COASTAL PROTECTION BENEFITS OF VEGETATION: A FOCUS ON WAVE HEIGHT REDUCTION

Mary Anderson Bryant
U.S Army Corps of Engineers
Engineer Research and Development Center
Coastal & Hydraulics Laboratory
Mary.Bryant@usace.army.mil

December 13, 2018

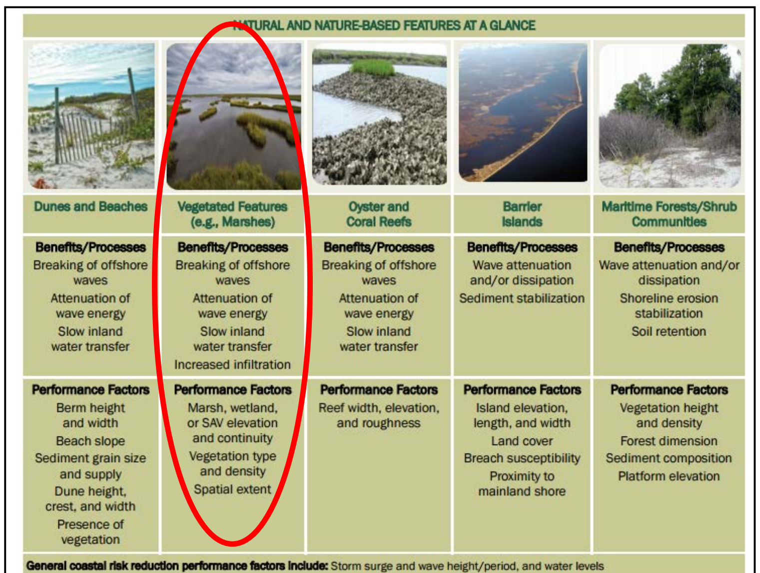
US Army Corps of Engineers

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

DISCOVER | DEVELOP | DELIVER

Motivation

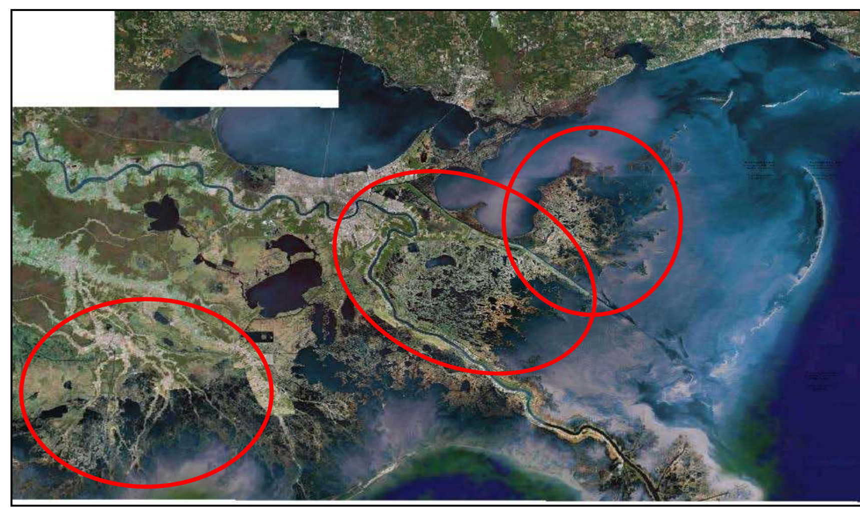
- vulnerability of coastal communities to waves, surge, and erosion
- incorporation of natural and nature-based features (NNBF) into coastal risk reduction strategies is gaining attention
- focus on capacity of vegetation to attenuate wave energy:
  - quantify engineering benefits/limitations for flood risk reduction and shoreline stabilization
  - accurately model coastal hydrodynamics in wetland-dominated areas



NATURAL AND NATURE-BASED FEATURES AT A GLANCE

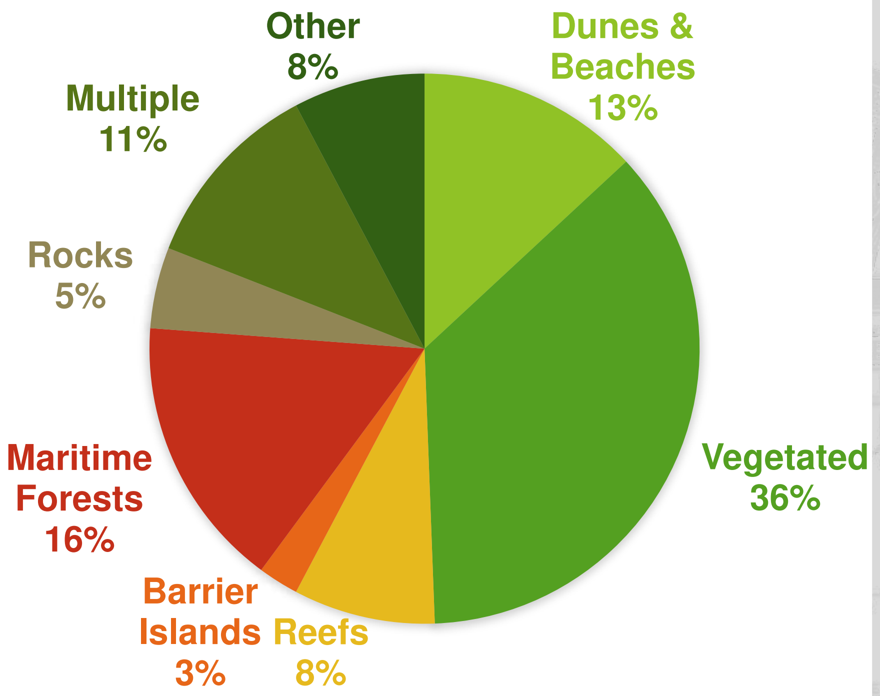
Dunes and Beaches	Vegetated Features (e.g., Marshes)	Oyster and Coral Reefs	Barrier Islands	Maritime Forests/Shrub Communities
Benefits/Processes Breaking of offshore waves Attenuation of wave energy Slow inland water transfer	**Benefits/Processes** Breaking of offshore waves Attenuation of wave energy Slow inland water transfer Increased infiltration	**Benefits/Processes** Breaking of offshore waves Attenuation of wave energy Slow inland water transfer	**Benefits/Processes** Wave attenuation and/or dissipation Sediment stabilization	**Benefits/Processes** Wave attenuation and/or dissipation Shoreline erosion stabilization Soil retention
Performance Factors Berm height and width Beach slope Sediment grain size and supply Dune height, crest, and width Presence of vegetation	**Performance Factors** Marsh, wetland, or SAV elevation and continuity Vegetation type and density Spatial extent	**Performance Factors** Reef width, elevation, and roughness	**Performance Factors** Island elevation, length, and width Land cover Breach susceptibility Proximity to mainland shore	**Performance Factors** Vegetation height and density Forest dimension Sediment composition Platform elevation

General coastal risk reduction performance factors include: Storm surge and wave height/period, and water levels

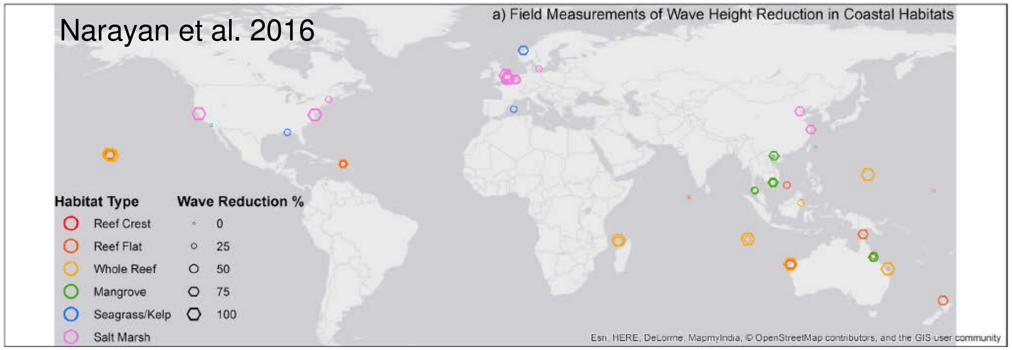


Overview

- wetlands and marshes are the most published NNBF in the context of reducing impacts of waves, surge, and erosion (Webb, University of Southern Alabama)
- 70+ studies encompassing:
  - field: measurements, observations
  - laboratory: isolating responses
  - modeling: mechanistic processes; regional, landscape applications; predictive capability



Field Studies



- dissipation of wave energy by wetlands/marshes is documented in numerous field studies
- earlier studies generally only measure wave dissipation (Wayne 1976, Knutson et al. 1982)
- more recent studies consider:
  - vegetated and unvegetated areas (Moller et al. 1999, Cooper 2005, Yang et al. 2012)

    attenuation at least 2x greater over vegetation than mudflats
  - different species (Ysebaert et al. 2011)

    attenuation greater with taller, rigid growth forms
  - seasons (Moller et al. 2006, Paul and Amos 2011)

    seasonal patterns of wave attenuation correspond to growth cycles
- commonality: generally conducted in low wave energy environments
- the variability in wave dissipation is LARGE due to extensive variety of plants
  - on average, salt marshes reduced wave heights by 72% (Narayan et al. 2016, considering 69 field measurements)
- field efforts serve as a body of evidence and foundation for laboratory efforts

Laboratory Studies

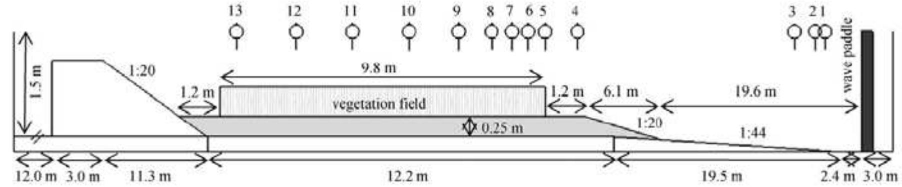
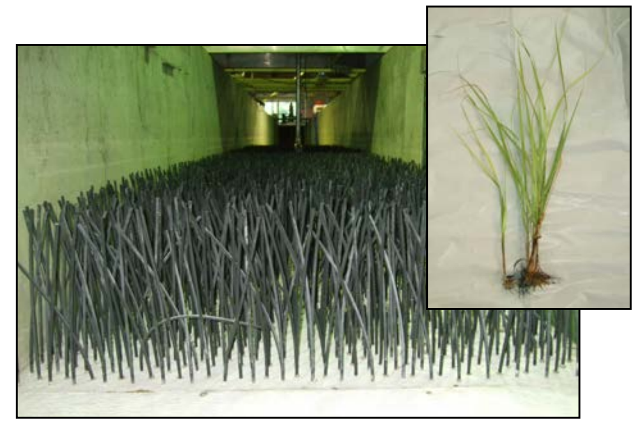


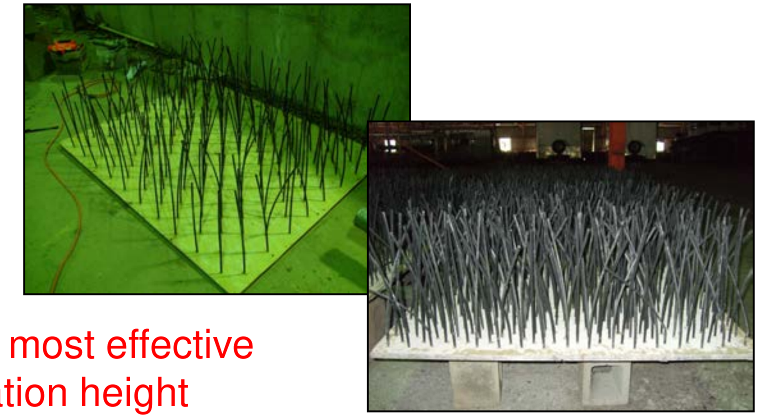
Fig. 1. Cross section of the flume and physical model setup (not drawn to scale). The white numbered circles are the locations of the wave gauges.

- laboratory offers a controlled environment to perform parametric analyses
  - identify critical wave reduction factors and isolate response as factors are manipulated
- vegetation modeled using artificial, idealized plant mimics most extensive approach
  - wooden dowels, foam, rope, flexible molded plastic

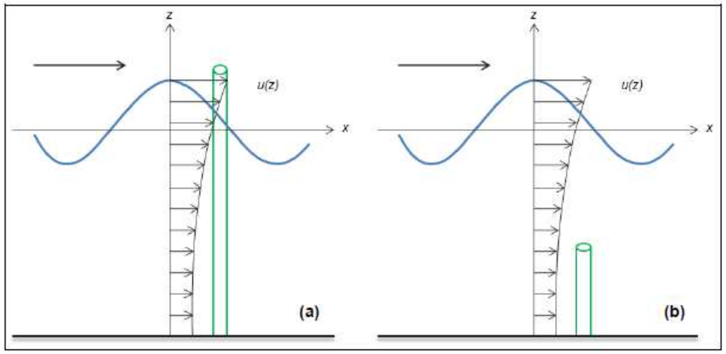


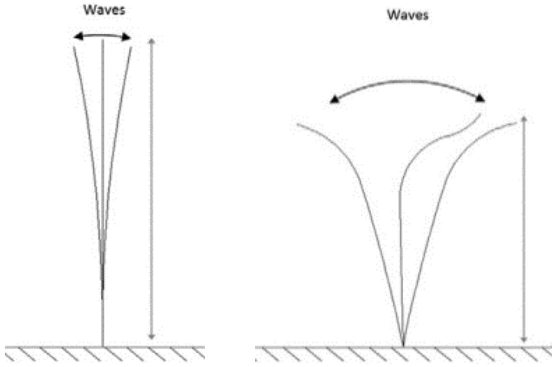
- *Spartina alterniflora* mimics
- three stem densities (100, 200, 400 stems/m^2)
- hydrodynamic conditions with varying wave heights, wave periods, and water levels (submerged to emergent)
- increase with stem density (15% bare vs 60% 400 stems)
- decrease with deeper water (30% sub vs 64% emergent)

Wave Reduction Factors



- stem density
  - greater attenuation with denser vegetation
- depth of water above marsh surface
  - greater attenuation with taller canopies - emergent most effective
  - decreased with larger ratios of water depth : vegetation height
- marsh width
  - total wave attenuation increases with longer beds
  - greatest reduction occurs over the first few meters
  - additional vegetation extents do not lead to proportional increases in wave damping
- stem stiffness
  - greater attenuation for stiffer vegetation than flexible vegetation
- incoming wave height and period
  - larger periods need longer distance to travel through vegetation for substantial dampening



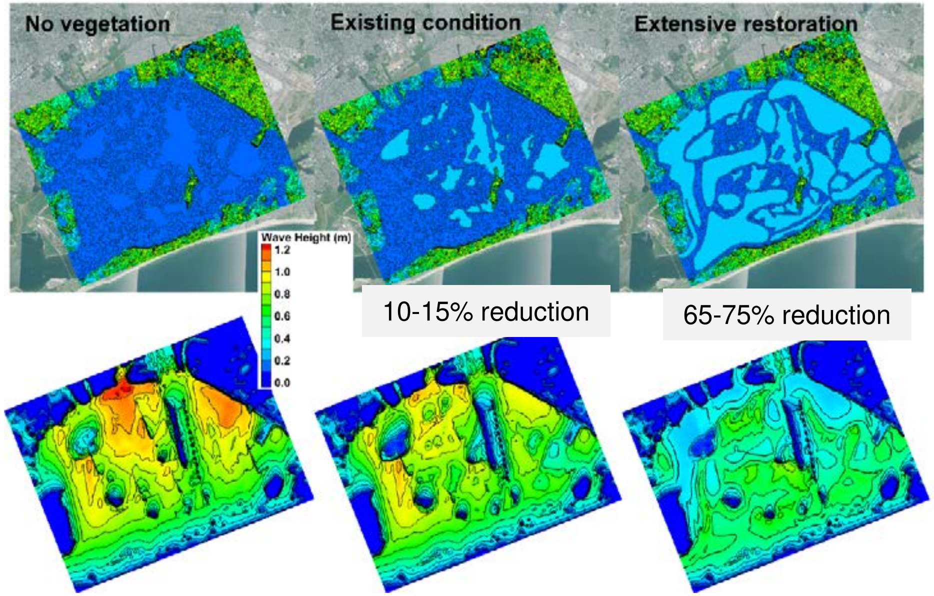


Emergent, stiffer, denser, and taller vegetation dissipate wave energy more effectively than submerged, flexible, and short-stemmed vegetation.

Losada et al. 2016

Wave Modeling

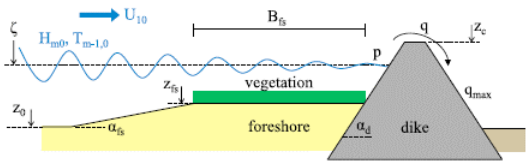
- numerical modeling allows for scaling to local and regional landscape scales
- incorporated into STWAVE, SWAN, XBEACH
- common inputs include stem density, stem height, stem diameter, and a drag coefficient
  - drag coefficient is calibrated and accounts for unknown plant behavior and bio-mechanical properties
- Jamaica Bay, NY example
  - waves generated by southerly winds during a hypothetical hurricane
  - significant wave mitigation along northern shoreline due to vegetation and associated bathymetry modifications



Incorporating with Infrastructure

- wave attenuation services of vegetation may be incorporated into hybrid engineering solutions, creating operational and maintenance benefits
- common configuration is dike accompanied by a vegetated foreshore
- Rupp-Amstrong and Nicholls (2007)
  - considerable amounts of money spent to build up salt marshes in front of bare dikes and to sustain existing dike-fronting salt marshes in Germany
  - with 80-m-wide salt marshes, a 3-m-high seawall would be required (£400/m) whereas the seawall would have to be 12 m high (£5000/m) in their absence
- Vuik et al. 2018
  - **method for comparison between nature-based flood defenses and traditionally engineered solutions**
  - vegetated foreshores cause a reduction in failure probability for both wave overtopping and wave impacts
  - vegetation has the highest effect on failure probabilities at low protection levels
  - less important for more robust dikes because vegetation is not expected to survive the extreme wave conditions for which dike is designed

Fig. 7. Salt marshes along a Wadden Sea dike in the Netherlands (Fig. 6), with the Wadden Sea and the marshes on the right hand side of the dike. Photo: Beeldbank Rijkswaterstaat.



In Summary

- quantifying the engineering benefits of NNBF is critical for implementation
  - supported by field, laboratory, and modeling effort
- risks addressed by wetlands:
  - reduced shoreline erosion
  - short wave attenuation (low-energy environments, wave heights < 2 feet)
- main wave reduction factors are known
  - incoming wave height and period
  - water depth above marsh
  - vegetation properties, including marsh width, density, bio-mechanics
- quantitative not fully understood due to complex interactions and site-specificity
- spectra of implementation including creating/restoring wide expanses, enhancing existing structures, and hybrid solutions with conventional infrastructure

Research Needs

- current demand for understanding relevant processes requires laboratory modeling with real vegetation
  - unclear how mimics relate to real vegetation
  - addressed with a cross-disciplinary approach of ecology and hydraulics
  - Moller et al. (2014) and Lara et al. (2016)

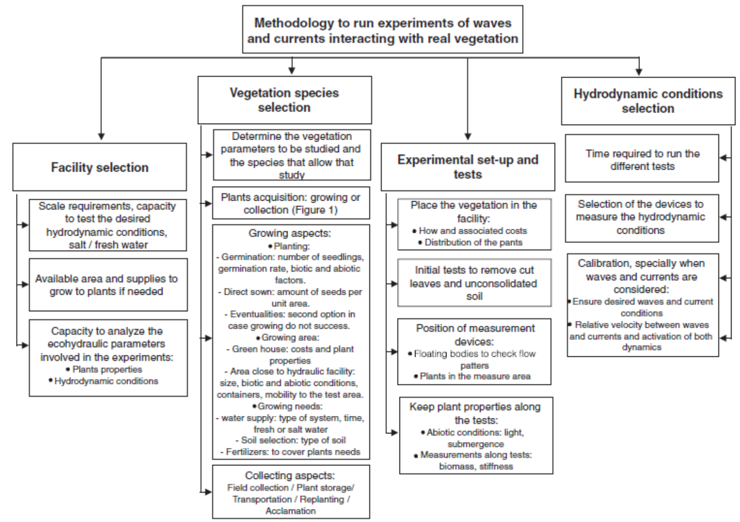
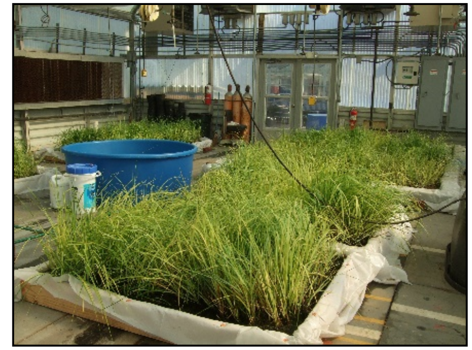
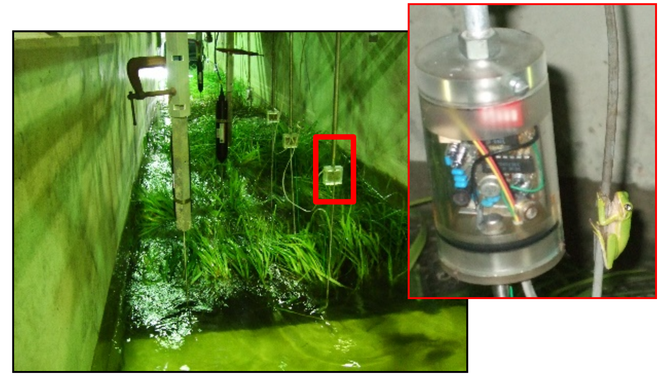


Fig. 9. Recommendations to design and perform experiments for the study of waves and current interactions with real vegetation.

- bridge the gap between small-scale laboratory findings and real-world storm scenarios
- current approaches for modeling waves through vegetation require further development
  - sensitive to calibrated drag coefficient that is highly variable
  - move beyond simplistic definitions of stem diameter, density, and height and incorporate meaningful parameters, like bio-mechanics
- limited understanding of the effects of vegetation breakage and uprooting (may lead to overestimation of dissipation)
- the degree to which wetlands attenuate surge and reduce flooding is the subject of debate and difficult to assess





Thank you!

Mary.Bryant@usace.army.mil