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

Interconnectivities between Shoreline Type and Structural Vulnerability

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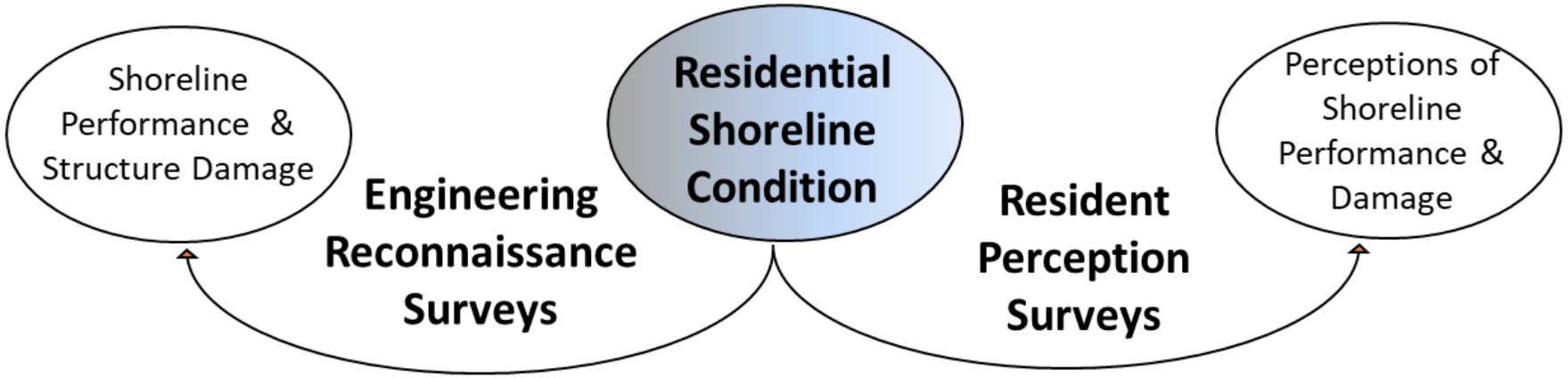
Outline



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 shoreline archetypes and physical damage
5. Homeowner perceptions of shoreline performance
6. Longitudinal study
7. Conclusions and Next Steps

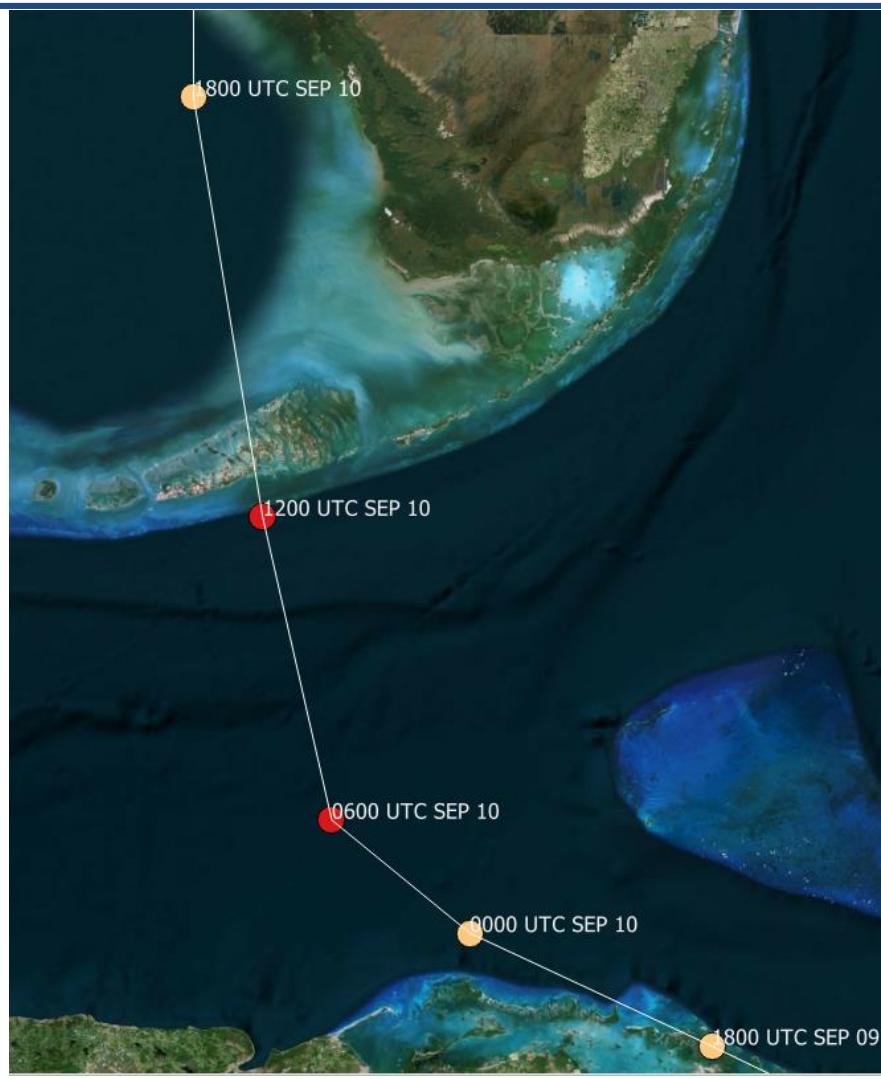
Florida Keys

- Structural Consistency, Shoreline Variability

Hurricane Irma

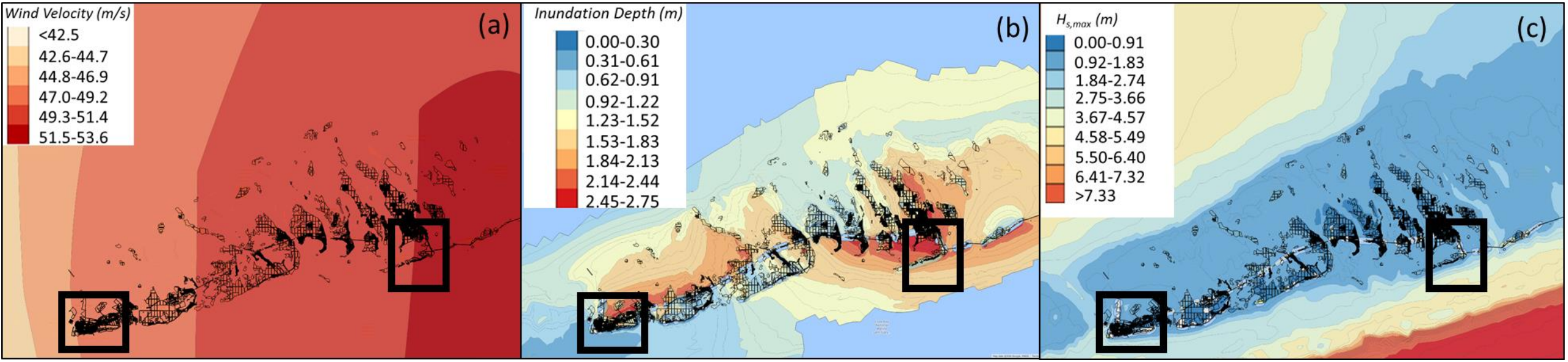
Duration	30 August-16 September, 2017
Keys Landfall	Cudjoe Key, 10 September, 2017, 1310 UTC, Category 4
Central Pressure	914 mBar (min)*; 929 mBar (Keys landfall)
Wind Speeds	185 mph (maximum)**; 130 mph (Keys landfall)
Storm Surge	3 m (Florida Keys)
Effects	Catastrophic damage in Barbuda, USVI, Caribbean,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

Parcel Scale Damage Assessments

- NEU-USNA Collaborative Effort
- 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 and Damage Observations

Mangrove: broken branches, loss of foliage, regrowth

Sandy Beaches: erosion

Revetment: armament displaced

Bulkhead: cracks, undercutting, collapse

Standardized Shoreline Damage Descriptions

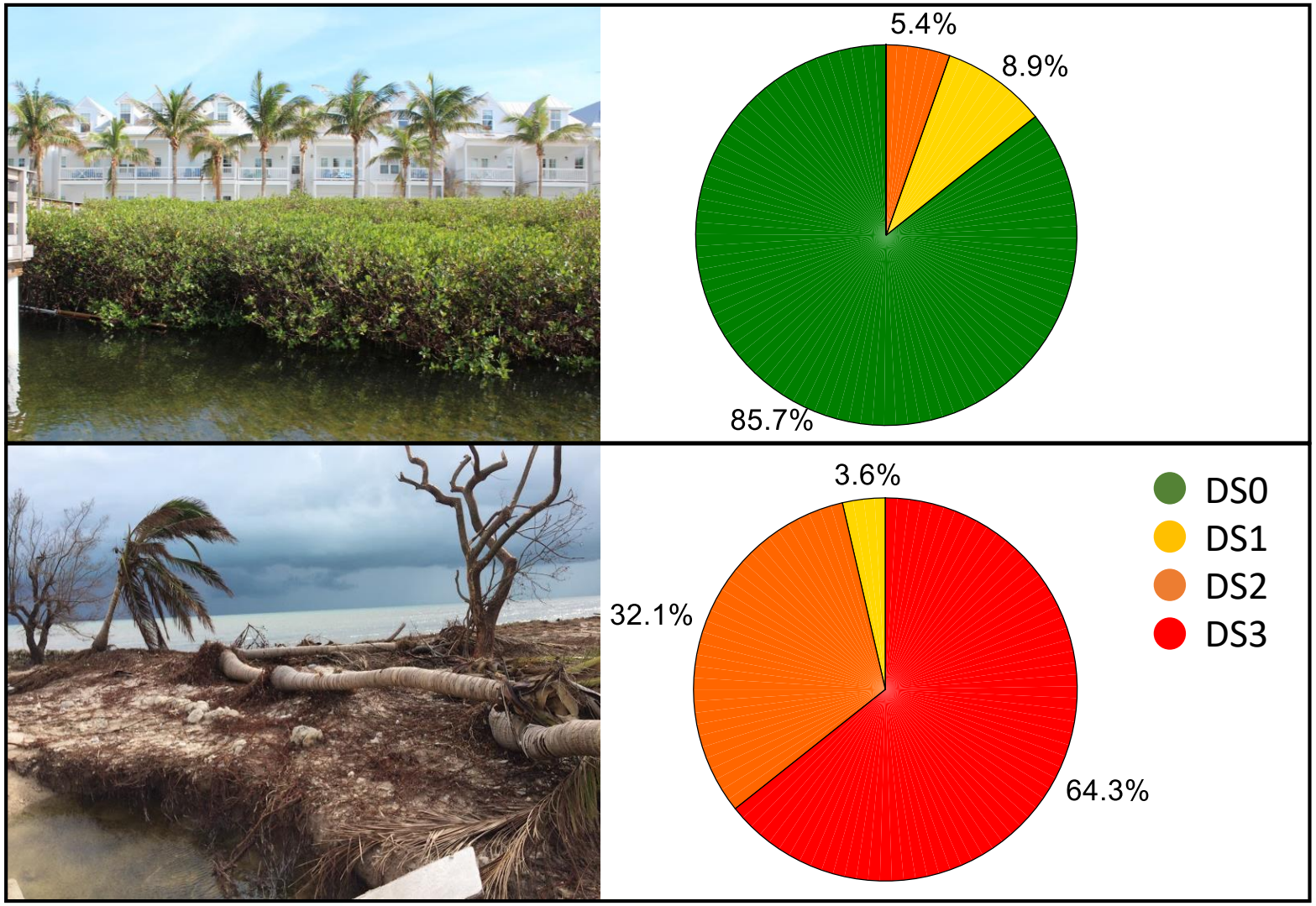
USNA UNITED STATES NAVAL ACADEMY

Shoreline Type	0	1	2	3
Mangrove	No Visible Damage	Aesthetic damage; loss of foliage; loss of <25% of mangrove tract in the form of dead/uprooted trees	Loss of 25-50% of mangrove tracts in the form of dead/uprooted trees	Loss of >50% of mangrove tract in form of uprooted/dead trees
Sandy Beach	No Visible Damage	Aesthetic damage; loss of <25% of vegetation/dune grasses; minor evidence of erosion	Loss of 25-50% of vegetation; significant erosion (>12" average dune height or shoreline recession per property)	Loss of >50% of vegetation; major erosion (>3' average dune height or shoreline recession per property)
Bulkhead/ Vertical Wall	No Visible Damage	Nonstructural/ aesthetic damage to components; repairs include patching concrete; repointing mortar, applying a skim coat	Failure or partial failure of structural elements including crumbling, bulging, collapsing, horizontal cracks>2" and scour>6"	Complete failure/ collapse of structure
Revetment	No Visible Damage	Nonstructural/ aesthetic damage to components; repairs include resetting fallen stones; <10% armament rocks displaced	Failure or partial failure of structural elements including crumbling, bulging, collapsing, horizontal cracks>2" and scour>6"; 10-25% armament rocks displaced	Complete failure/ collapse of structure >25% armament rocks displaced, requiring complete repair
Hybrid	No Visible Damage	Aesthetic damage; loss of <25% of vegetation; minor evidence of erosion <10% displaced rocks from sills	Loss of 25-50% of vegetation; significant erosion: >12" shoreline recession; 10-25% displaced armament rocks; partial failure of structural elements	Loss of >50% of vegetation; major erosion: >3' shoreline recession >25% displaced rocks; complete failure




Standardized Shoreline Damage Assessments

- 56 surveyors, 12 shorelines
- 95 % Confidence Intervals > 0.5 DS
- Larger variation for intermediate damage states



Component-Based Structural Damage Assessments

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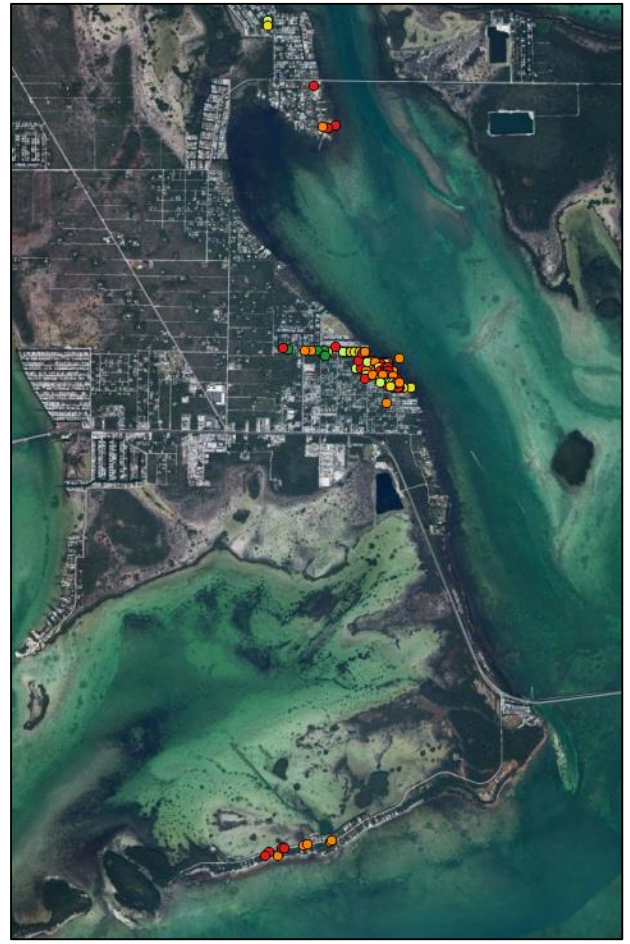
Key West

Big Pine Key

Damage State

- 0
- 1
- 2
- 3
- 4



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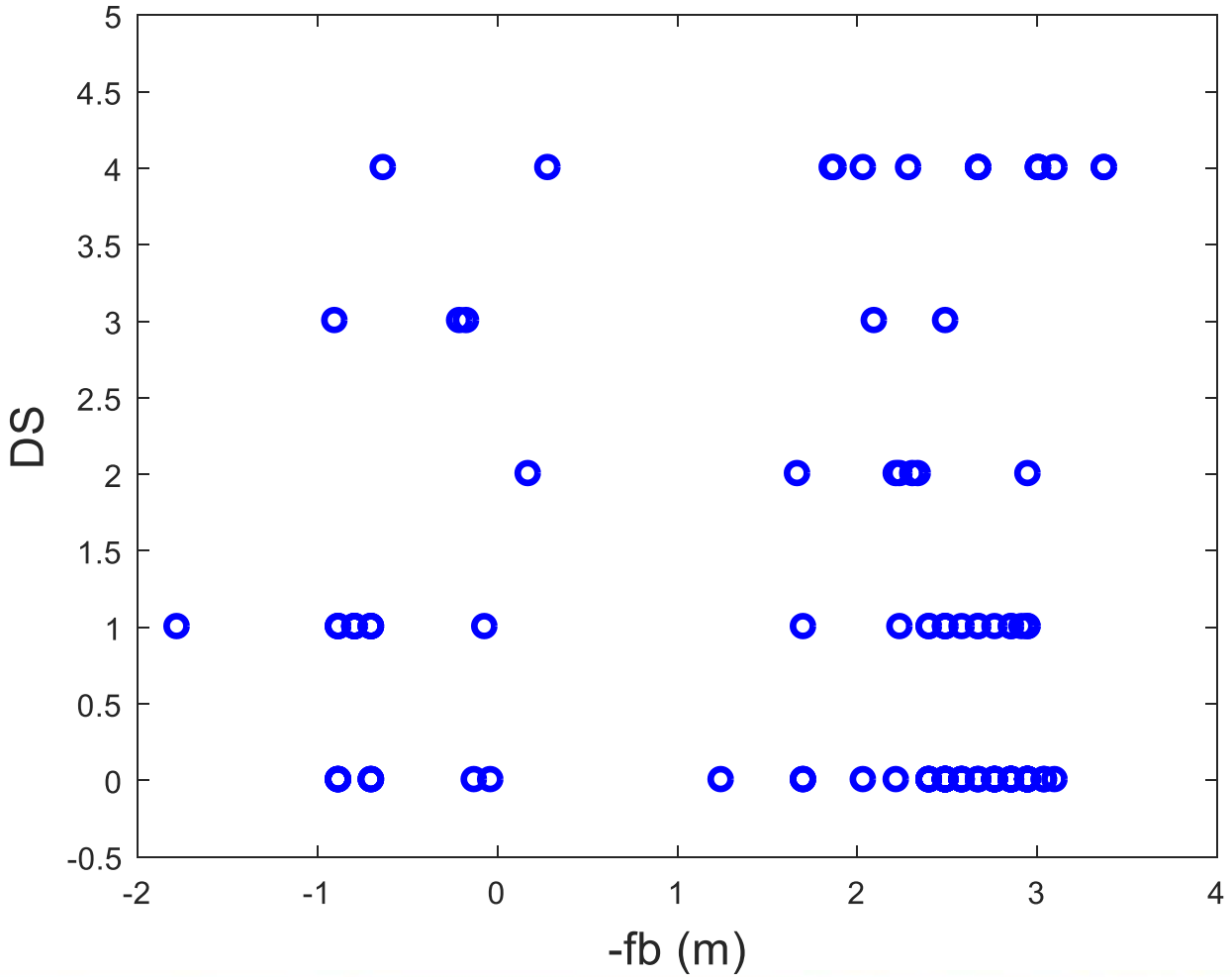
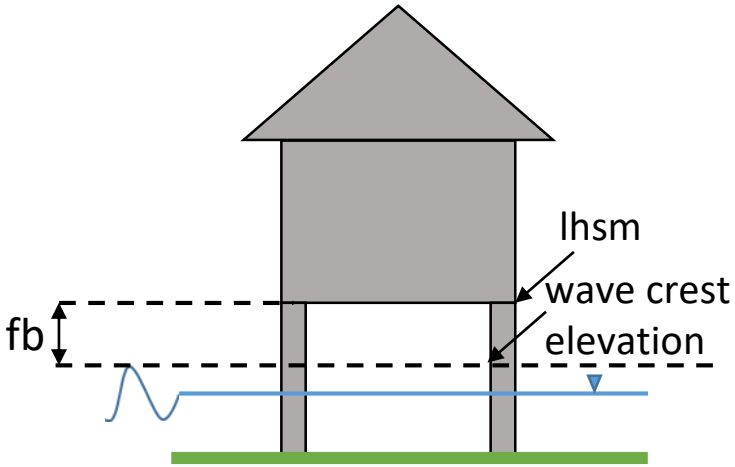
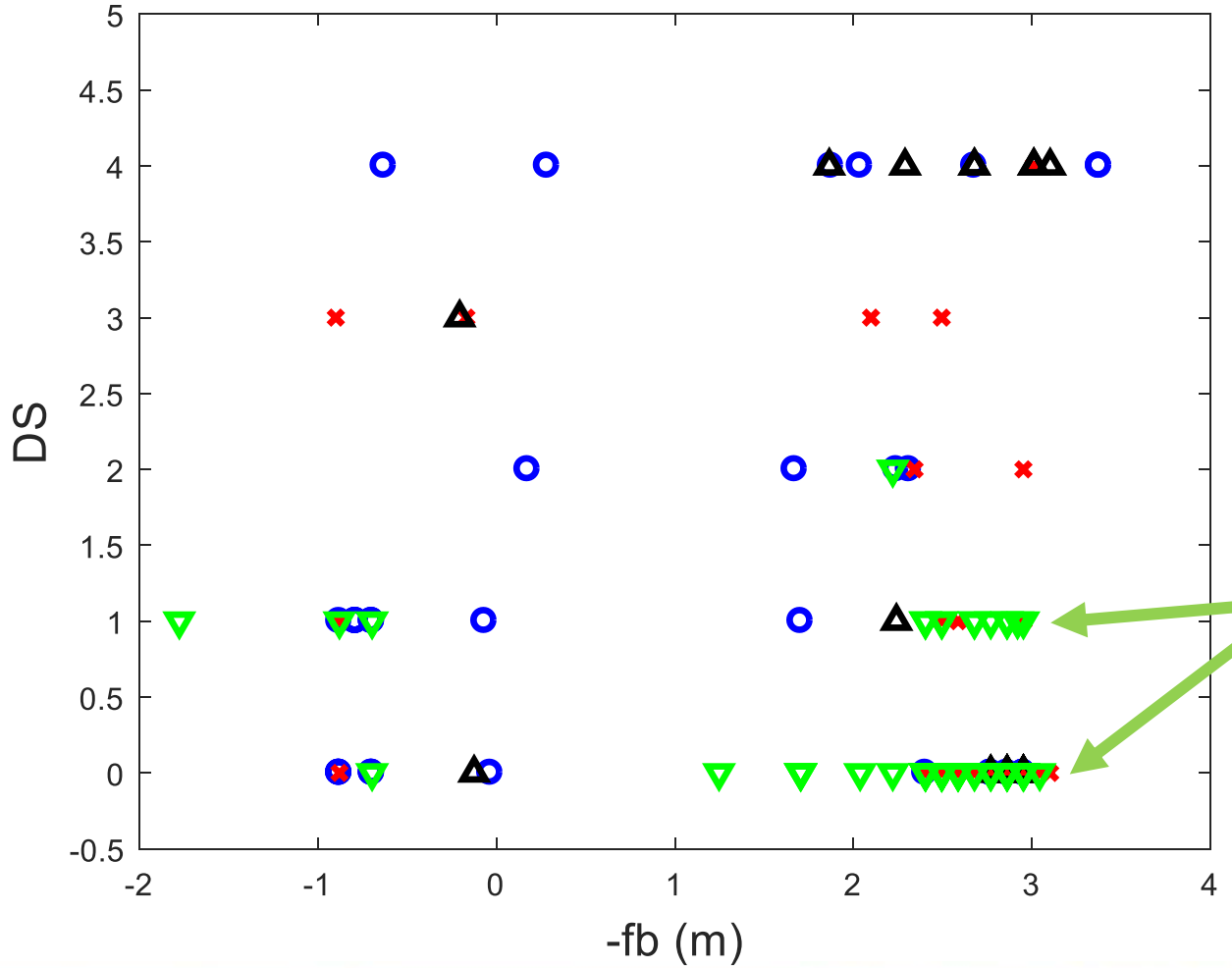
Relate Hazard to Structural Damage (?)





fb=freeboard
DS= damage state

Shoreline Characteristic Affects Structural Damage



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

Multinomial Logistic 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	1.32×10^{-23}	161
Structure	0.041	---	4.89×10^{-24}	271

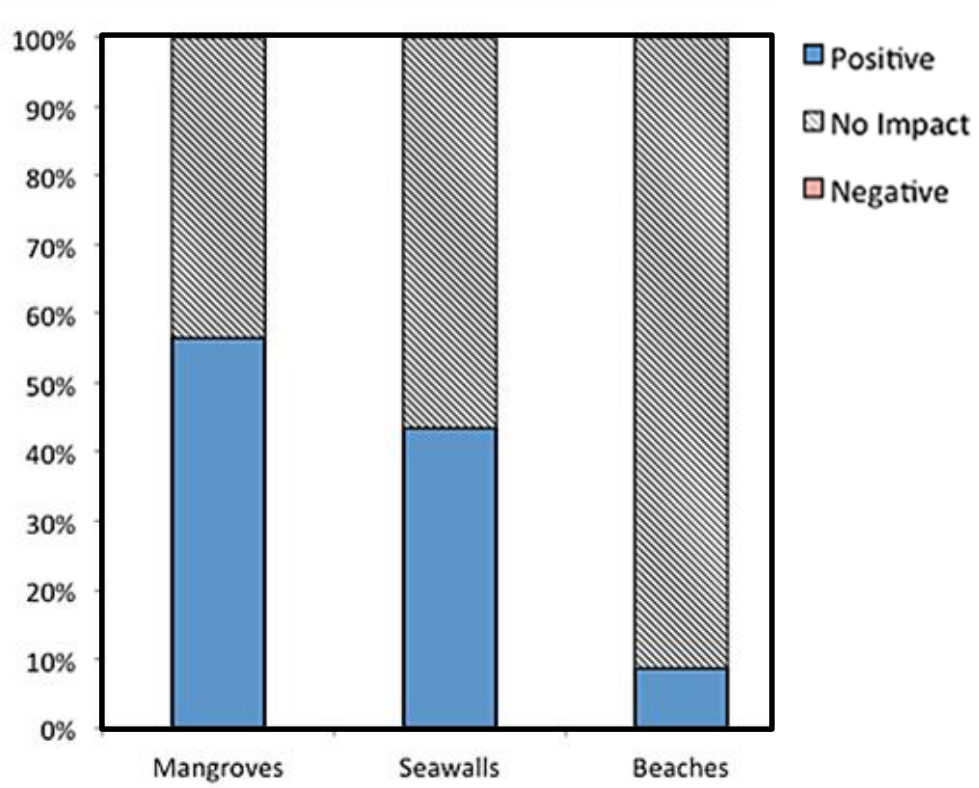
Homeowner Perceptions

- 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"

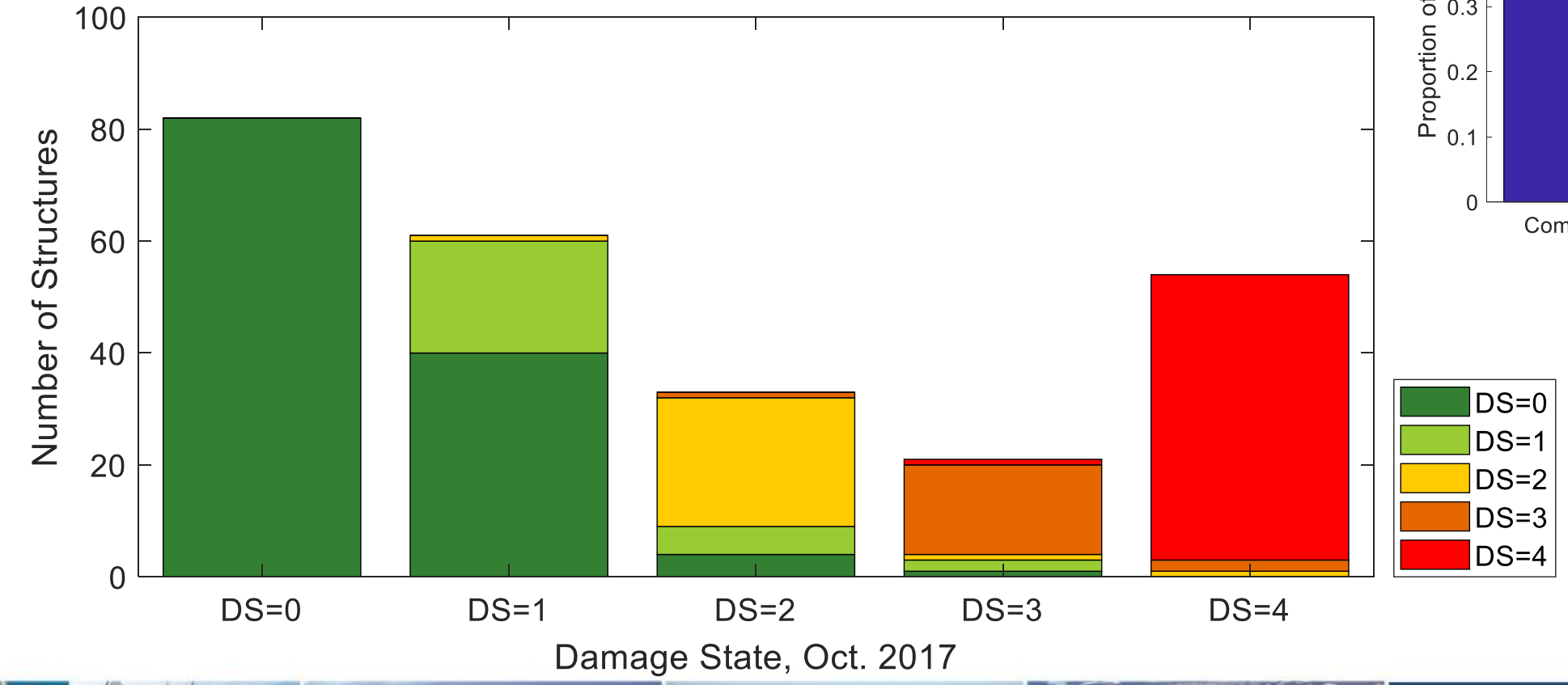
"90% of beaches were swept away"

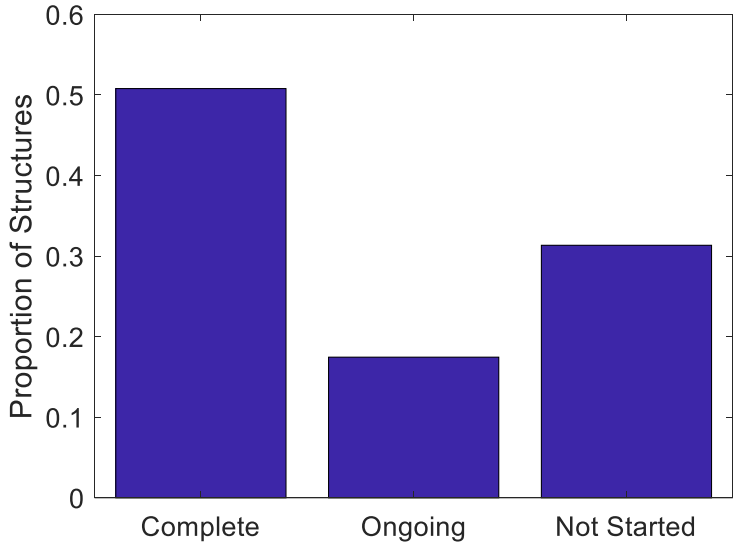
"Without mangroves, the impact of the storm would have been much worse"



Longitudinal Study

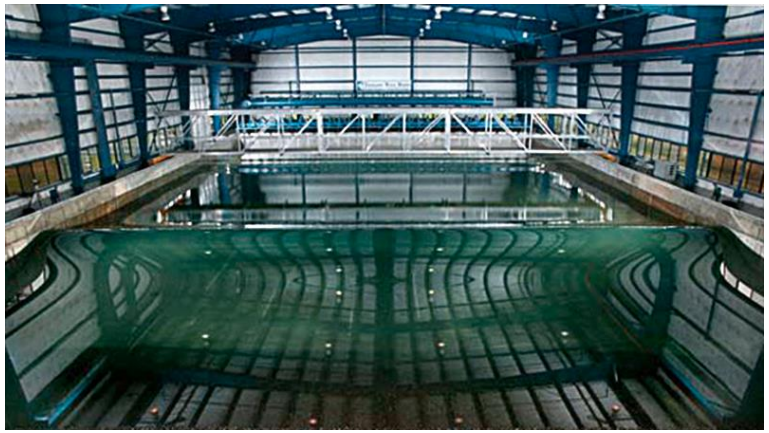
- Six month return visit, March 2018
- Re-evaluate damage to 250 structures from October survey

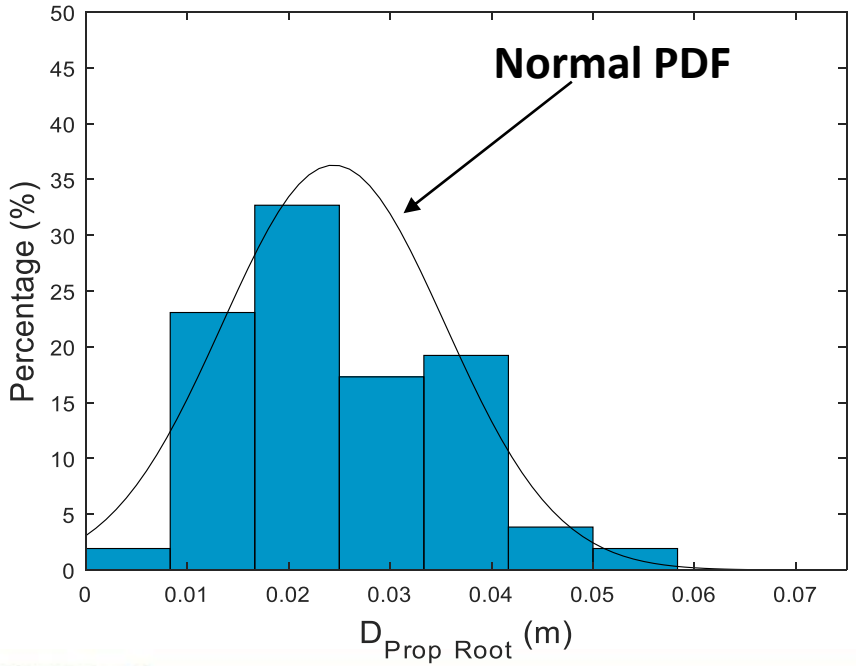




Ongoing Work

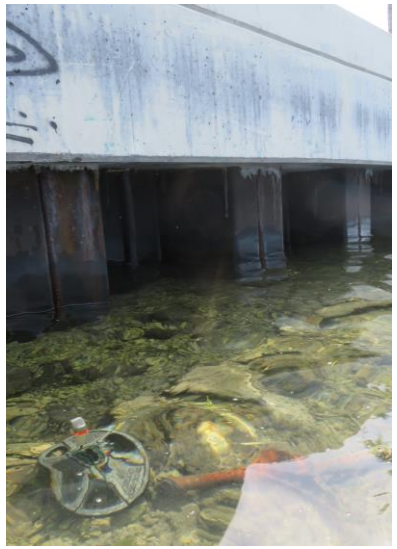
- **July, 2018**: Field study to characterize mangrove prop root density, average diameter, elastic modulus, canopy characteristics
- **Fall, 2018**: 1:16 scale laboratory experiments
  - Effects of roots, leaves, scaling
- **Spring, 2019:** Field experiments, Key West, FL





Conclusions

- Case study of damage to shorelines, structures after Hurricane Irma
- Ongoing longitudinal investigation to identify recovery trends, repair decisions
- **Natural and nature-based features** may mitigate overland flow and resulting inland damage during storm events **in coordination with engineered structures**
  - Need quantitative measurements!
- **Homeowner perceptions are important!**
  - Need multidisciplinary efforts to find creative solutions to coastal adaptation.

Thank you for your kind attention!