Ecologically engineering living shorelines for high energy coastlines

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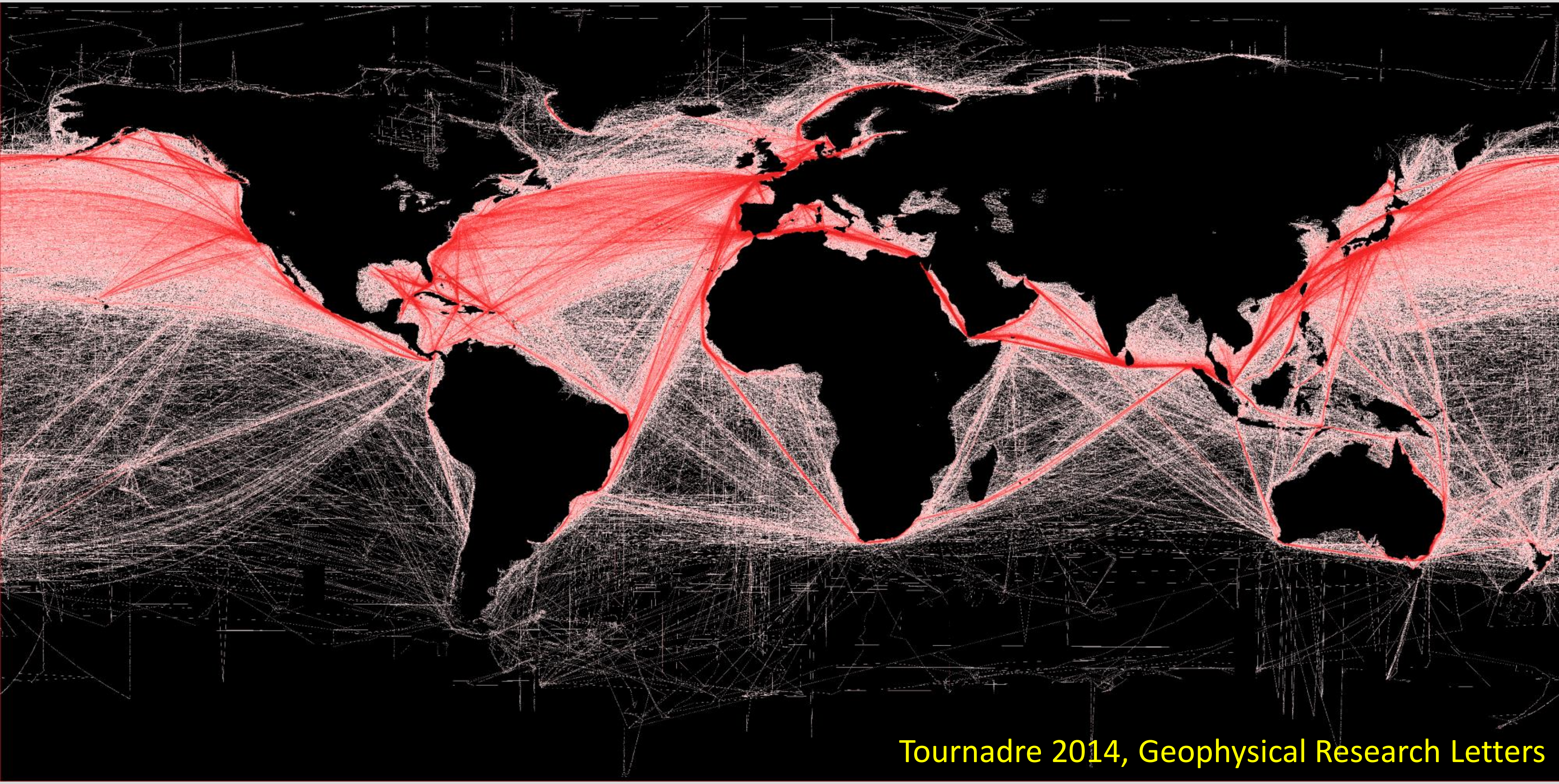
Ocean ship traffic up 300% worldwide since 1990



Large container ships & fishing vessels

Boats

Boats

Boats

Boats

Boats

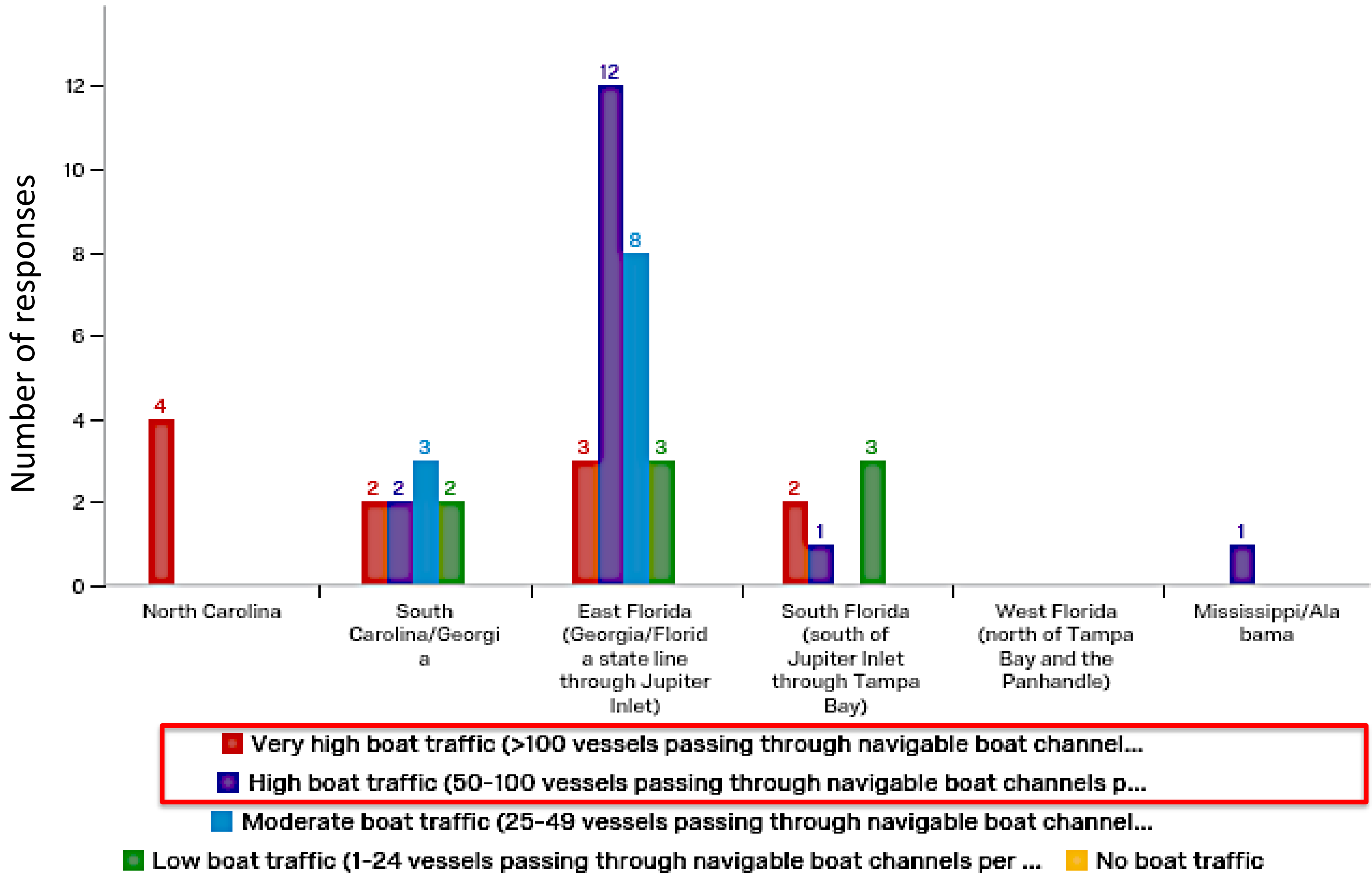
Small boat traffic rarely monitored, but on the rise
Ecological effects unknown

Studies examining the effects of wakes on turbidity & wetland erosion

Sorenson 1973; Zabawa & Ostrom 1980; Nanson et al. 1994; Osborne & Boak 1999;Castillo et al. 2000; Parnell & Kofoed-Hanson 2001; Bauer et al. 2002; Grizzle et al. 2002; McConchie & Toleman 2003; Glamore 2008; Houser 2010; Tonelli et al. 2010; Bilkovic et al. 2017

Black text= primary literature/ Grey text = grey literature

Experts in SE US indicate boat traffic in estuaries is high



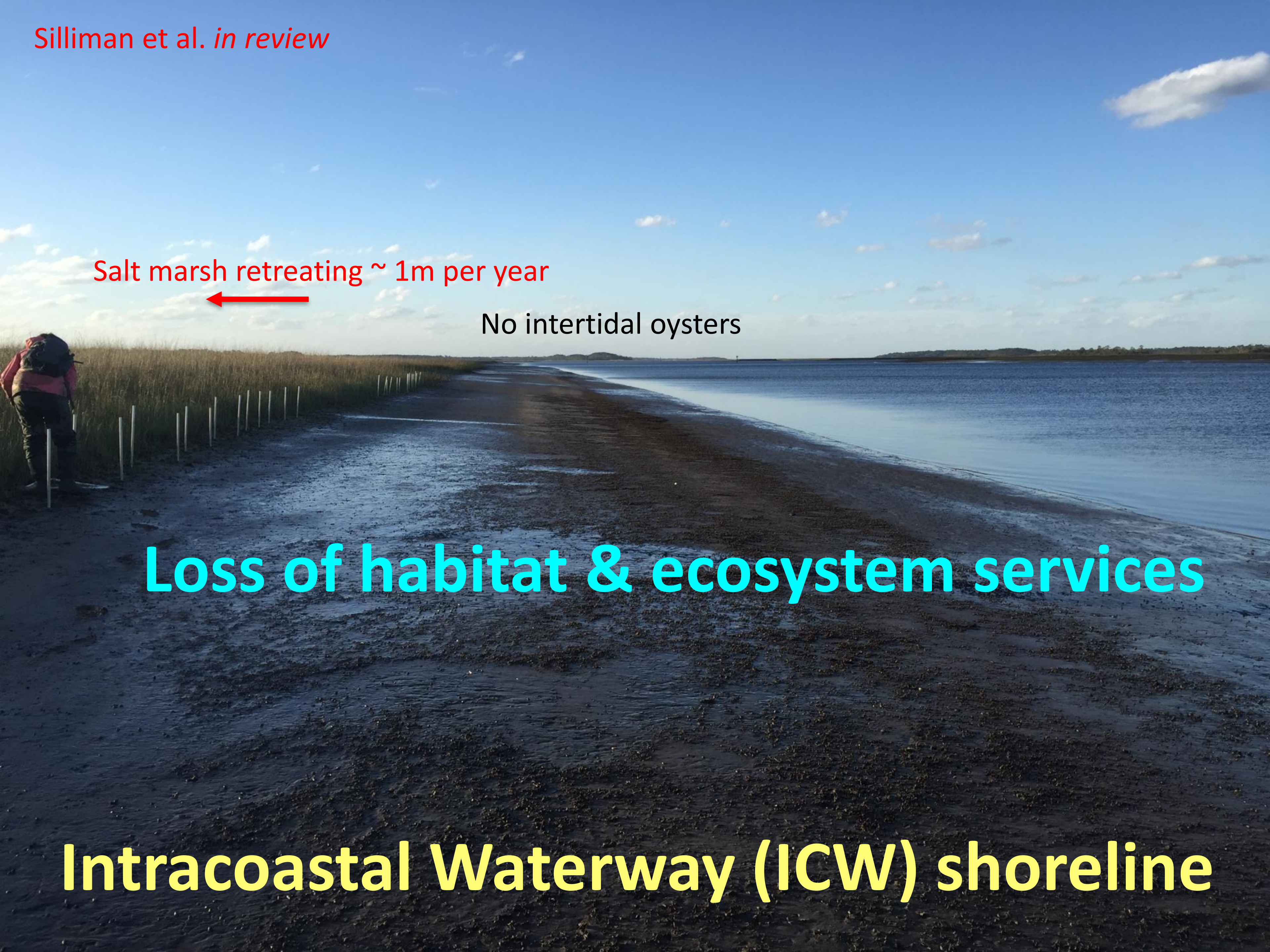
Intracoastal Waterway (ICW)

3,000 miles of natural waterways & dredged channels

Artery for commerce & recreation

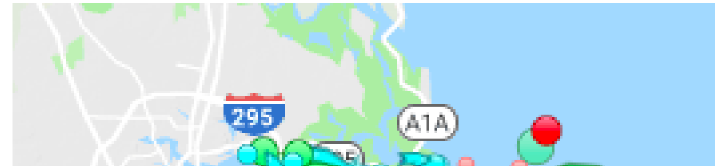
Boat highway through low-energy coastal wetlands

Intracoastal Waterway (ICW) shoreline


Silliman et al. *in review*
Salt marsh retreating ~ 1m per year
No intertidal oysters
Loss of habitat & ecosystem services
Intracoastal Waterway (ICW) shoreline

1) What is the wake climate in this Florida estuary?
2) Can we engineer ‘living shorelines’ to dissipate boat wakes & protect shorelines?

Boat traffic & wake climate in ICW

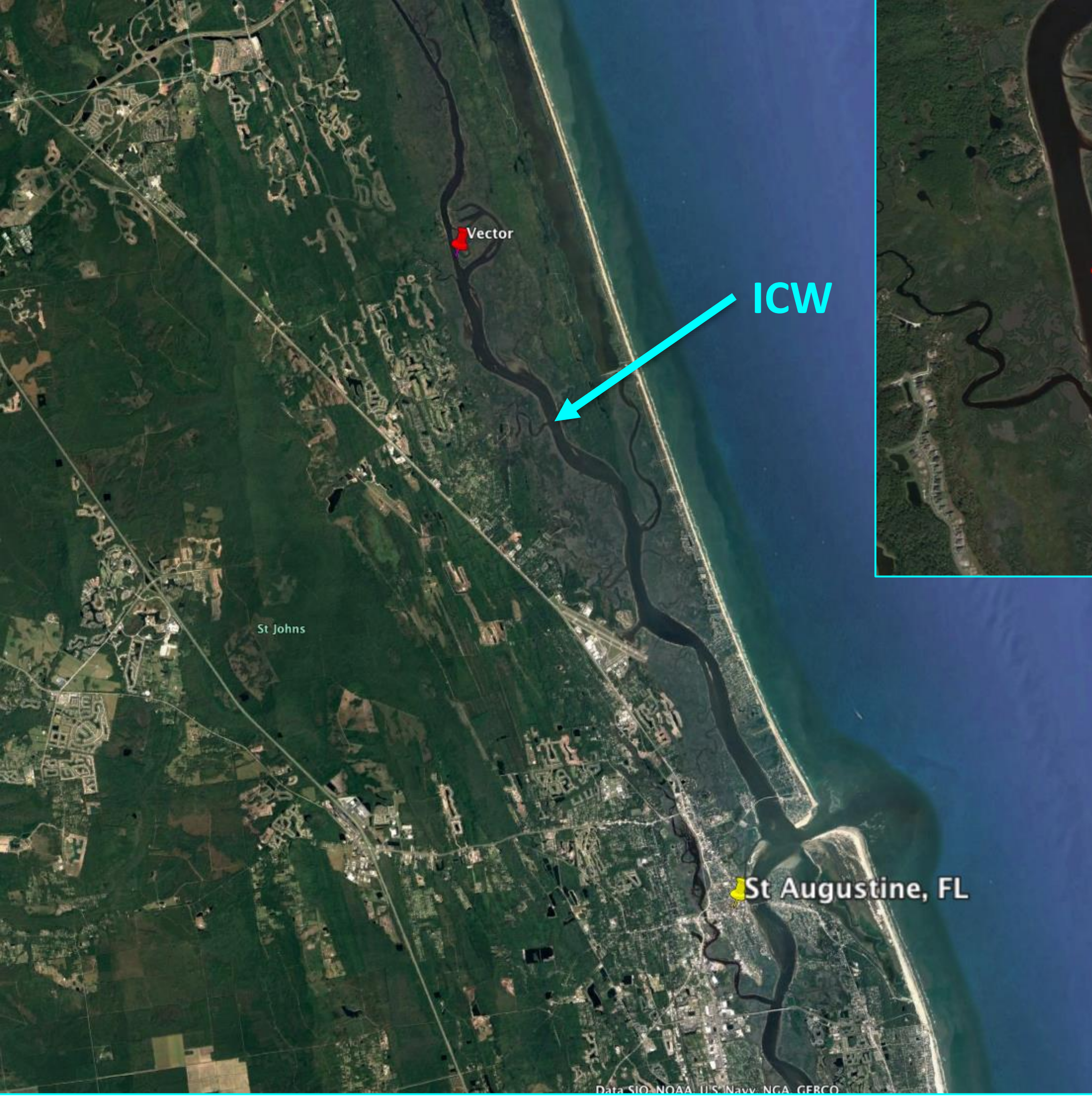


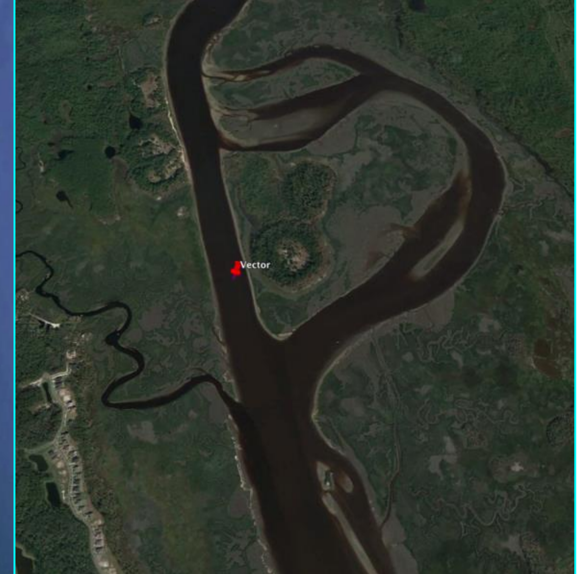
Tracked boats:

- Automatic Identification System (AIS) transponder data
  - # boats per day

All boats (tracked & non-tracked):

- Nortek Vector Acoustic Doppler Velocimeter
- Wakes characterized (Sheremet et al. 2012)
  - # wakes per day, max. wake height

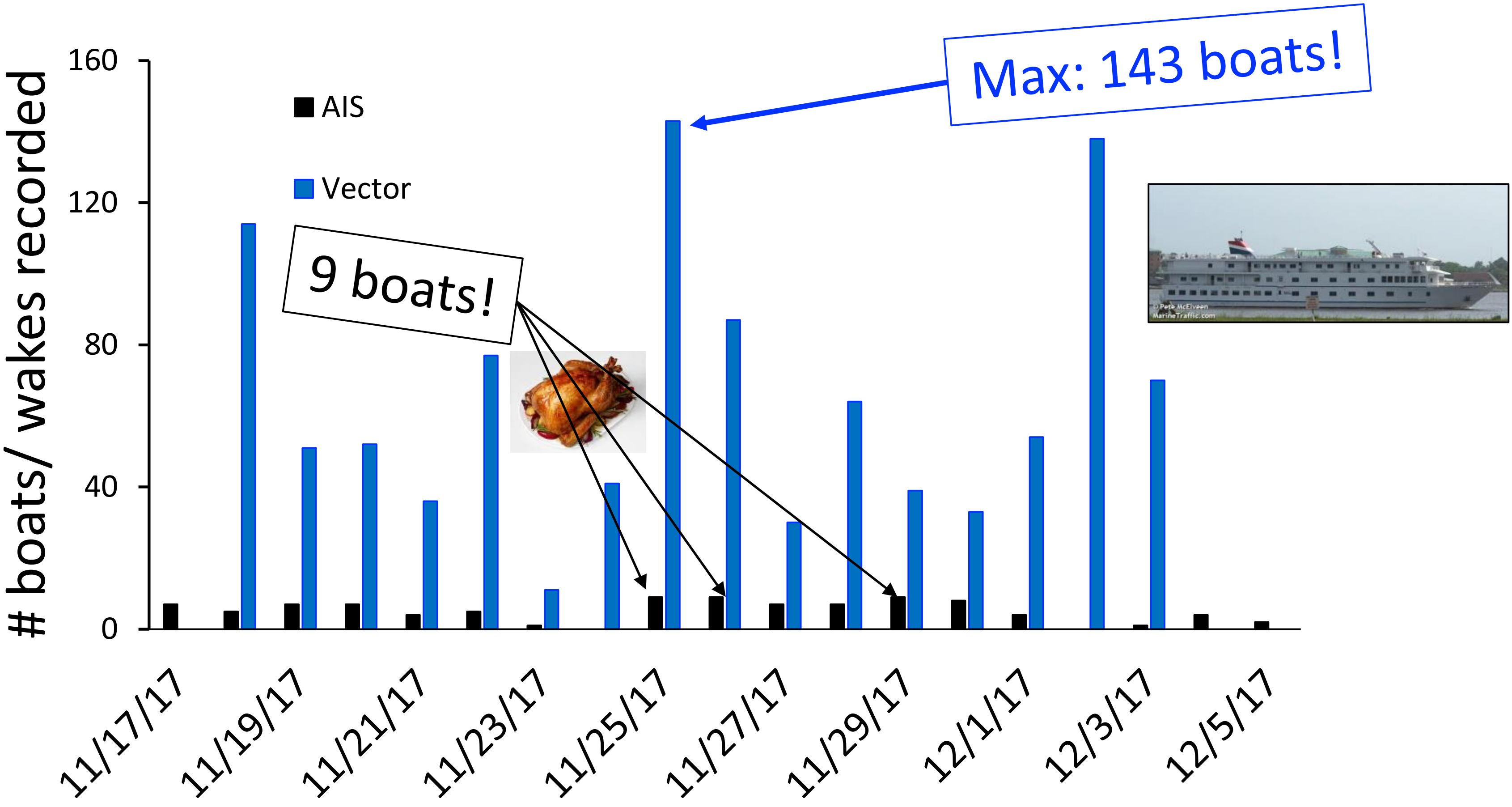




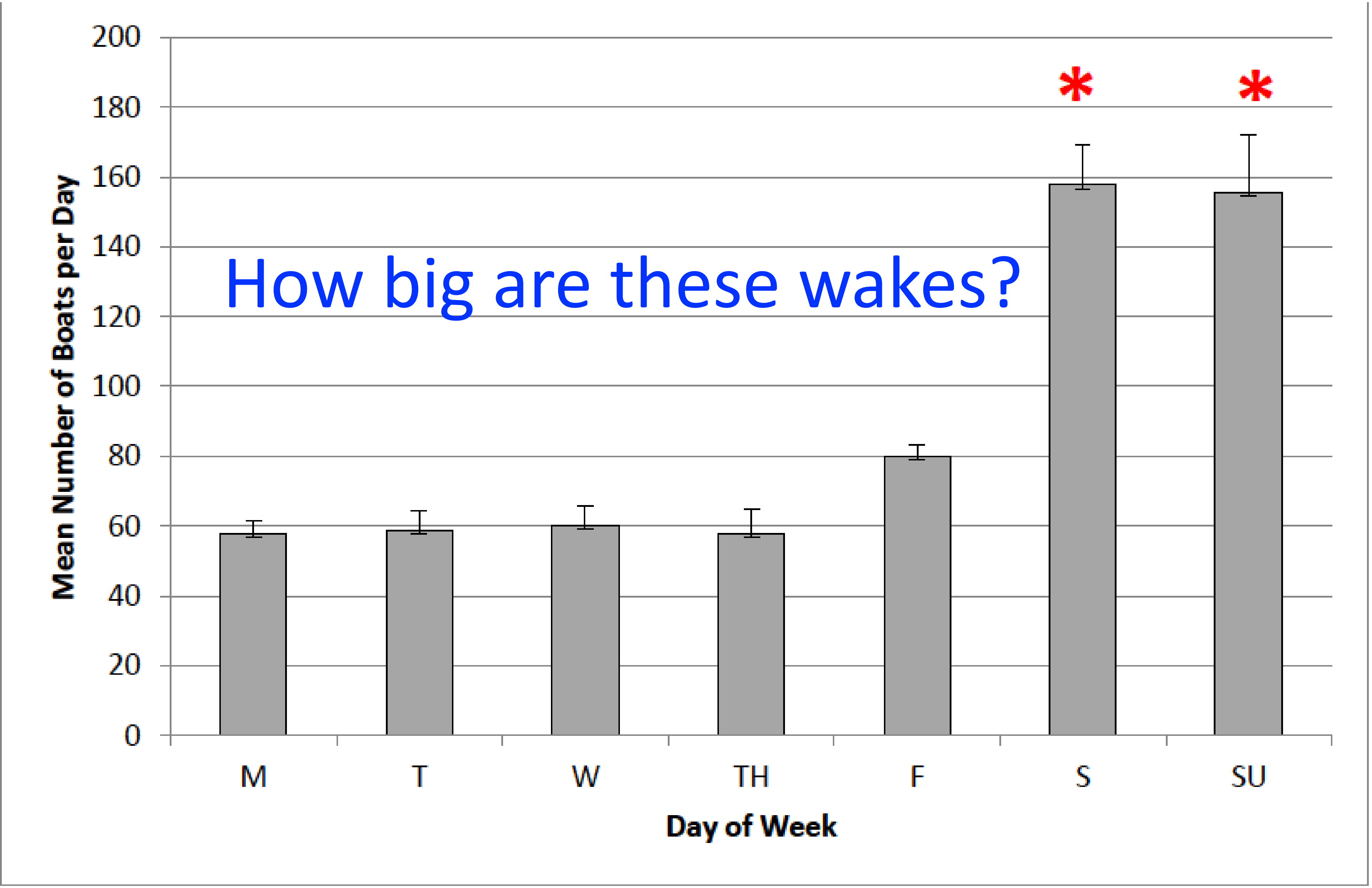
Boat traffic recorded by AIS & Vector: Nov. 17 – Dec 5, 2017

Experiment location

Tracked boats common, but non-tracked boats far more common

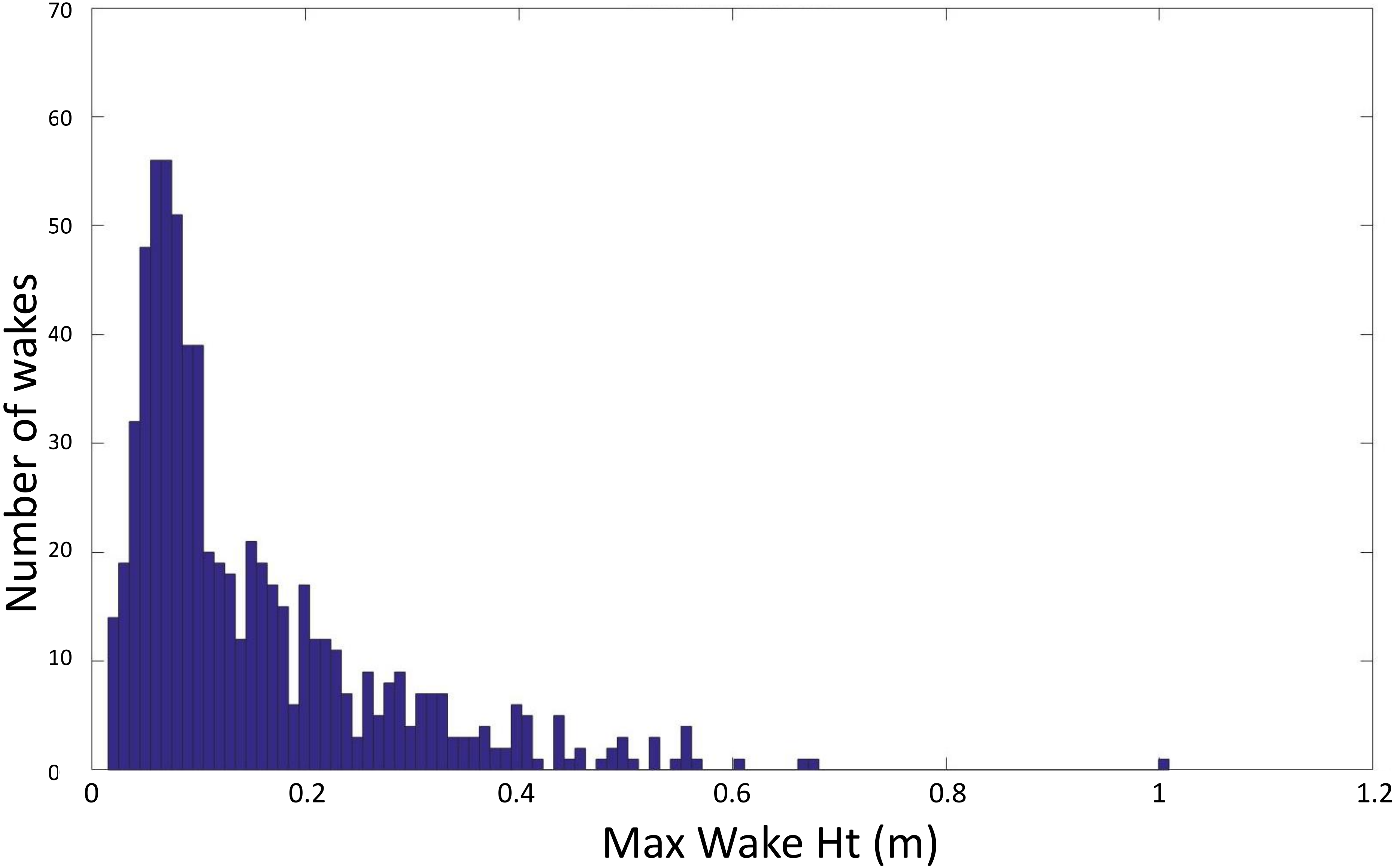


Even higher boat traffic recorded from April through July

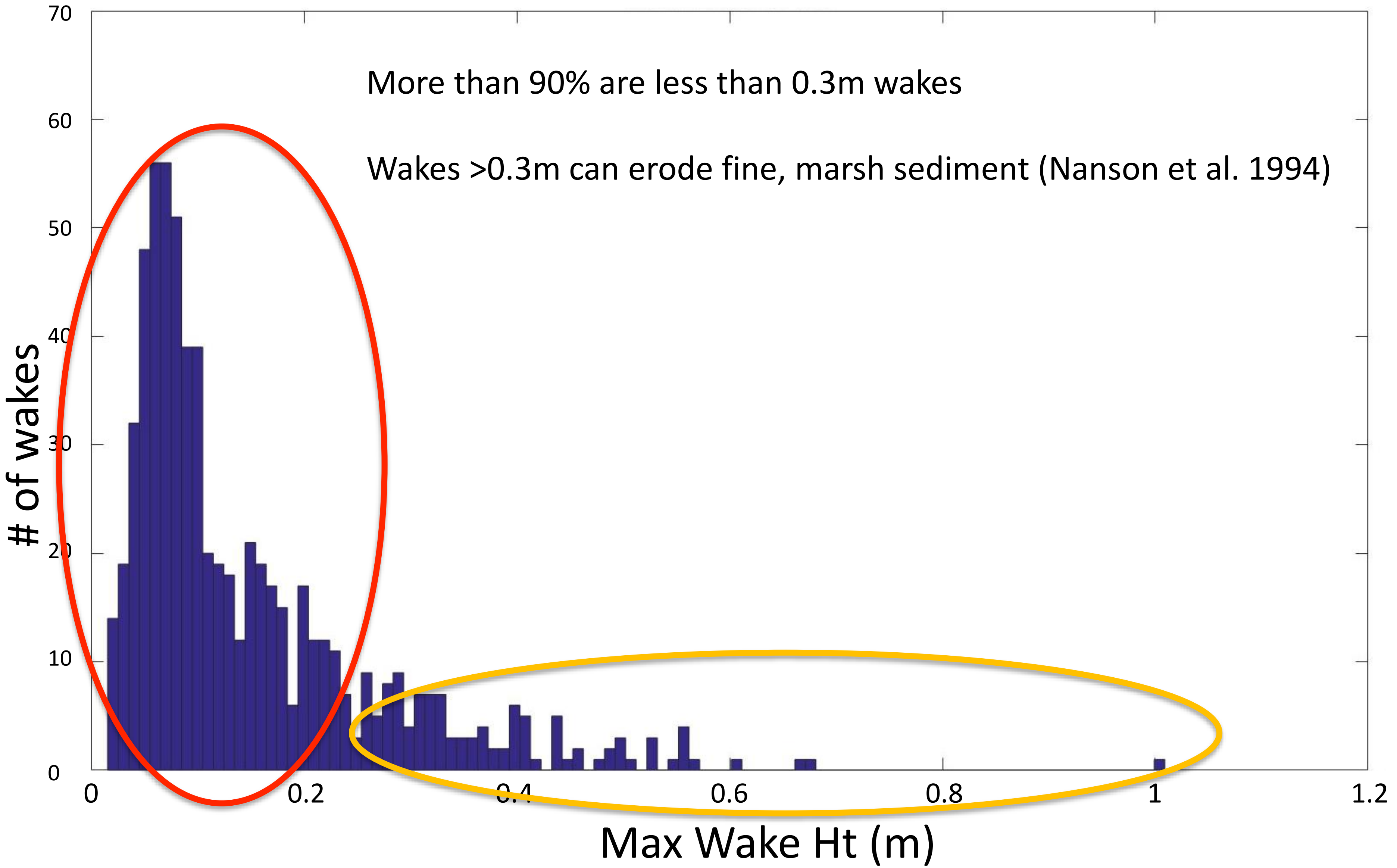


Justin Dahl, Bethune-Cookman University MSc Thesis, 2016

Maximum wake height



Maximum wake height

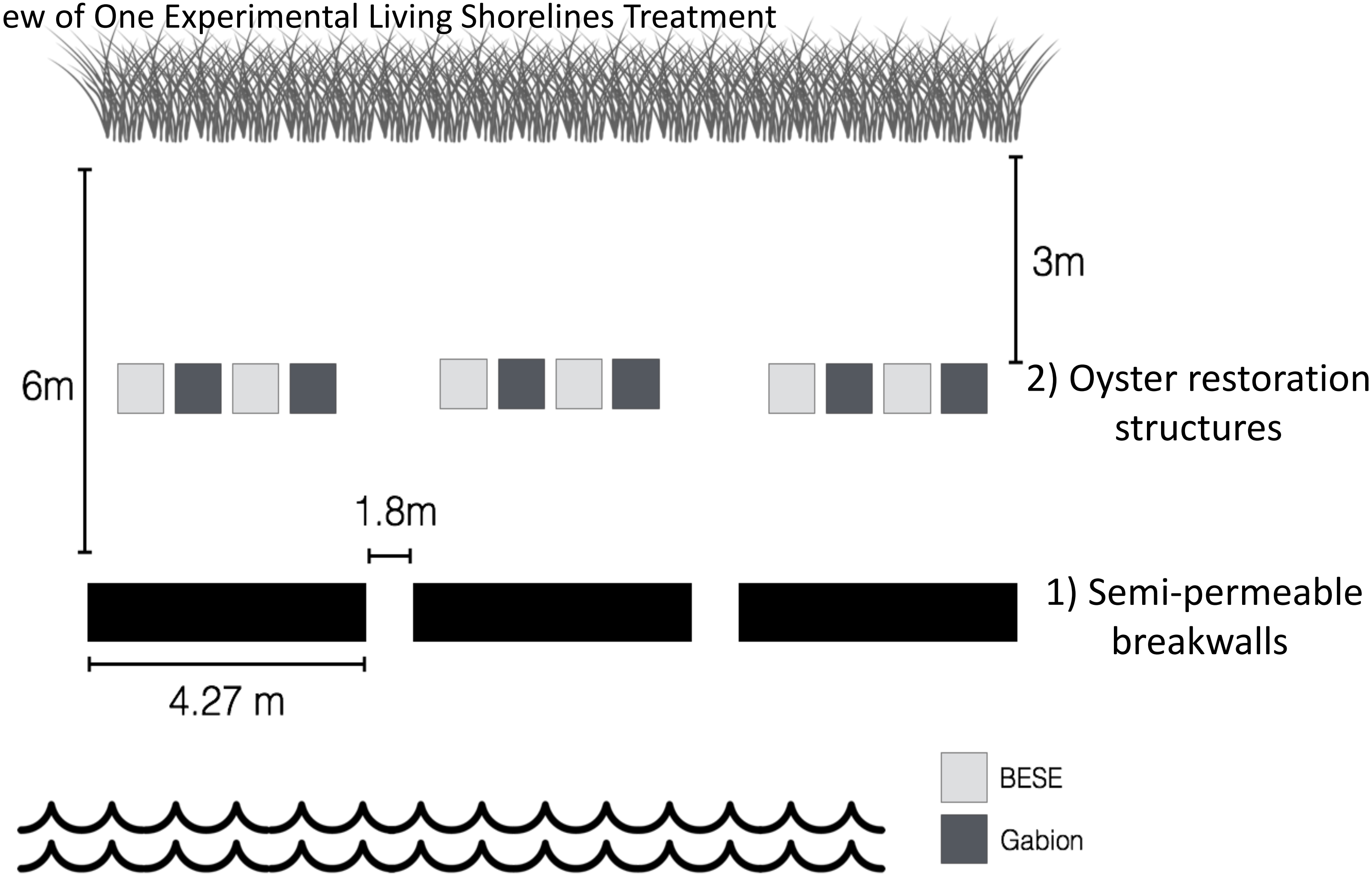


Can we protect shorelines from boat traffic *without armoring*?

Many living shoreline designs fail

Our approach: ***two*** lines of defense

Bird's Eye View of One Experimental Living Shorelines Treatment



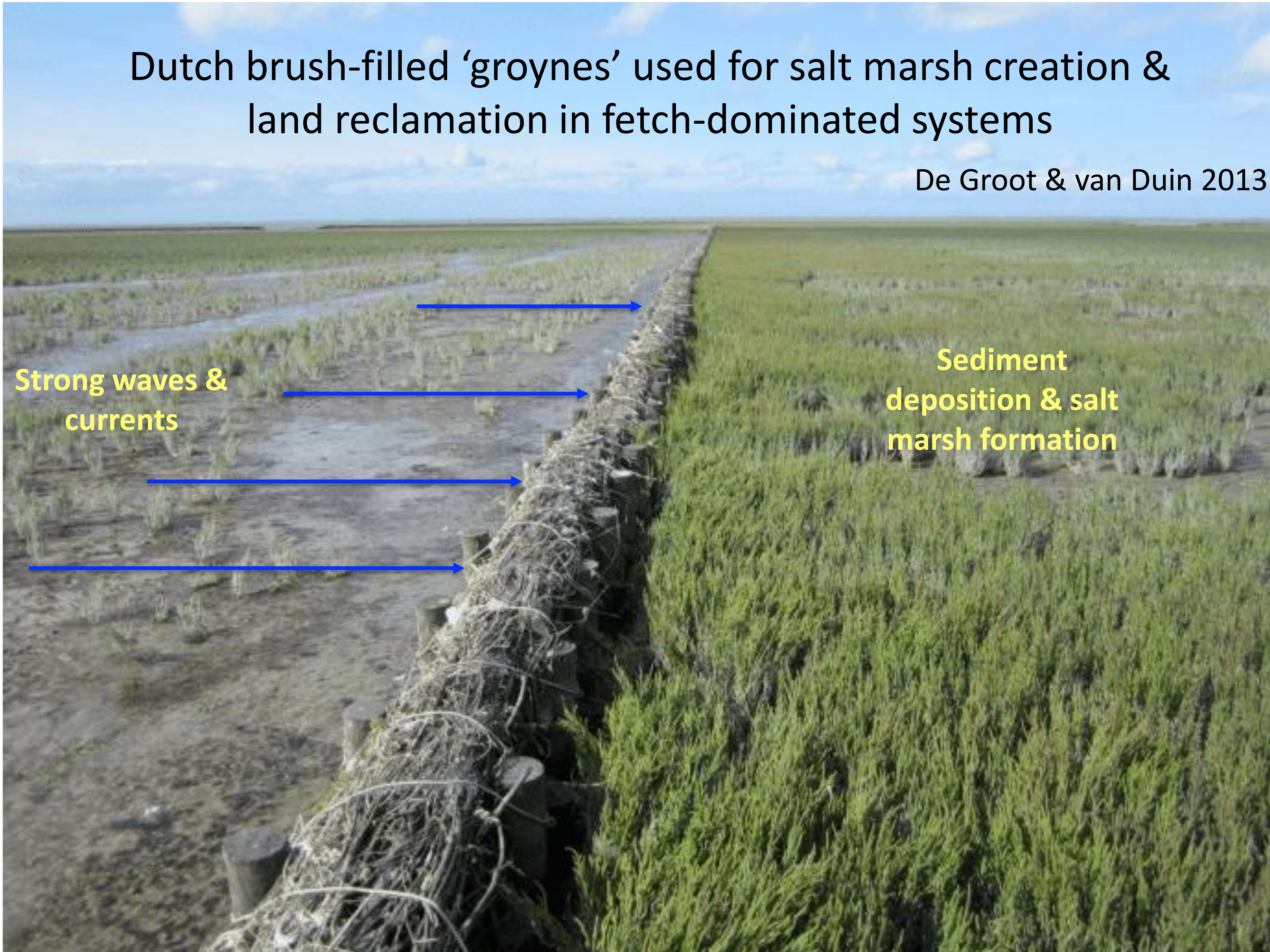
Paired living shoreline & unmanipulated controls at 6 sites of varying channel width
1 year pre-treatment + 1 year of post-treatment monitoring




Oyster shell-filled gabions

Dutch brush-filled ‘groynes’ used for salt marsh creation & land reclamation in fetch-dominated systems

De Groot & van Duin 2013



Are the break walls dissipating wakes?

Challenges with Wake Analyses

Wind waves: stationary; homogeneous; isotropic. Change slowly in time/space/ do not have preferential directions

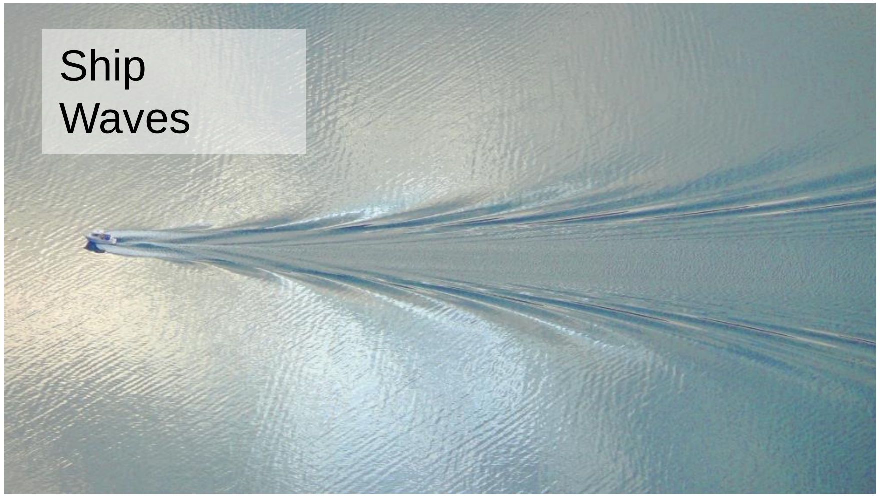
Powerful statistics to characterize wind waves: e.g., define mean height, period, wavelength.

Ship waves (wakes): intermittent, non-stationary; localized in space; directional

Statistical description is difficult.

Goal

1) Define essential wake characteristics
2) Develop statistical description of wakes
3) Use these to study wake transformation & evaluate the effectiveness of breakwaters.



Measuring boat wakes: March 2018

Offshore-onshore array of ADVs

Vector 5223:
39' from wall
2'6" above ground

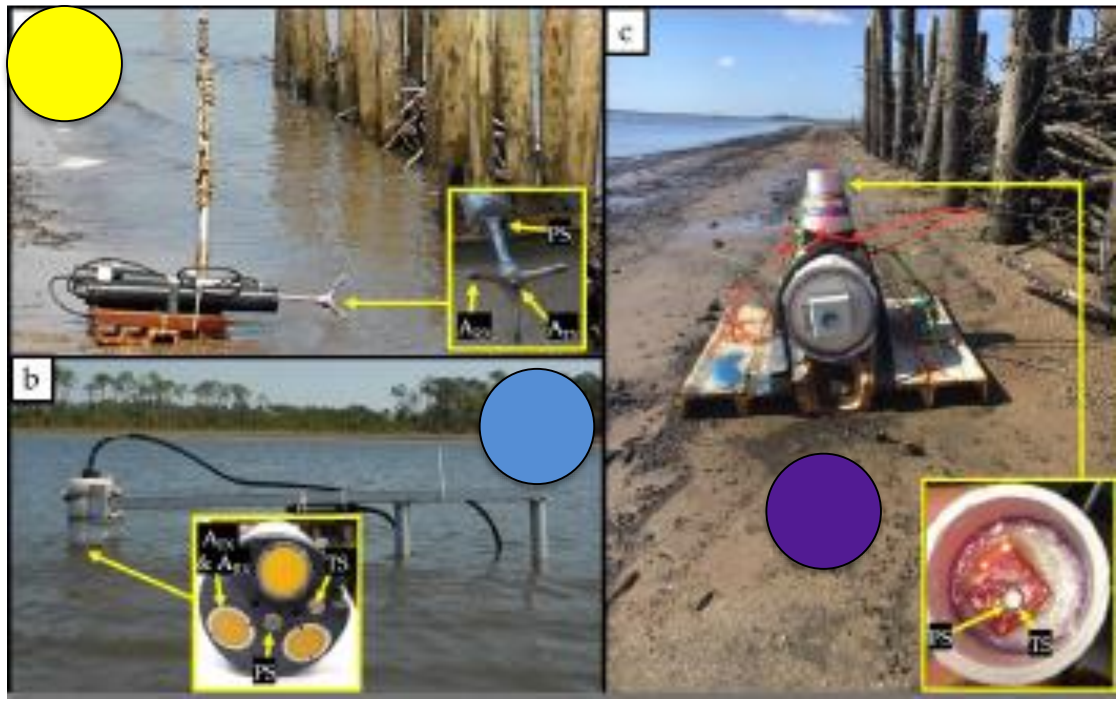
Vector 5342:
26'5" from wall
2'6" above ground

Vector 5385:
5'7" from wall
7" above ground

Vector 5365:
2'6" from wall
7" above ground

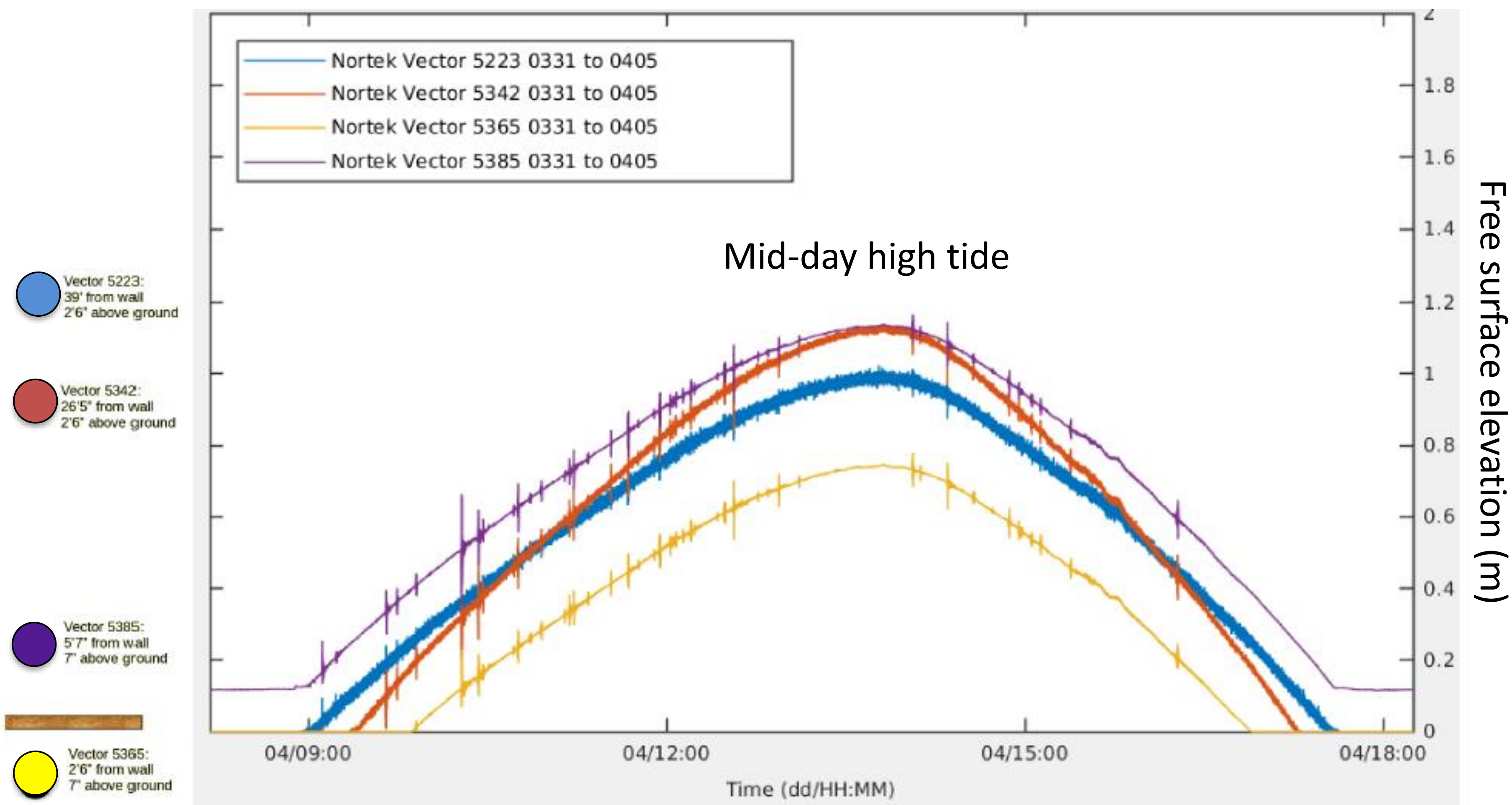
Channel

Salt marsh edge

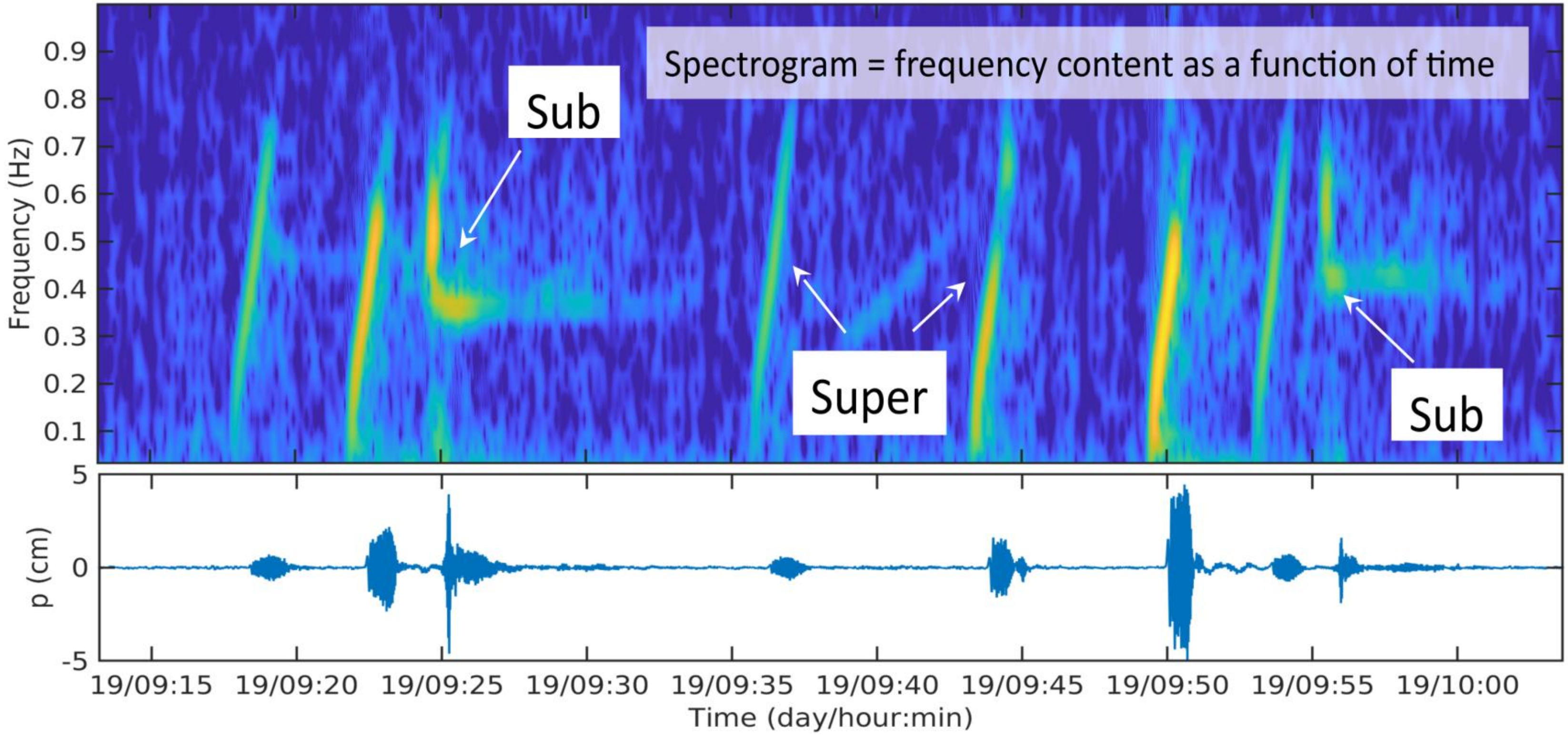


Acoustic Doppler Velocimeter (Nortek Vector); surface elevation and 3D velocity (East, North, Up); sampling 8 Hz.

Nortek Vector array deployment: March 4, 2018



Identify wakes in pressure & flow velocity records as ‘*chirps*’
Chirp = signal in which frequency increases or decreases with time



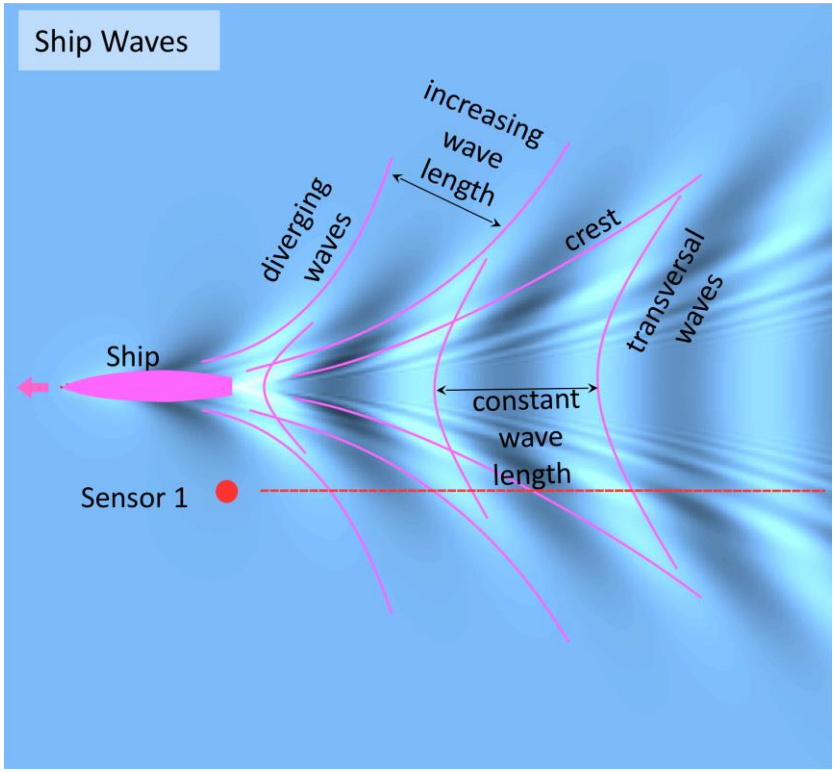
Lots of wakes, funny spectrogram shapes!
Sub = subcritical wakes (boat speed < wave speed)
Super = supercritical wakes (boat speed > wave speed)

Two families of waves created by boats

1) **Diverging waves**: wedge, crests separate with distance resulting in longer waves
2) **Transversal waves**: parallel crests; ~ constant wave length

Surface elevation sensor (i.e. the ADV & red dot in image below) detects water velocity profile along the dashed red line and records:

- Diverging waves as a **chirp =** signal with shifting (increasing) frequency.
- Transversal wave as a **monochromatic wave**: nearly constant frequency.

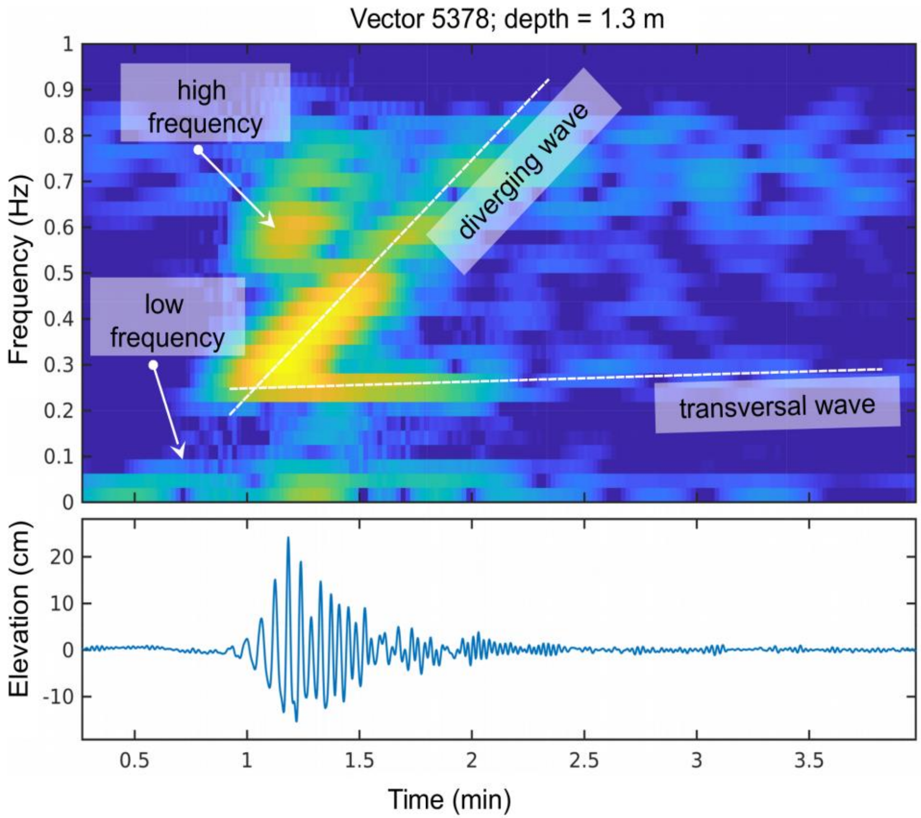


Wake Analysis

a) Spectrogram = frequency content as a function of time.
b) Free surface elevation as a function of time.

1. chirp = diverging wave
2. monochromatic tail = transversal wave
3. high-frequency component
4. low-frequency component

- *1 and 2 are generated by ship*
- *3 and 4 are generated during the shoaling transformation of the wake*

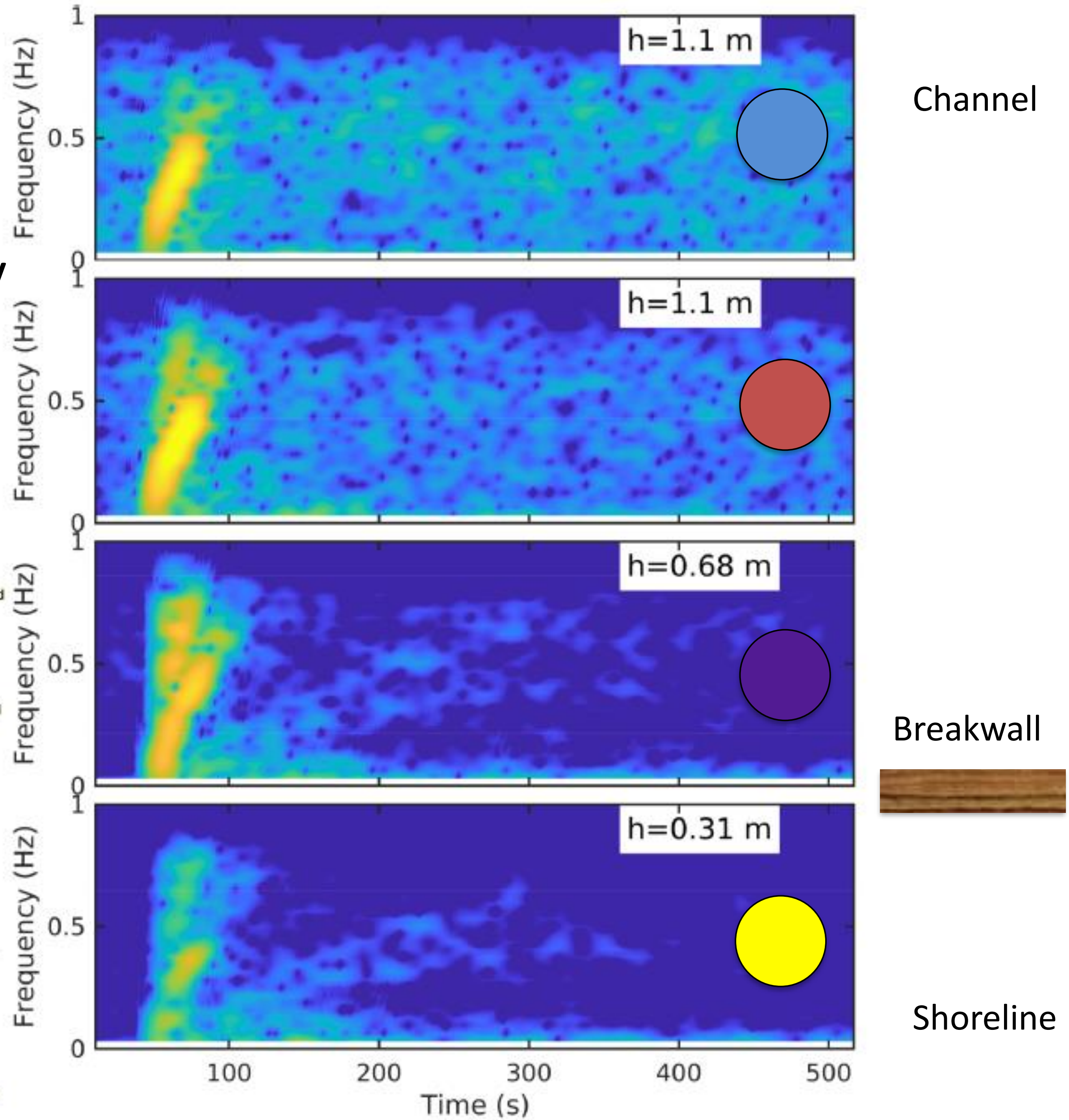


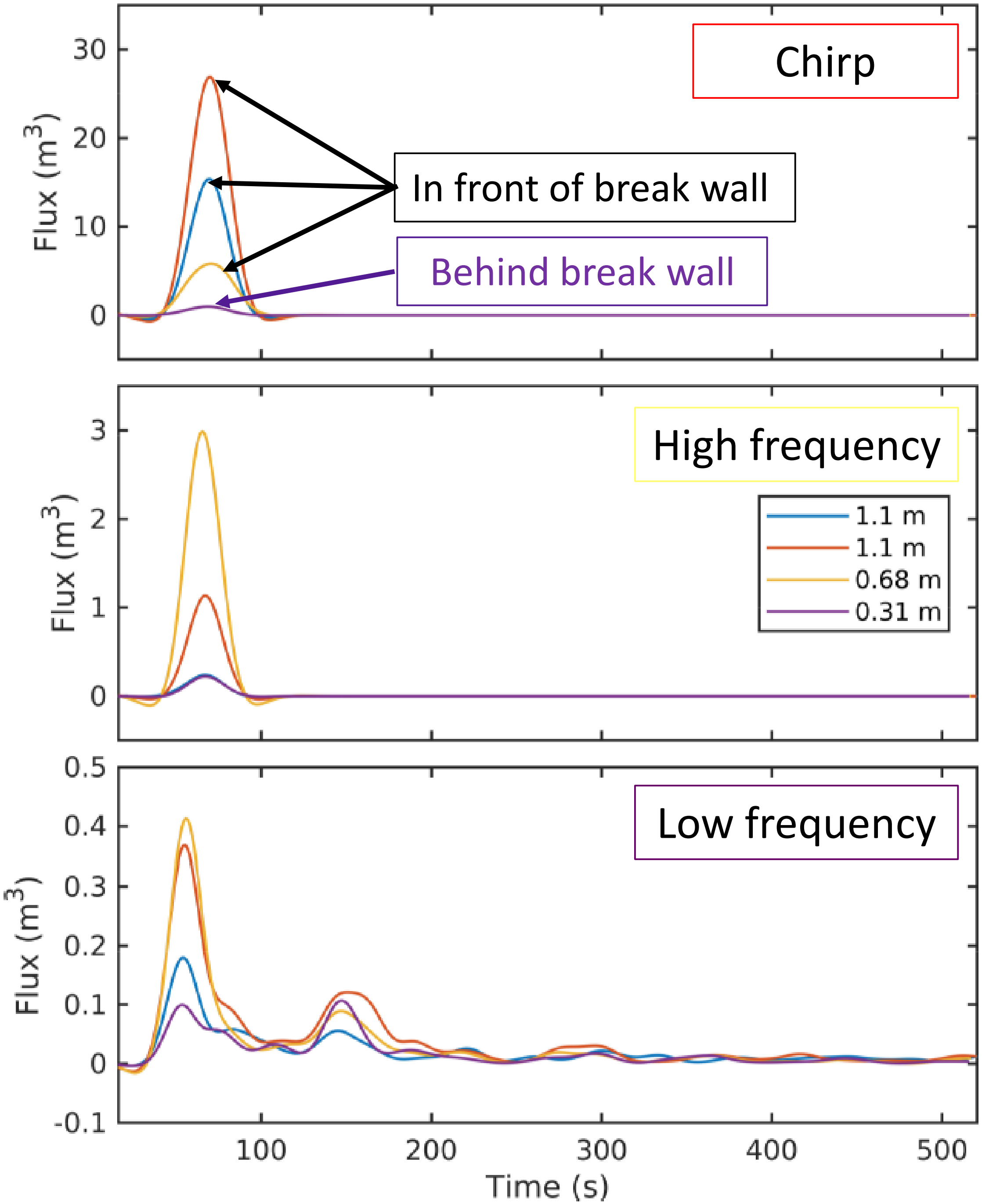
Shoaling transformation induced by decreasing channel depth

Understanding the <u>shoaling transformation</u> is key for evaluating breakwater efficiency. Typically:

- short (high-freq.) waves: efficiently dissipated
- long (low freq.) waves: dissipated less.

Measure energy flux of chirp, transvers wave and low & high frequency components in each wake at each sensor



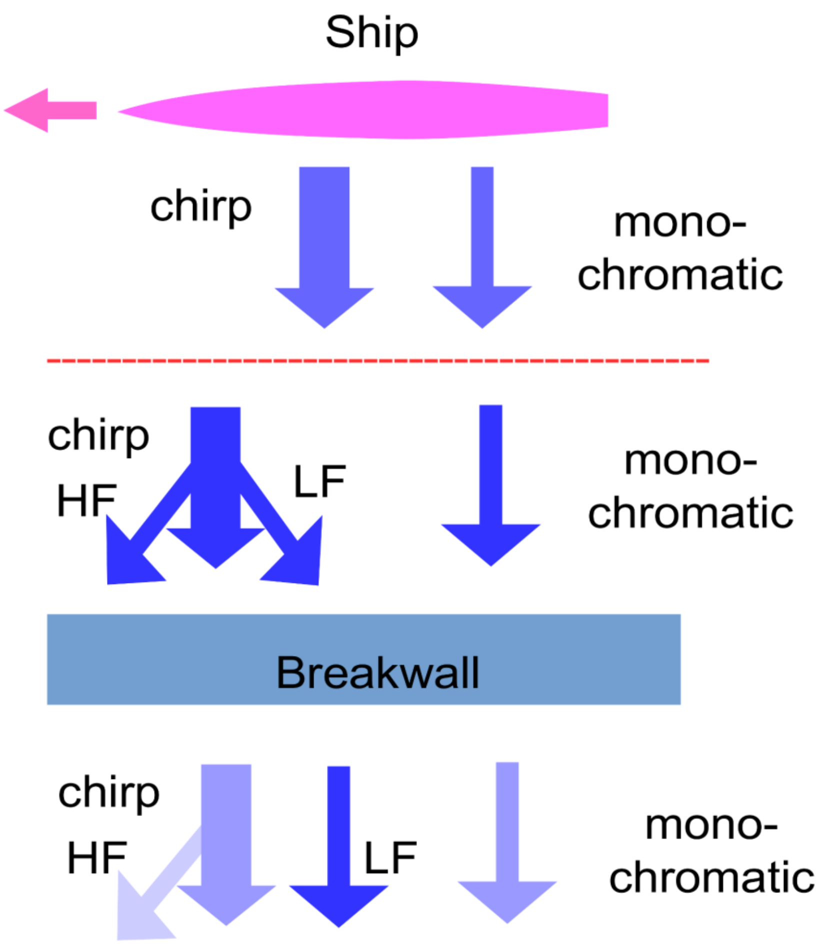


Chirp flux far larger

Breakwalls significantly reduce flux in all 3 components

The wall dissipated this wake

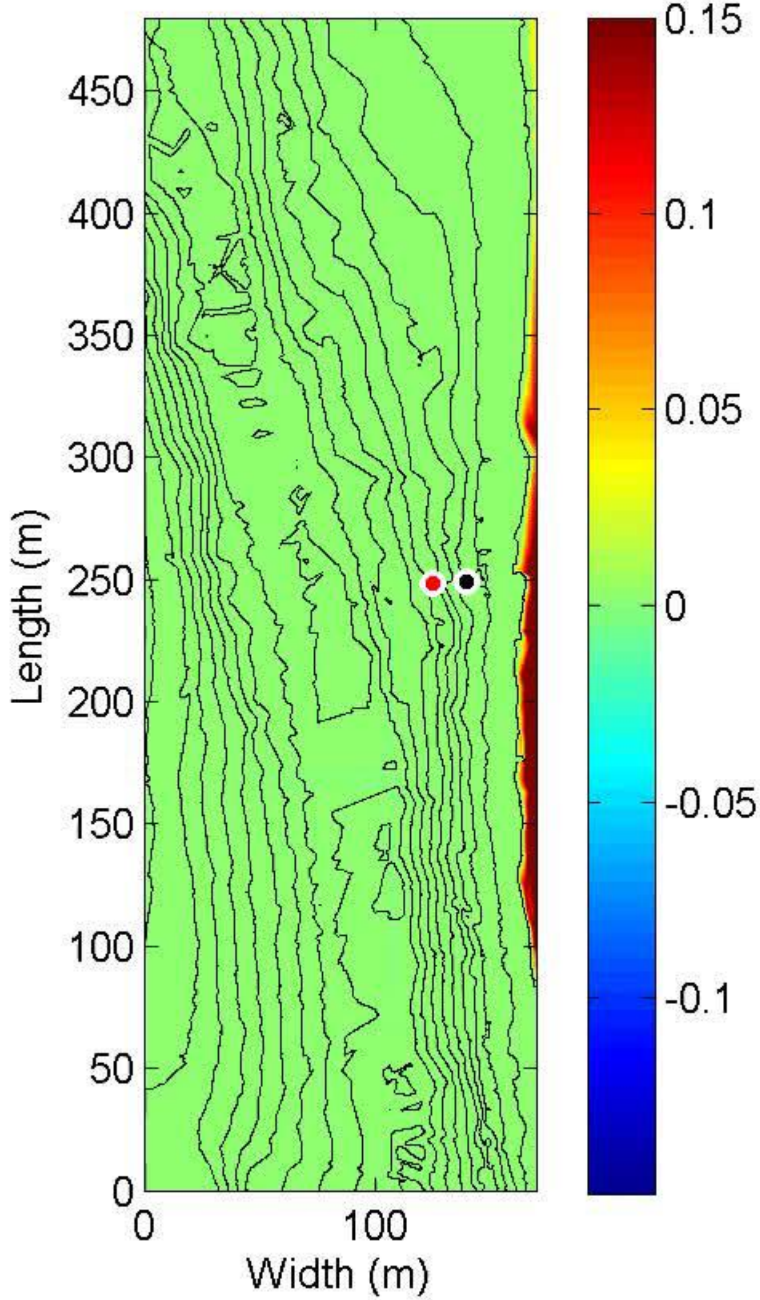
Summary



HF = high frequency waves
LF = low-frequency waves

Still lots to do to understand:

- Boat speed
- Boat size
- Channel bathymetry
- Tidal phase (ebb currents > flood)
- Sediment suspension
- Breakwall porosity

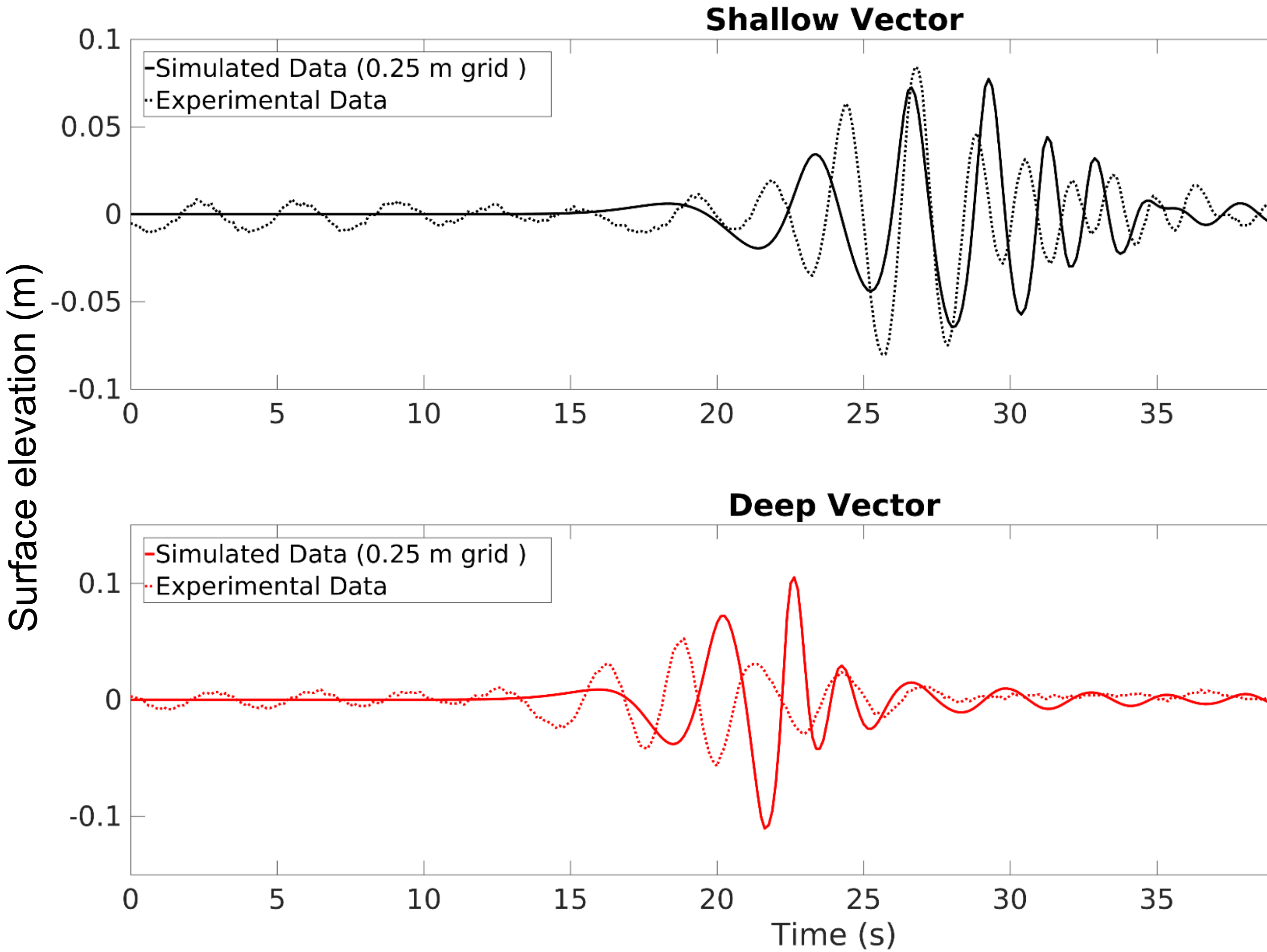


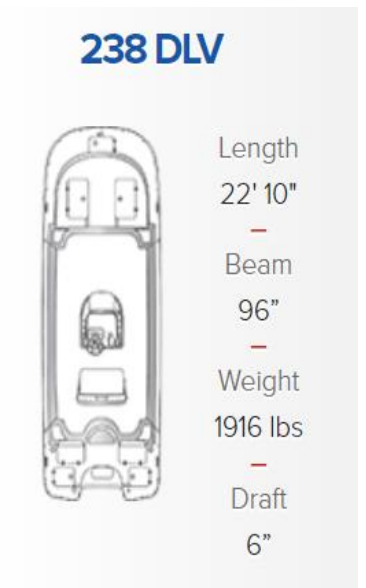
FUNWAVE TVD:
fully nonlinear Boussinesq wave model initially developed by Kirby et al. (1998).

Goal: compare field-collected data on boat wake behavior to model output

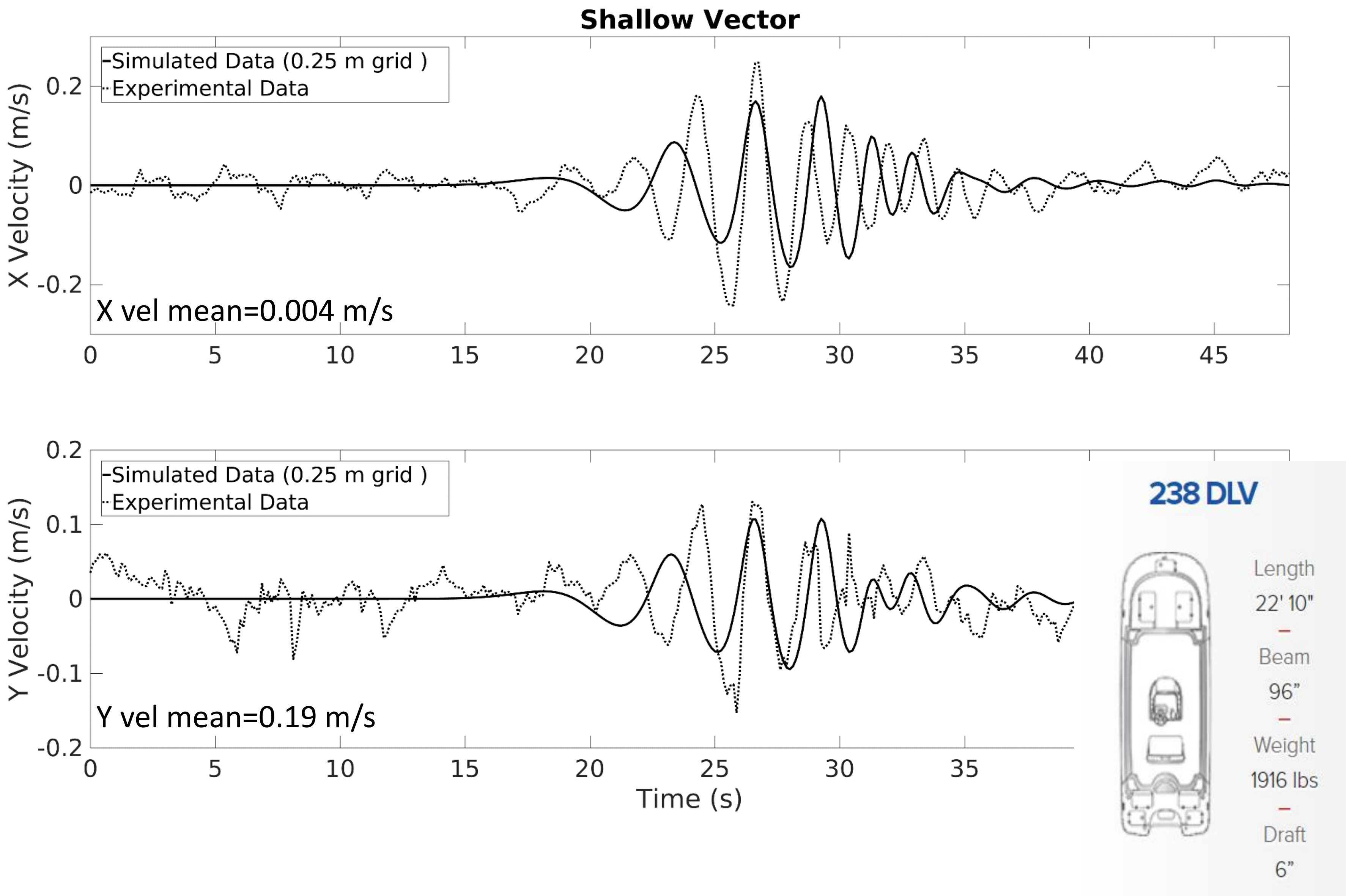
Approach to evaluate breakwall effectiveness under different bathymetry, tidal height, boat size & speeds

Test 1: field experiment using CESD lab vessel: Free surface elevation.

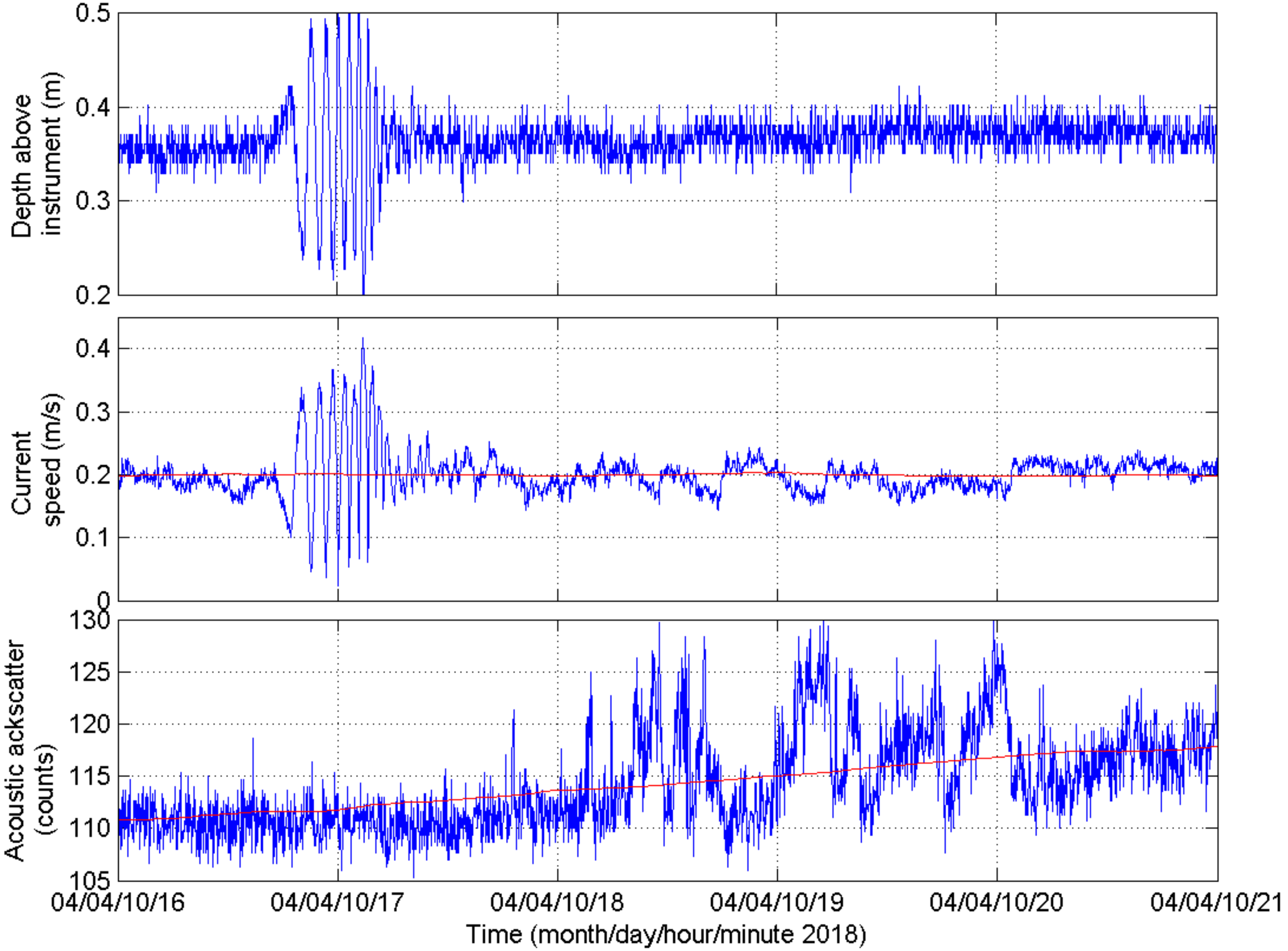




Test 1: field experiment using CESD lab vessel: Flow velocity.

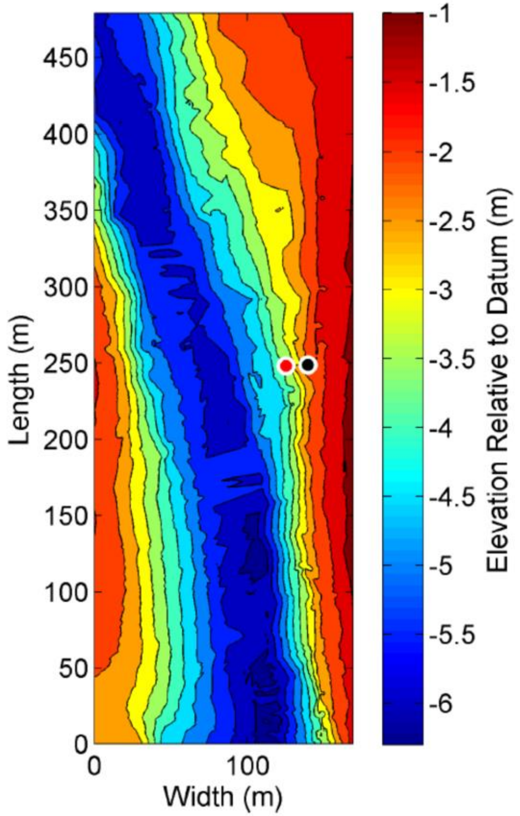


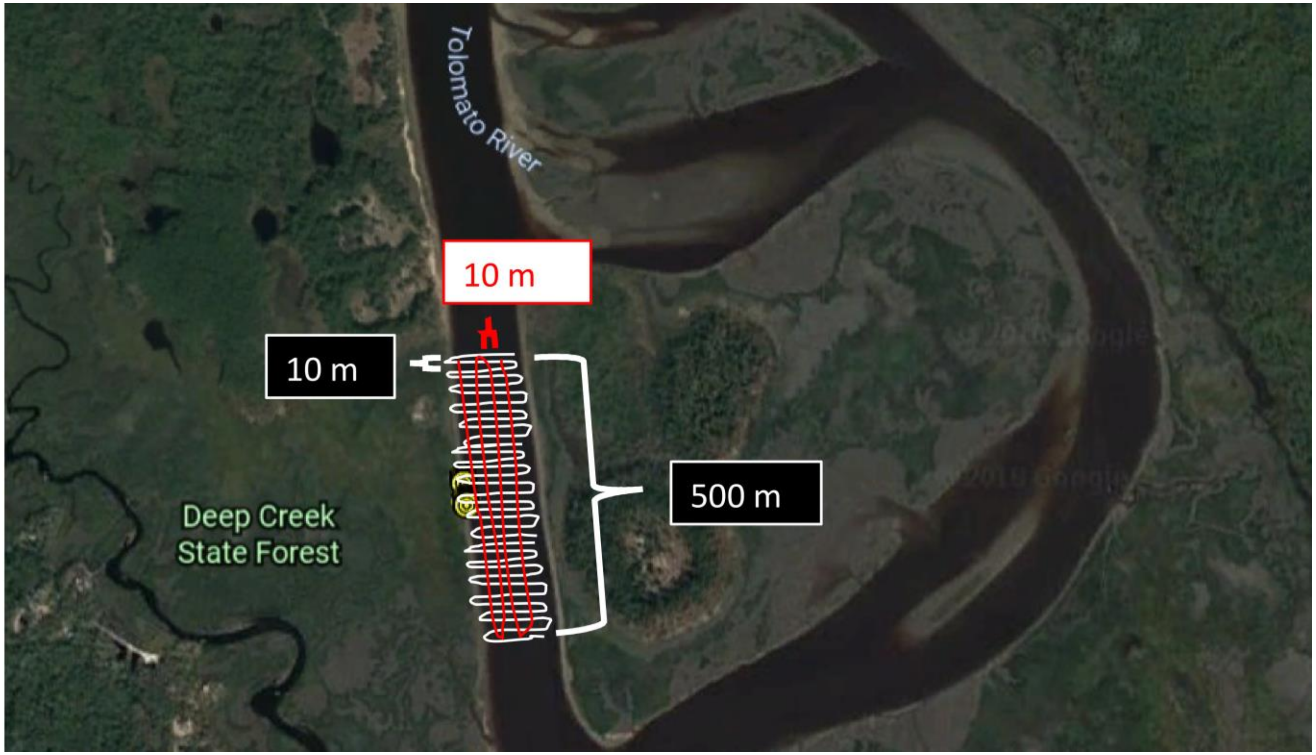
On-going analyses of backscatter: Significant increase in turbidity after wake…

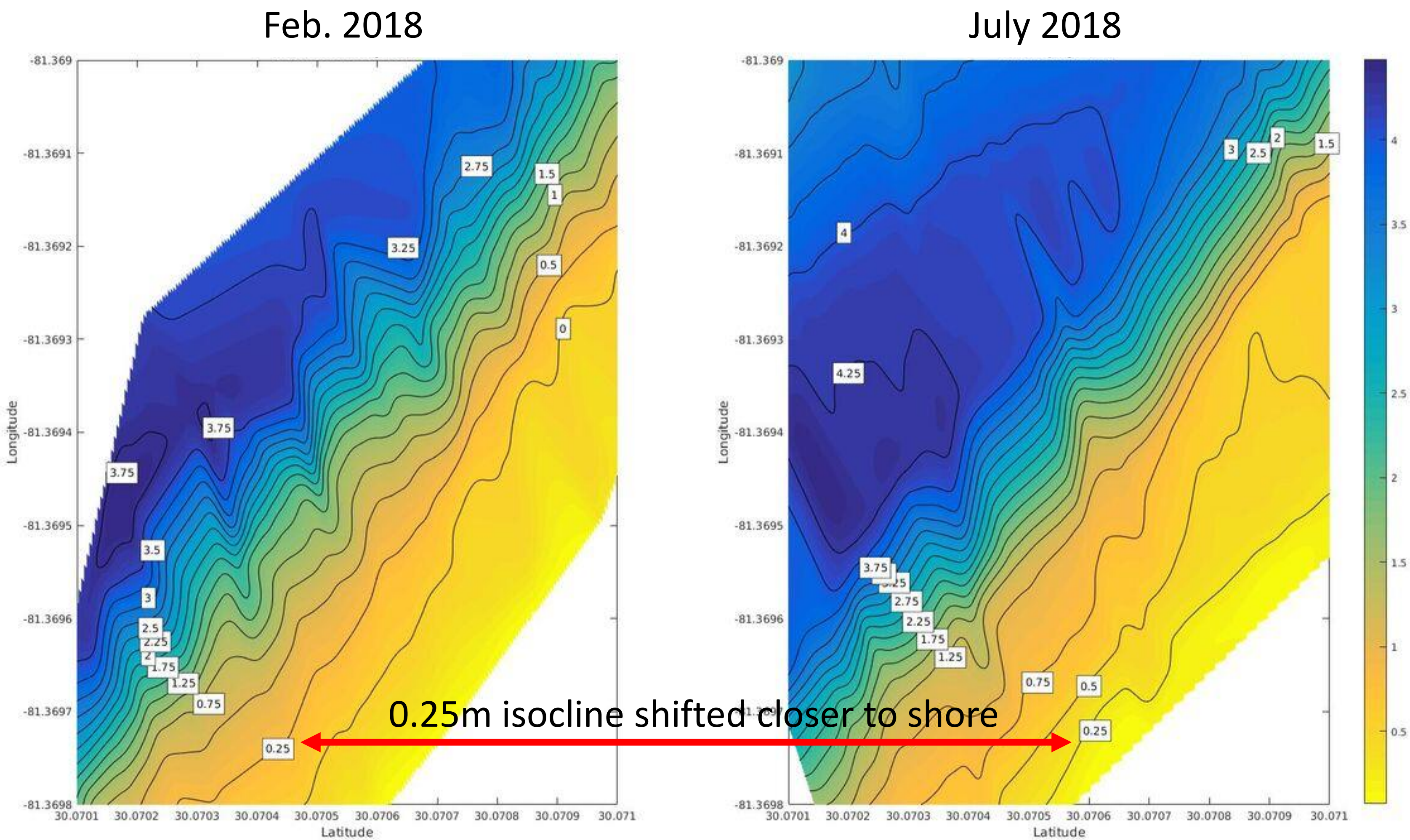


How is the channel bathymetry changing?

Q-Boat 1800^{TM} Teledyne Oceanscience Remotely-Operated Instrumentation Boat on loan from US Navy Research Lab







Bathymetry scans using Teledyne Q-boat indicate significant erosion of intertidal bed

Breakwall longevity

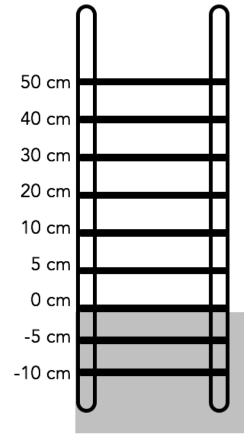
Wakes loosen branches

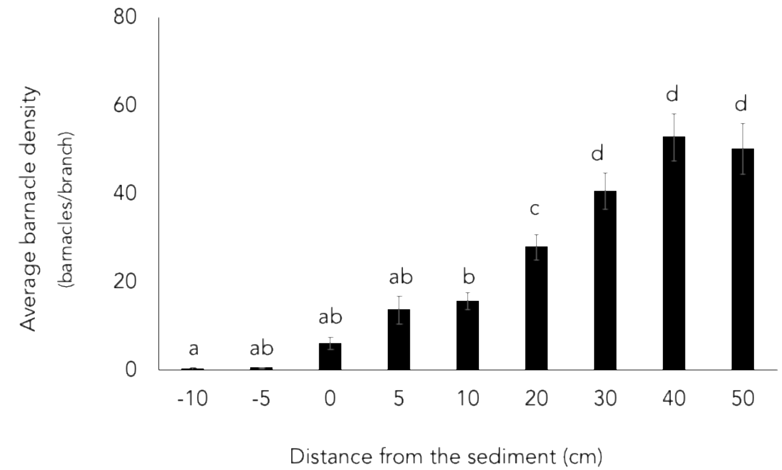
Maintenance time-intensive

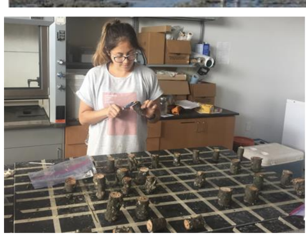
- Site location
- Branch supply
- Heavier duty equipment
  - Post installation
  - Securing branches

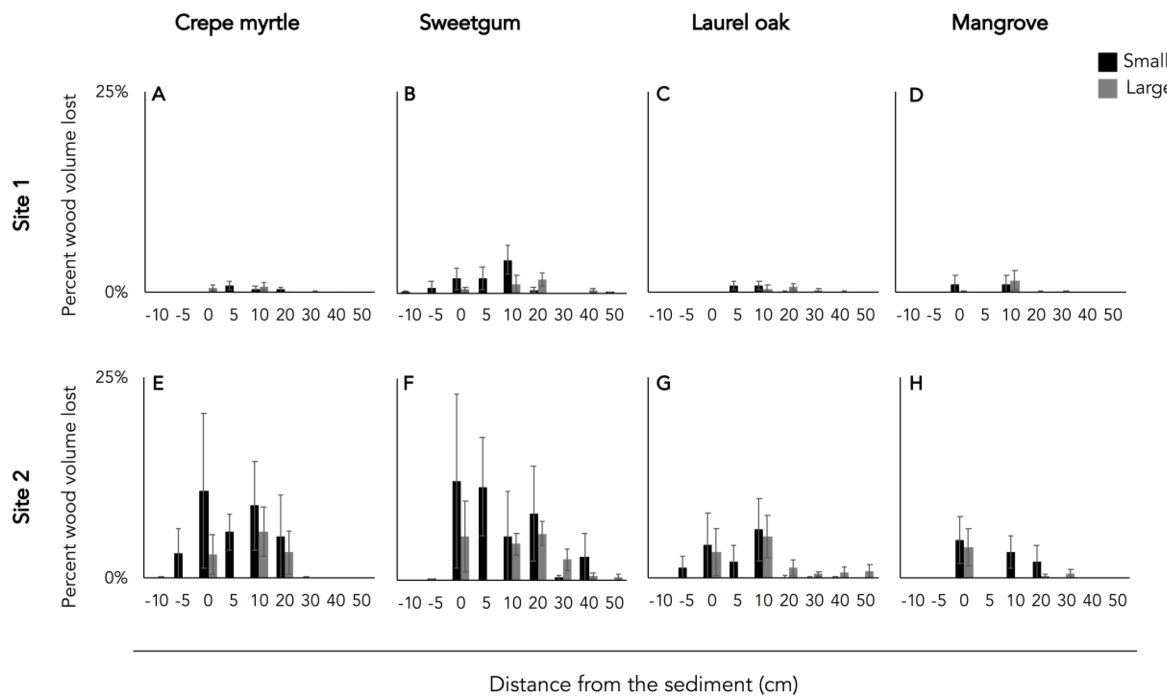
Bio-fouling & Shipworm Infestation

- Shipworms infest surface
- Barnacles foul higher
- Variable across sites
- Reduced by duct tape







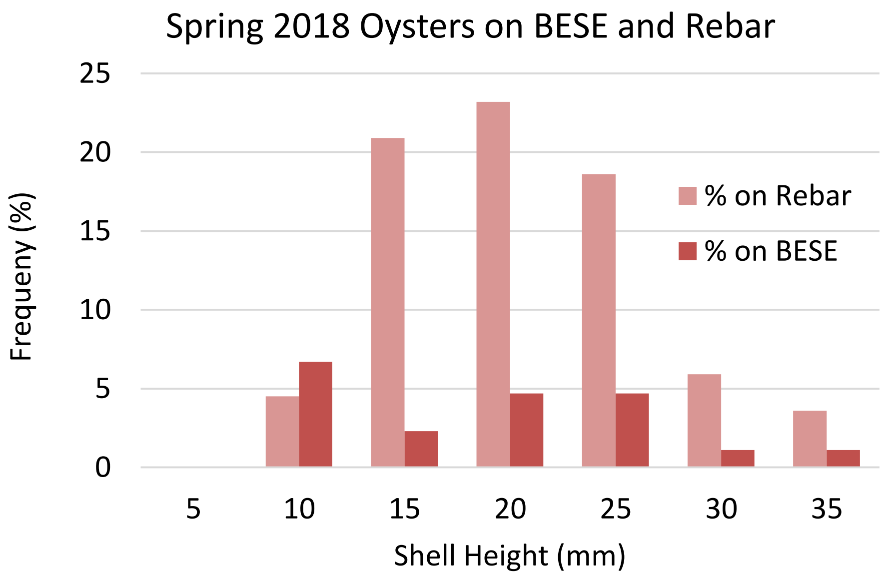


Bersoza & Angelini *in review*

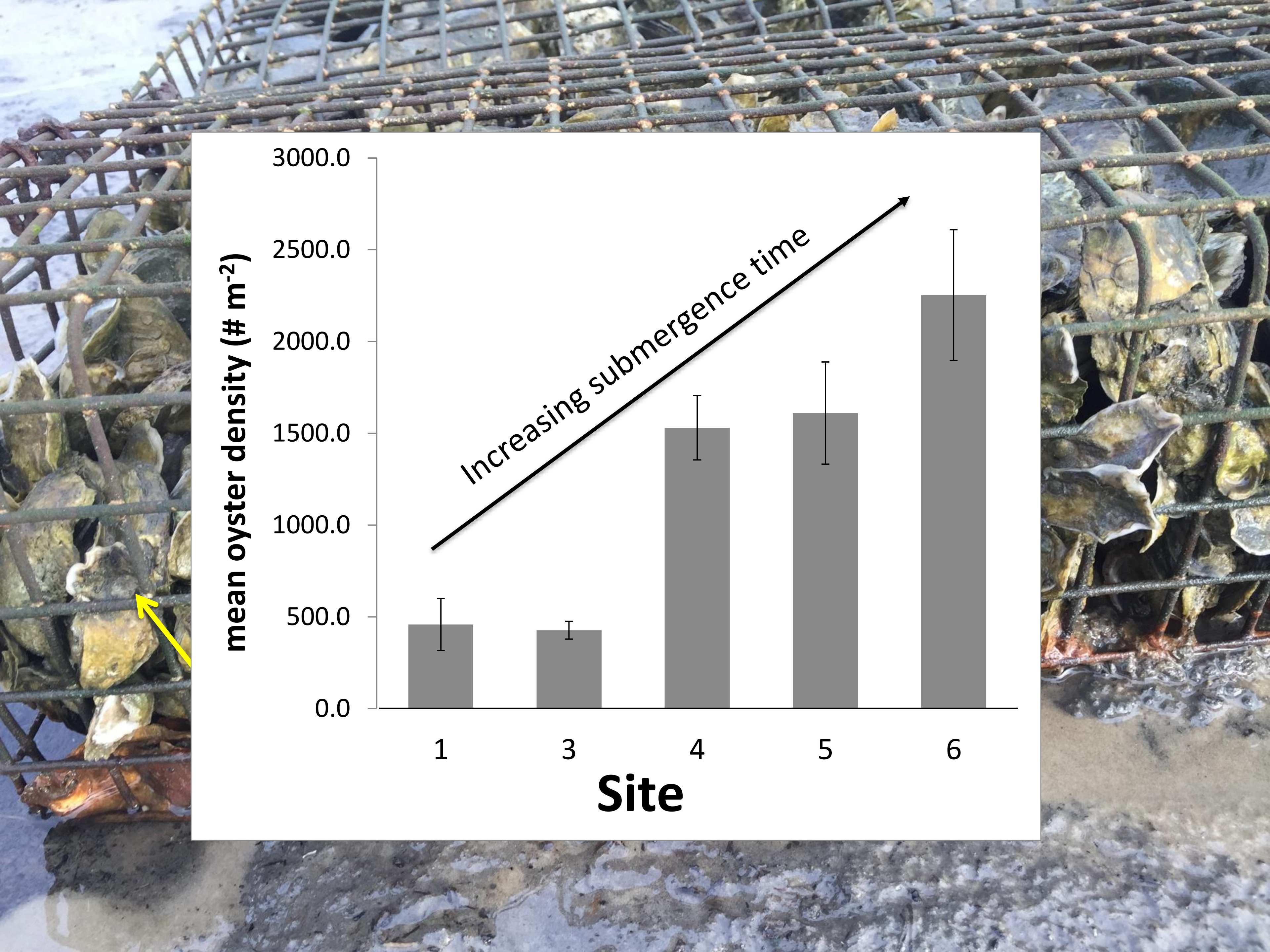
How have oyster reefs and salt marshes responded to the breakwalls?

BESE versus Gabions

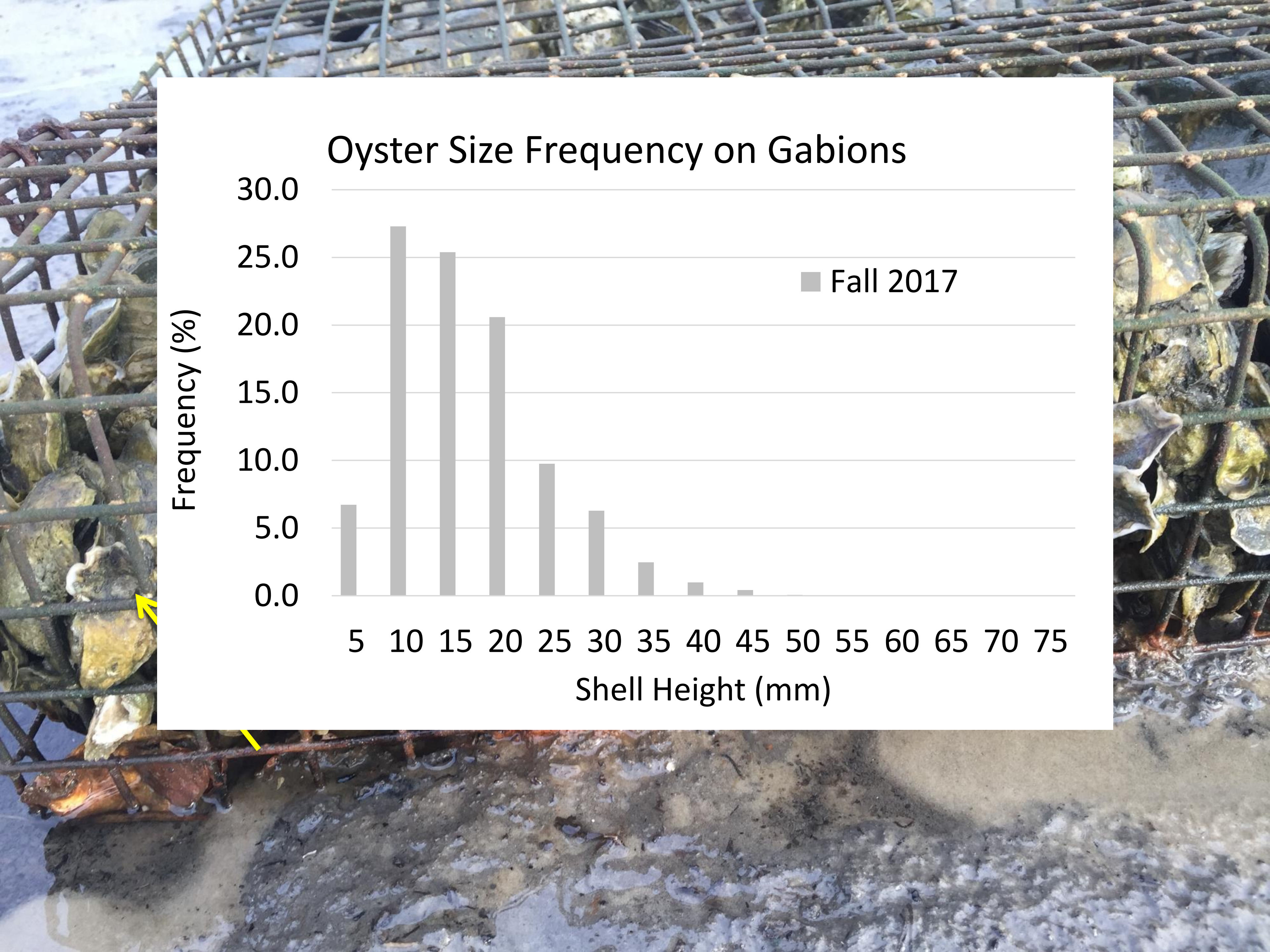
Very few oysters in 2017!



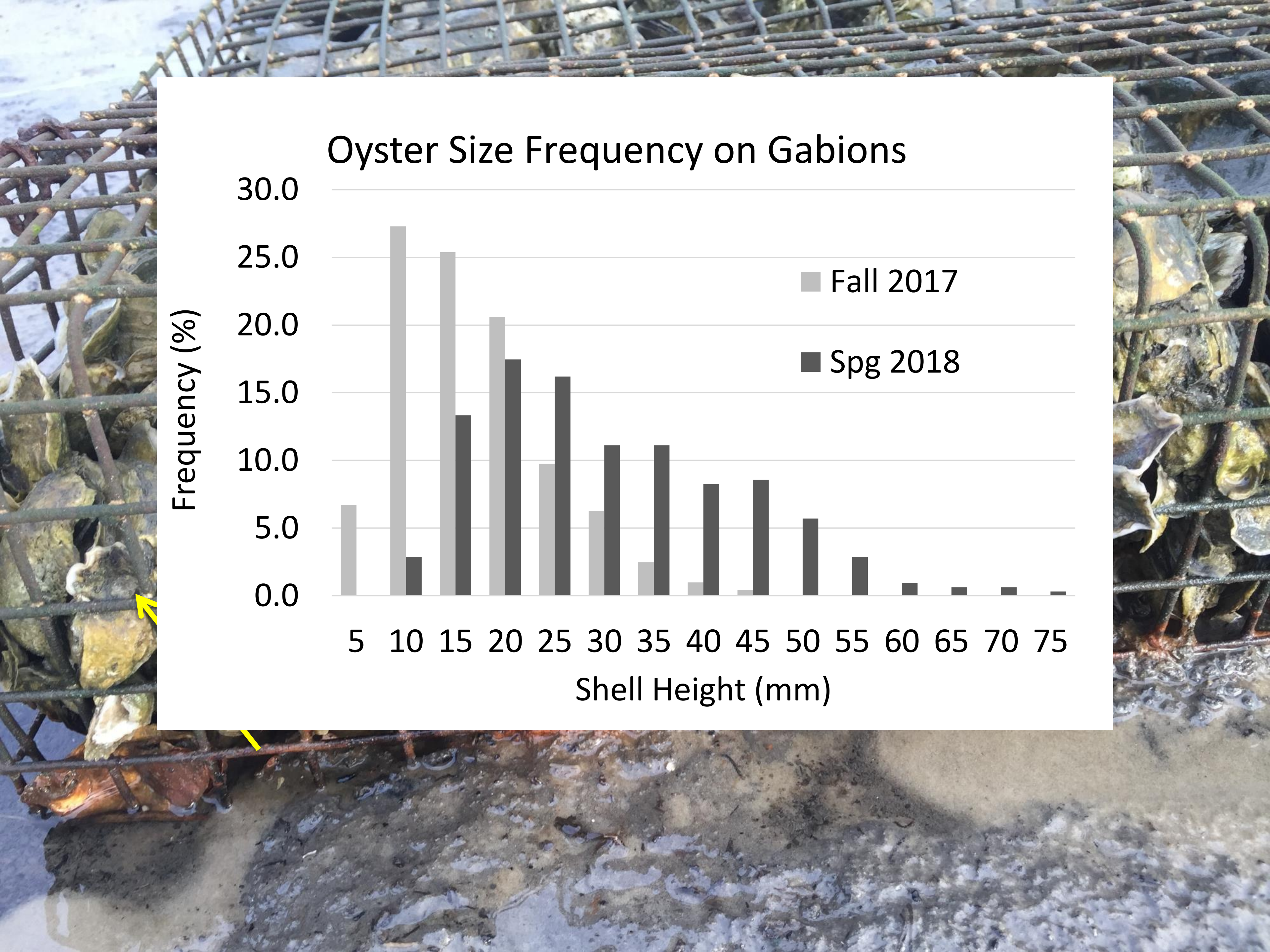

Gabions: Great Recruitment!



3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
mean oyster density (# m-2)
Increasing submergence time
1
3
4
5
6
Site

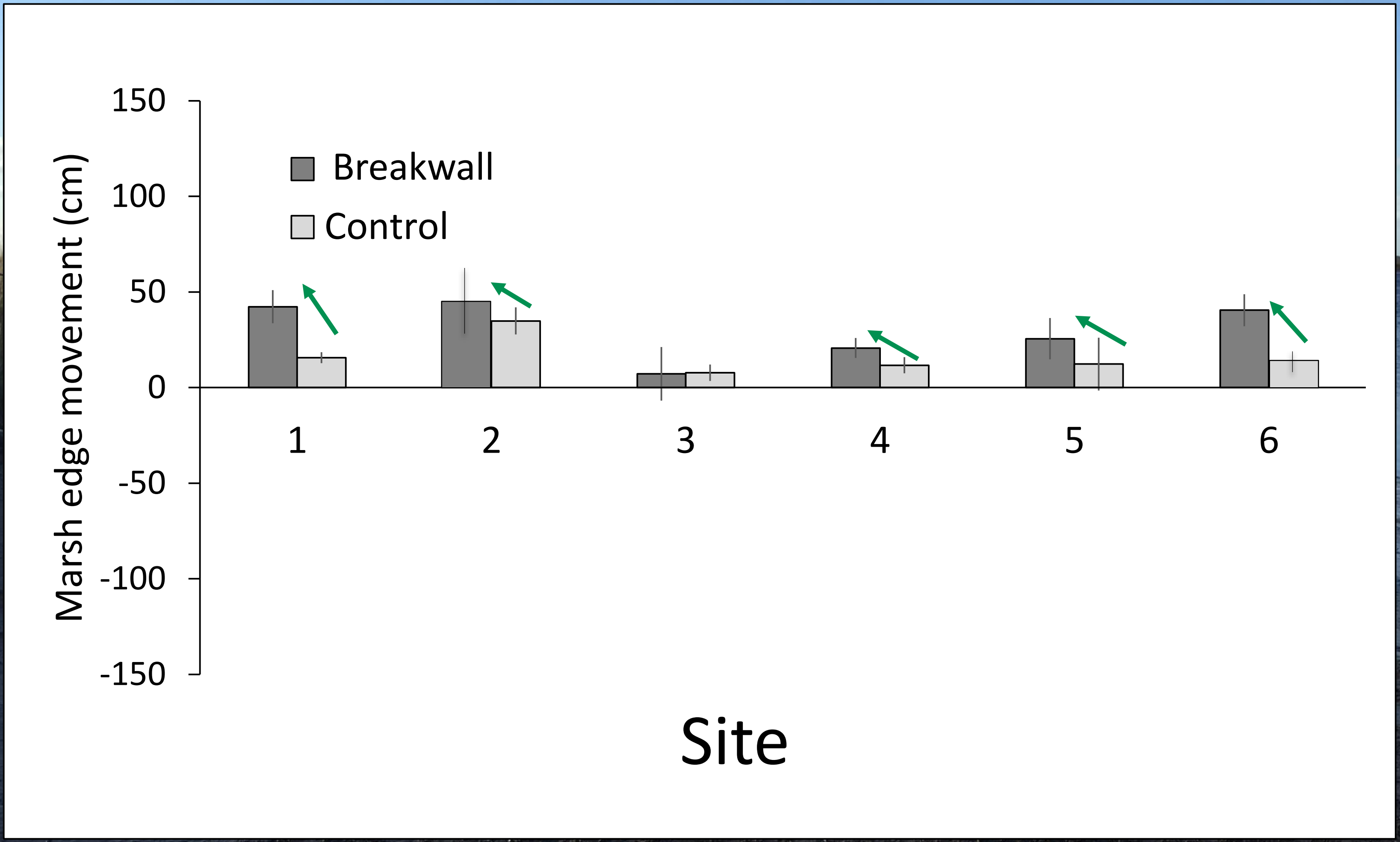


Oyster Size Frequency on Gabions
Frequency (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
Shell Height (mm)
Fall 2017


Oyster Size Frequency on Gabions
Frequency (%)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Fall 2017
Spg 2018
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
Shell Height (mm)

Tracking salt marsh response: 15 poles, 1m apart

Post breakwall construction: overall trend of progradation Especially in breakwall treatments



Study Take-Home Messages

1) Boats impose an artificial wave climate that is driving loss of ecosystems & services
   - Most damaging stress in some waterways
2) Semi-permeable breakwalls can dissipate wakes
   - Shipworms pose a threat to long-term durability
   - Stimulate oyster growth & marsh progradation
3) Construction & maintenance costs likely outweigh avoided loss of habitat & sediment

Acknowledgements

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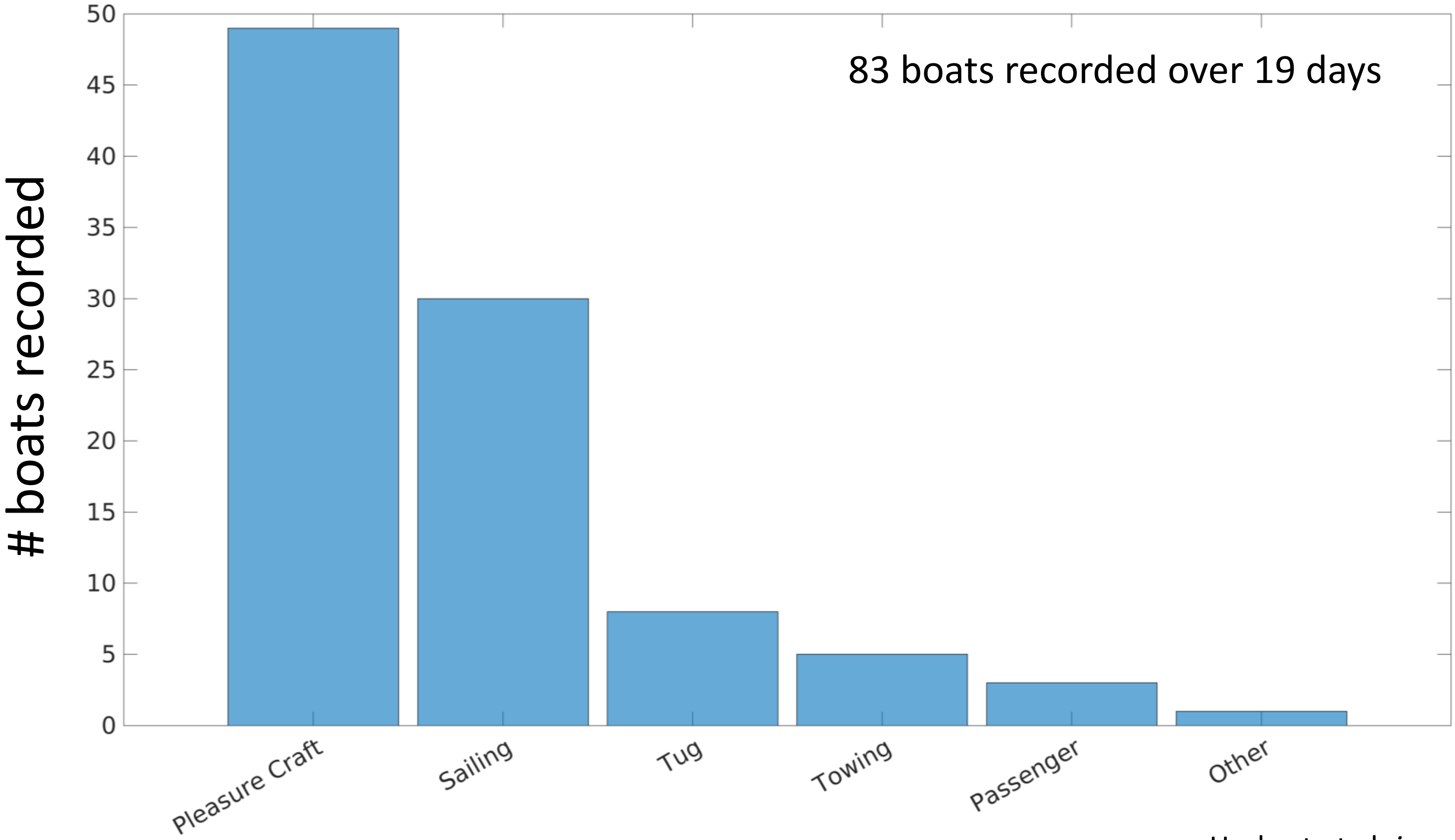
Permitting: Janice Price & US Army Corps of Engineering Coastal Permitting Division

AIS-tracked boats



Herbert et al. *in preparation*

Numerical simulations

Model: FUNWAVE TVD, fully nonlinear Boussinesq wave model initially developed by Kirby et al. (1998).

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Jeffrey C. Harris, Department of Ocean Engineering, University of Rhode Island

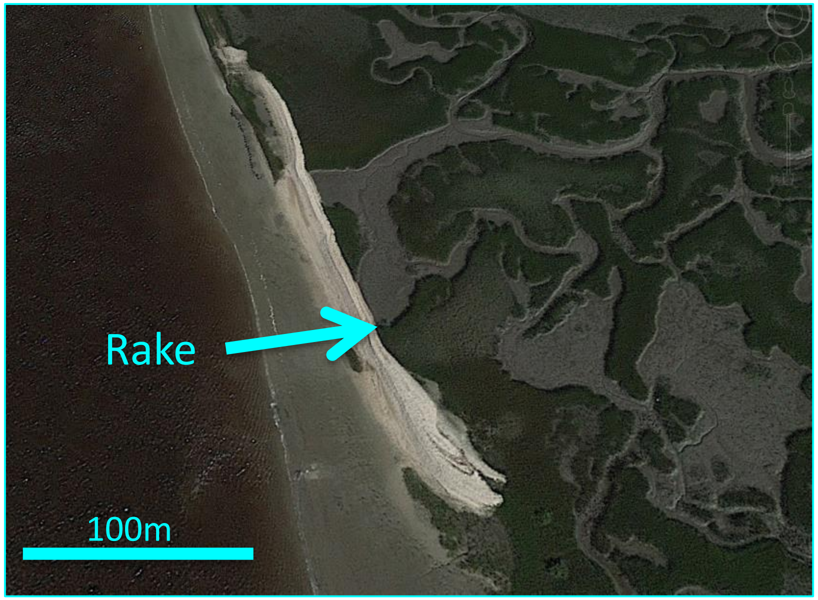
Matt Malej, U.S. Army Engineer Research and Development Center

Goal: compare field-collected data to model output

Model input data: bathymetry; boat information (length, width, draft, track with time stamps)

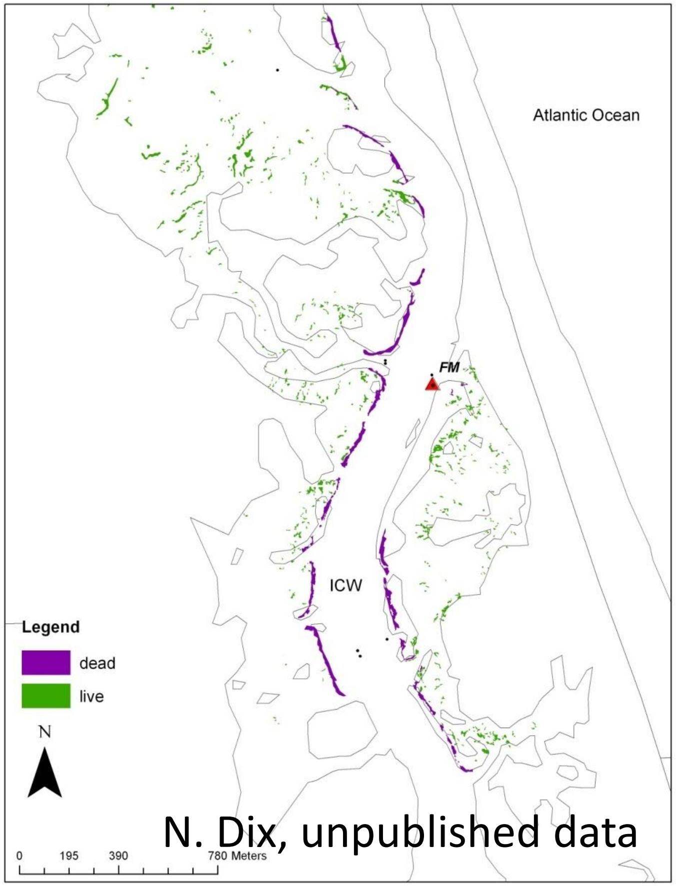
Validation data: location of wave instruments; time series data of pressure and velocity

Dead oyster 'rakes' along the ICW

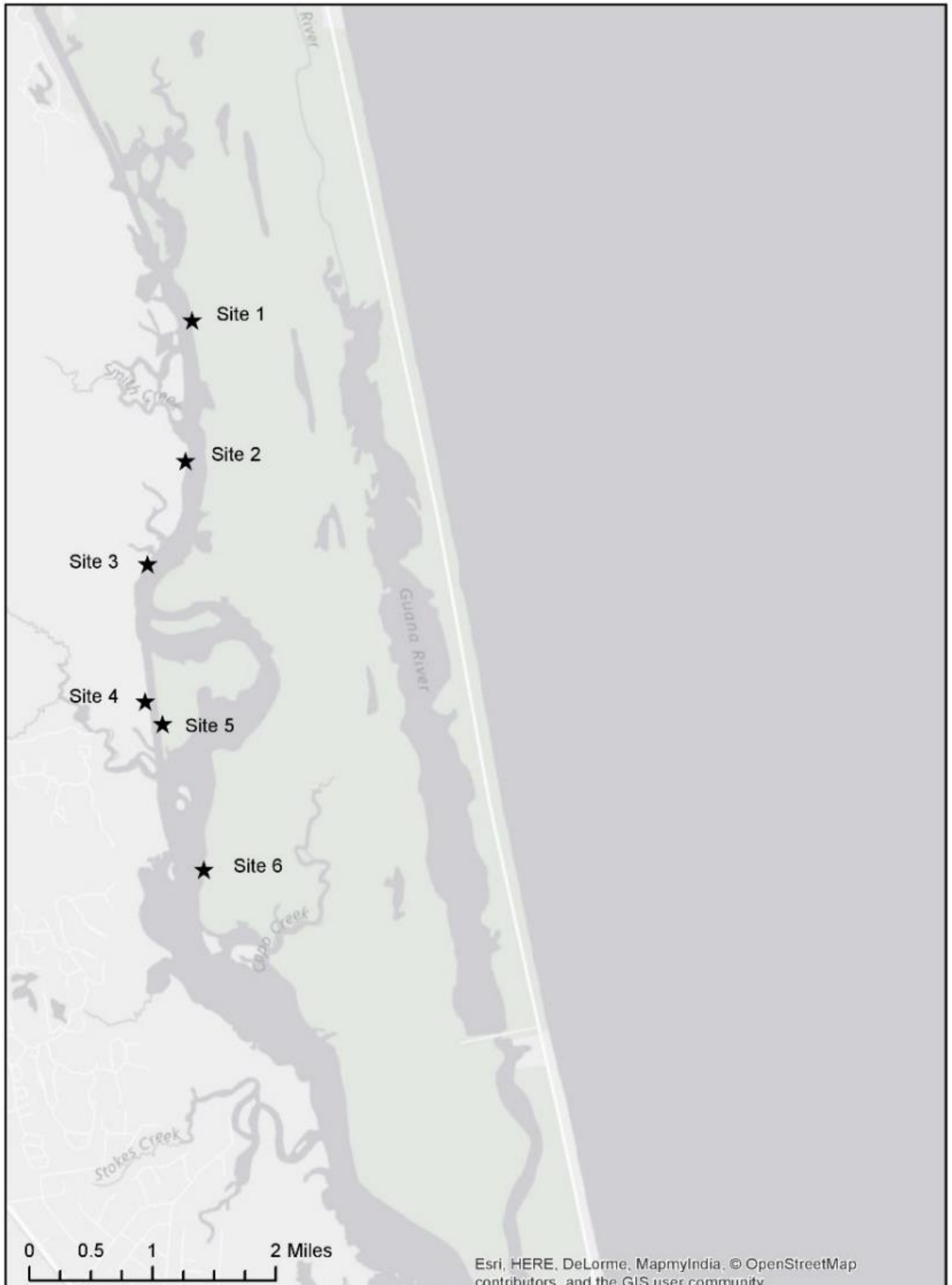


Rakes stand 1m above high water line
Detected in 1940's
Now pervasive along ICW

Grizzle et al. 2002



N. Dix, unpublished data



Unmanipulated control shorelines

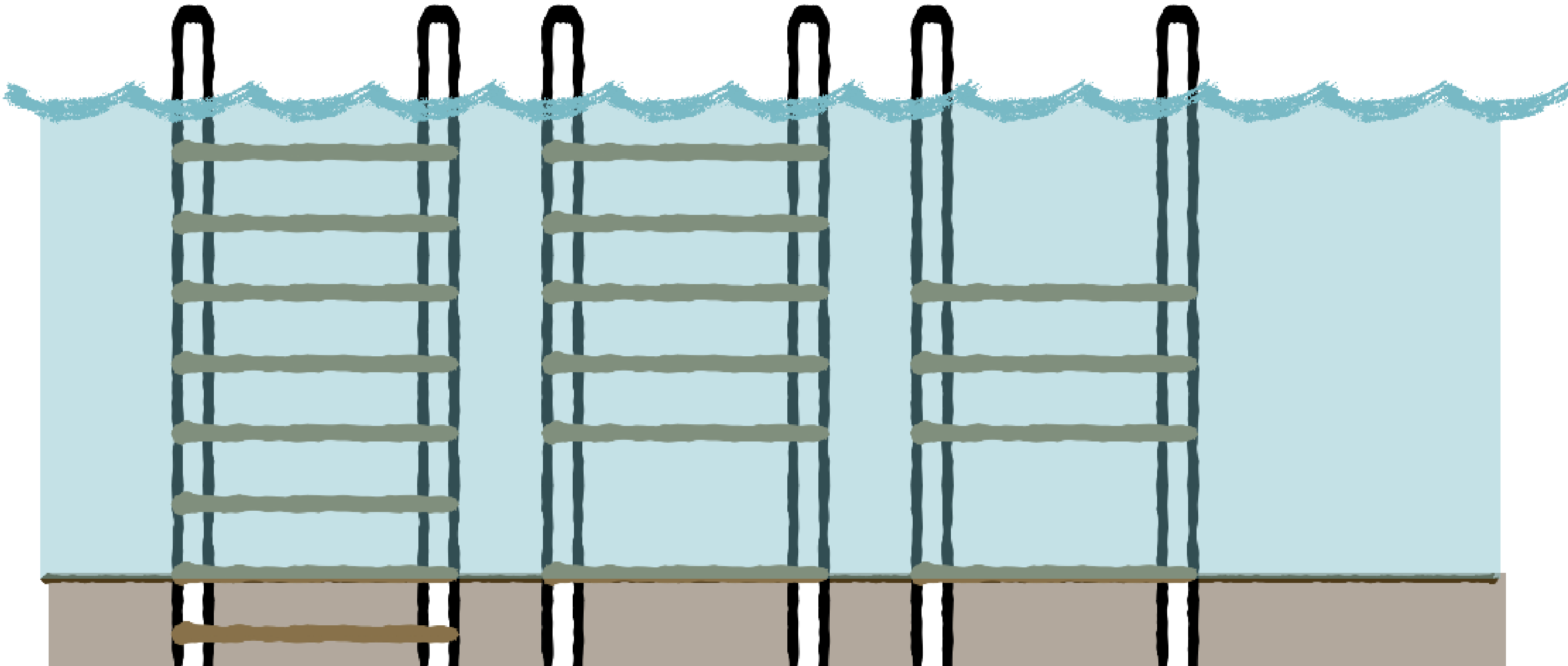
3, 60cm-tall break walls + oyster structures

6 sites of varying channel width

1 year pre-treatment monitoring

1 yr of post-treatment monitoring

Maintained every 3-5 months



All branches were completely submerged at high tide.

Shipworm Damage:
Far higher close to mud line & in softer woods

Varied between sites & years




Field experiment: understanding shipworm dynamics

4 common tree species
Multiple distances from sediment
Replicated at 2 estuaries & 2 years

Prior to break wall construction, marsh retreat widespread
Erosion rate varied considerably across sites