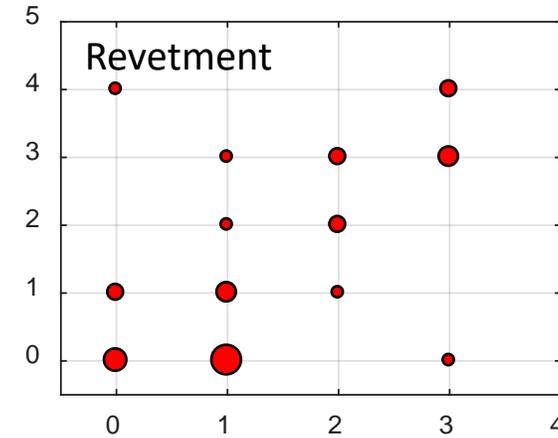
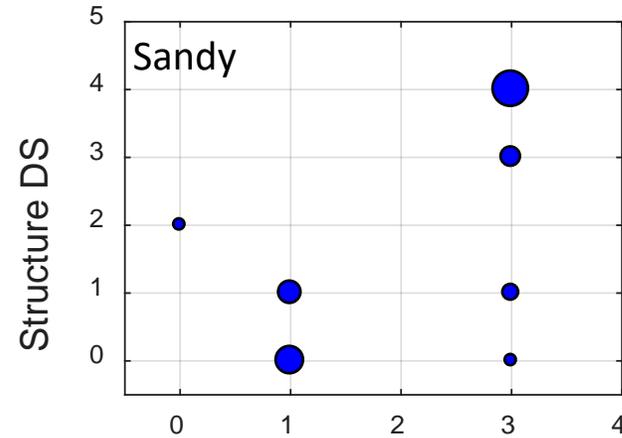
Relate Hazard, Structural Damage, and Shoreline Type



Structures with mangrove shorelines: lower DS for higher wave crest elevations above LHSM



Shoreline Damage Affects Structural Damage



Structural & Shoreline Fragilities: Multinomial Regression

Multinomial Logistic Regression:

- Shoreline Damage, Structural Damage as ordinal response variables
- Shoreline type (mangrove vs. other) as a categorical predictor variable

$$Y_{i,k} \sim \prod_{i=0}^1 \frac{N!}{Y_{i,k}!} P(DS = DS_i | x_k)$$

Log Odds/ Relative risk
$\frac{P(DS = 0)}{P(DS > 0)}$
$\frac{P(DS \leq 1)}{P(DS > 1)}$
$\frac{P(DS \leq 2)}{P(DS > 2)}$
$\frac{P(DS \leq 3)}{P(DS > 3)}$

Statistical Significance and AIC for Empirical Multinomial Fragility Models

Model	p_{fb}	$p_{\eta wave}$	$p_{Shoreline}$	AIC
Shoreline	---	0.0028	1.32 x 10 ⁻²³	161
Structure	0.041	---	4.89 x 10 ⁻²⁴	271



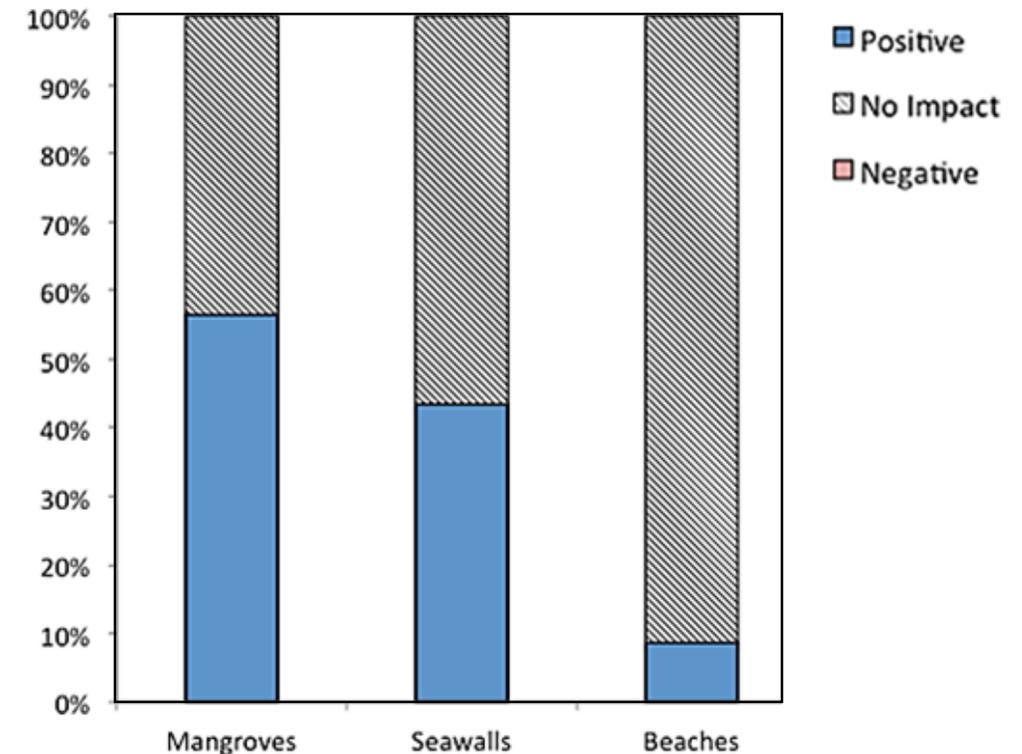
Interconnectivities between Shoreline Type, Structural Damage, and Homeowner Perceptions

- Mixed mode interviews
- Perceived impact of mangroves, seawalls, and beaches, on social and ecological systems during Hurricane Irma

“Mangroves are the only thing keeping the island from eroding”

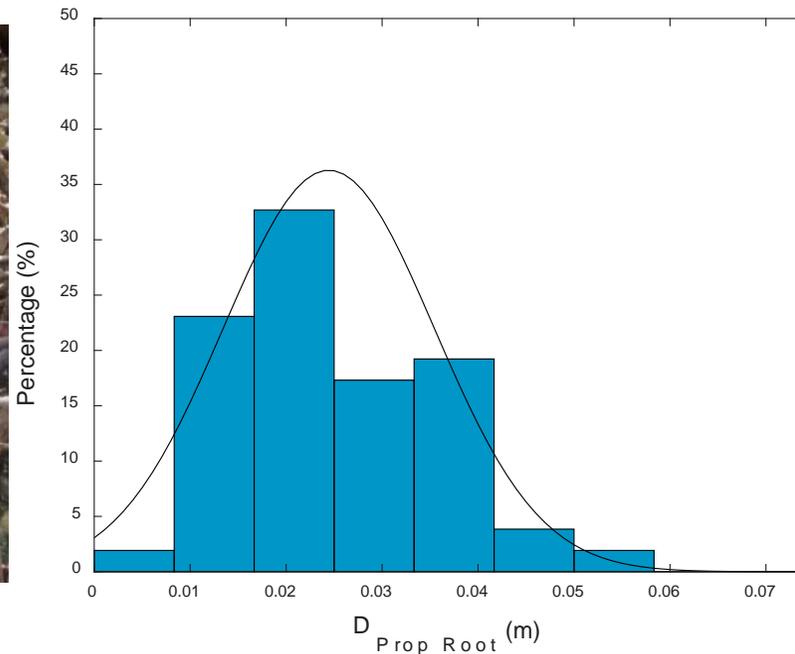
“90% of beaches were swept away”

“Without mangroves, the impact of the storm would have been much worse”



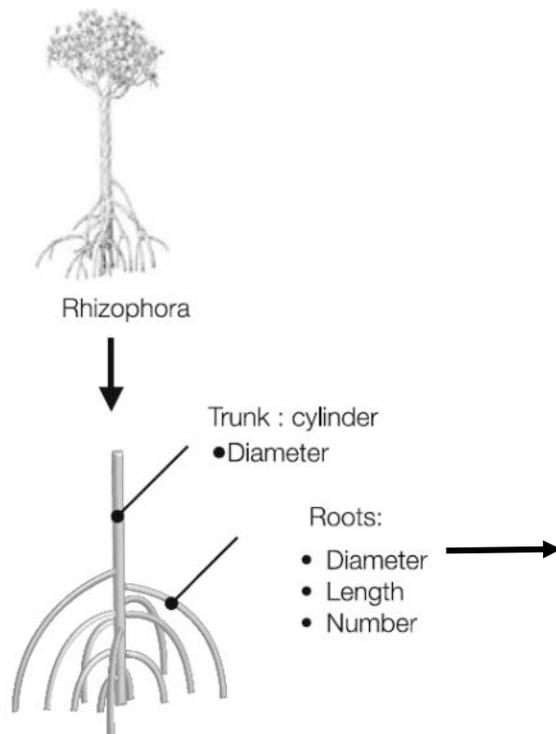
Field Characterization of Mangrove Shorelines

- Field study to characterize mangrove prop root density, average diameter, elastic modulus, canopy characteristics

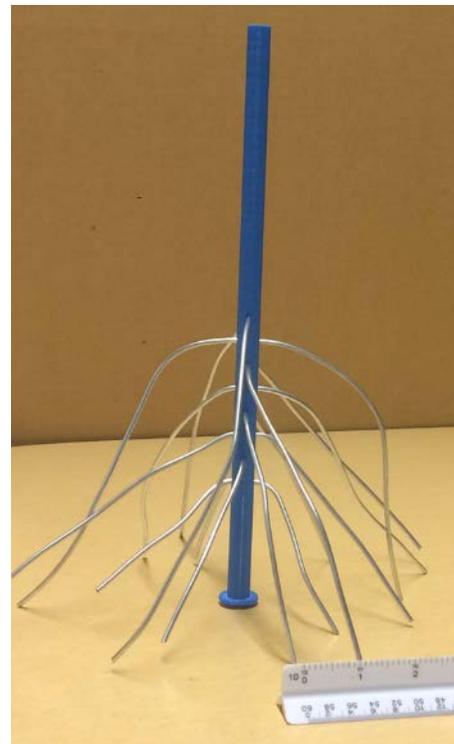


Laboratory Characterization of Mangrove Effects on Wave Propagation/Transformation

- Parametrization following Ohira et al. (2013), Maza et al. (2017)
- 1:16 scale physical model



Ohira et al. (2013)

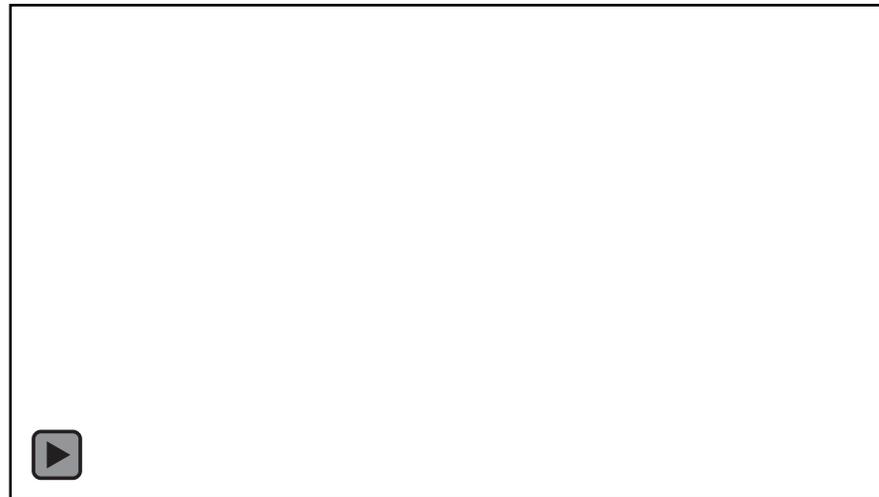
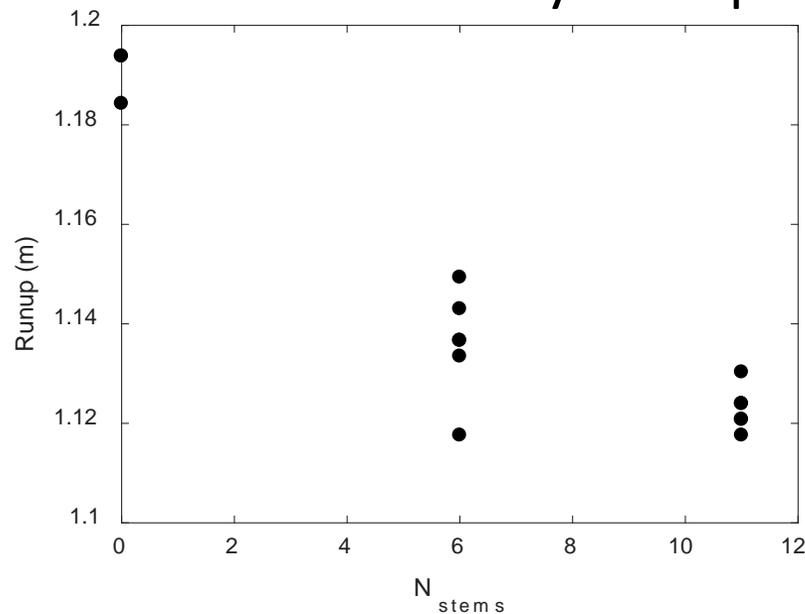


Parameter	Key West (1:1)	Model (1:16)
Material	Red mangrove	ABS (3D Printed)/ Galvanized Steel
d_{trunk}	0.11 m - 0.28 m	0.013 m
d_{root}	0.01 m - 0.06 m	0.0025 m
N_{roots}	12-24	16
h_{root}	1.0 m - 2.0 m	0.125 m



Laboratory Characterization of Mangrove Effects on Wave Propagation/Transformation

- Preliminary run-up tests in USNA Hydromechanics Laboratory



Compared to bare earth baseline

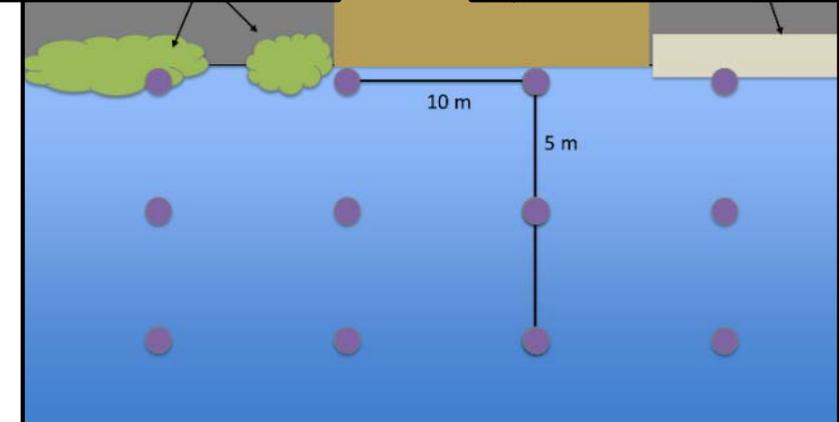
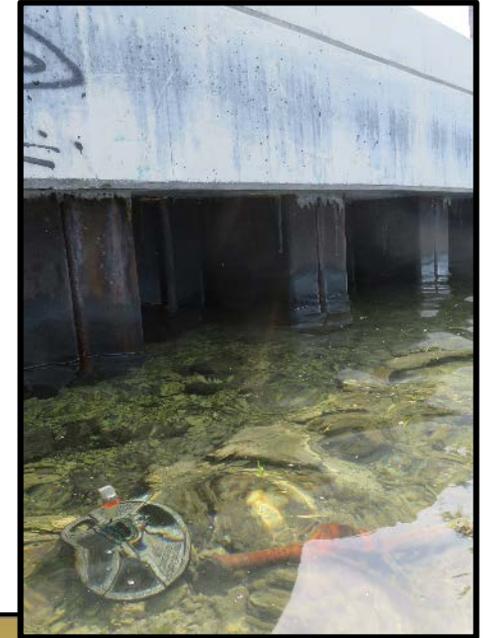
1 row: 4.7% run-up reduction

2 rows: 6.0% run-up reduction



Field Measurements of Mangrove Effects on Wave Transformation/Propagation

- Measurements fronting seawalls, mangroves, hybrid
- Boat wakes, wind waves
- Collaboration and coordination with City of KW, TNC



Conclusions

- Case study of damage to shorelines, structures after Hurricane Irma
- Ongoing longitudinal investigation to identify recovery trends, repair decisions, quantify mangrove benefits
- **Natural and nature-based features** may mitigate overland flow and resulting inland damage during storm events **in coordination with engineered structures**





Thank you for your kind attention!



Northeastern

