Success Criteria and Results of Oyster Restoration and Related Efforts for Coastal Resilience

"The preservation of oyster beds is as much the role of the State as preservation of forests."(K.A. Möbius,1877)

Loren D. Coen[*], & M.S.N. Chowdhury[+],

[*]HBOI, FAU; [+]Instit. Mar. Sci., Univ. Chittagong, Bangladesh

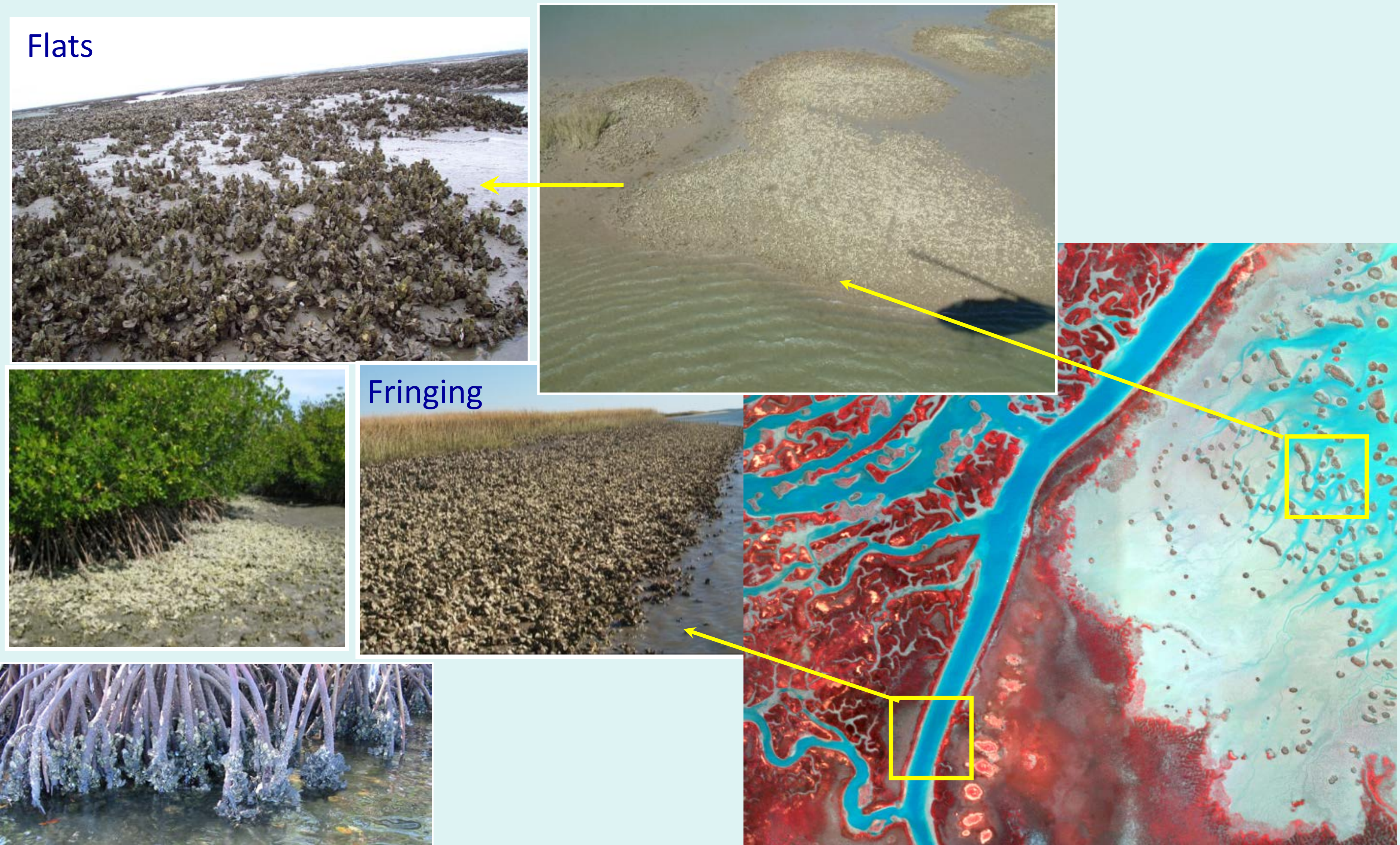
OIMMP, Oct. 11, 2019

Crassostrea virginica (Eastern oyster) has an extensive range ---

Subtidal Oyster Reefs Are Where Most Commerical Oysters Are Harvested From and Very Different from…..

Intertidal *C. v.* Oyster Reefs that Predominate In Many Estuaries

(e.g., southern NC, all of SC, GA, most of FL, seaside of VA)



However, for *C. virginica*, Gulf Estuaries are not Like East Coast (Atl.) U.S. Estuaries

Gulf Estuaries	East Coast Estuaries
Prolonged warm temperatures	Greater seasonality moving N. in Atl.
Extended spawning period from spring-fall (Hayes and Menzel 1981)	Spawning period compressed and/or limited to summer spawn (Kennedy and Battle 1964)
Faster growth of spat (Menzel 1951; Butler 1954) and juveniles (Gunter 1951; Loosanoff 1965) Growth can be slower in warm summer months	Growth slowed by lower winter temperatures
Oysters reach up to 90 mm in just 2 years	Oysters reach up to 90 mm in 4-5 years
Less vertical complexity often	More vertical complexity
Long residence times (Solis and Powell 1999)	Short residence times (Herman et al. 2007)
Main pathogen: Dermo only	Main pathogens: Dermo, MSX, *Bonamia*
Main region of U.S. commercial harvests now	Relatively low commercial harvests (aquacult. incr.)

Add differences in tidal range, semi- vs. diurnal, mixed tides, exposure for intertidal oysters, etc.

Adapted from Walles, et al. 2016; La Peyre, Pollack, Geiger 2015 NAS; Coen and Humphries 2017

In GOM for Example, Differences in Tidal Range, Semi- vs. Diurnal Tides, Exposure for Intertidal Oysters, etc.

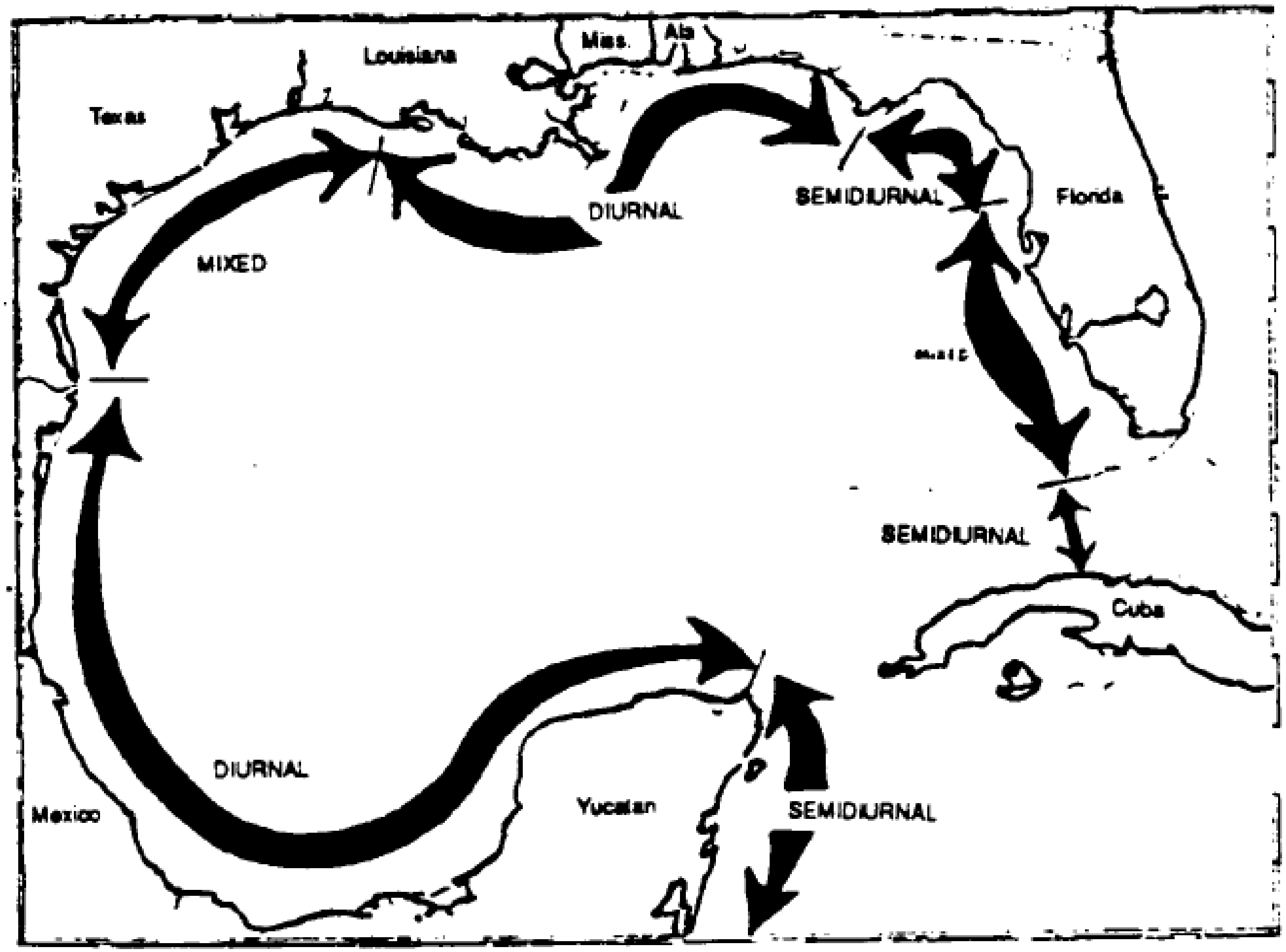


Figure 2. Gulf of Mexico tidal regimes (after Eleuterius 1975).

Intertidal Reefs Effect and are Affected by Waves in Numerous Ways

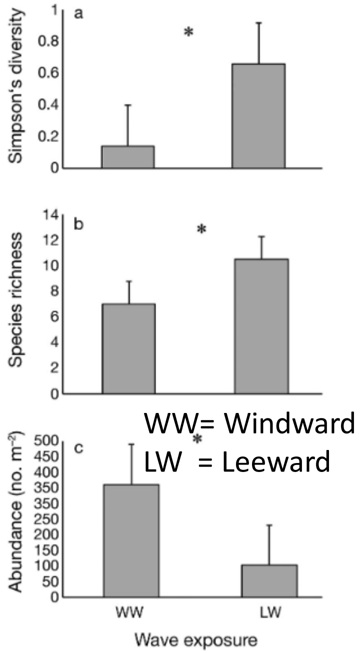
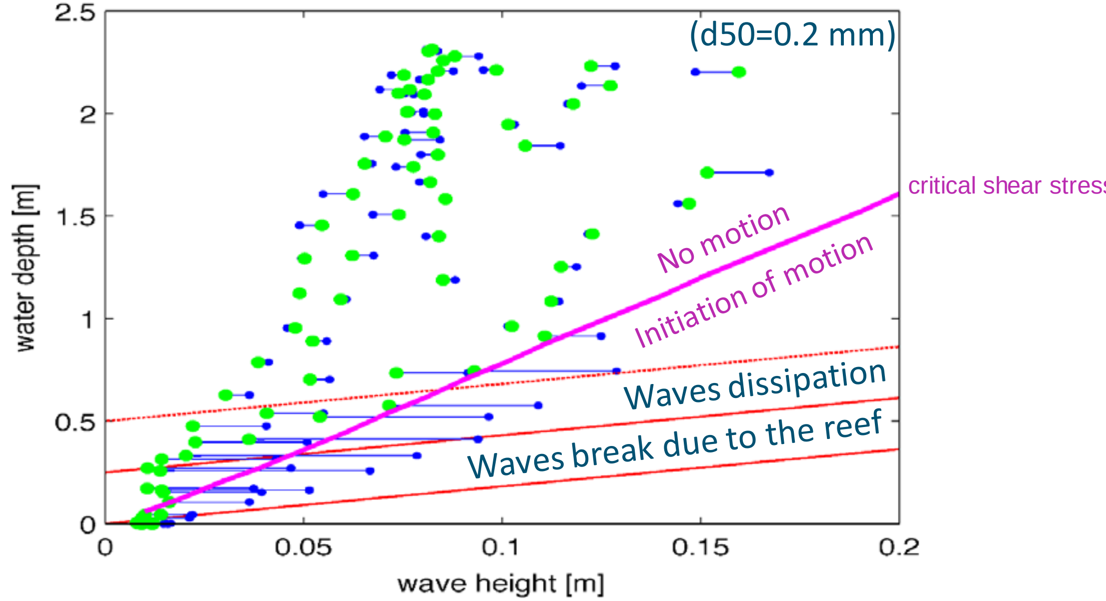
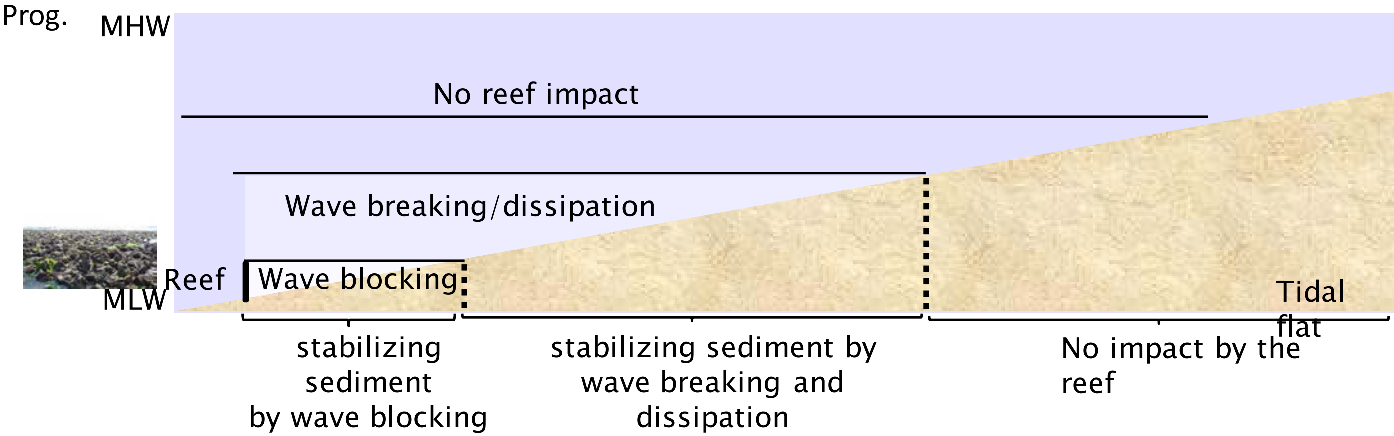


Fig. 4. Community measurements + SE. Comparisons of (a) Simpson's species diversity, (b) species richness, and (c) species abundance for windward (WW) and leeward (LW) sites *p < 0.05, ANOVA

Lunt, et al. 2017. Wave energy and flow reduce the abundance and size of benthic species on oyster reefs. Mar. Ecol. Prog. Ser. 569.



Ysebaert, T., et al. Reef depth, reef height, etc., unpublished MS



In Our Prior 2011 Work, We Found Oyster Reefs Were Being Lost Worldwide at Alarming Rates

Figure 1. The global condition of oyster reefs in bays and ecoregions. The condition ratings of good, fair, poor, and functionally extinct are based on the percentage of current to historical abundance of oyster reefs remaining: less than 50% lost (good), 50% to 89% lost (fair), 90% to 99% lost (poor), more than 99% lost (functionally extinct). Ecoregion boundaries are from Spalding and colleagues (2007). Not all regions with oysters could be assessed because of a lack of data (see text).

For U.S., We Examined the Decline in *C. virginica* in GOM, East Coast: *Reef Area and Biomass Saw Significant Declines*

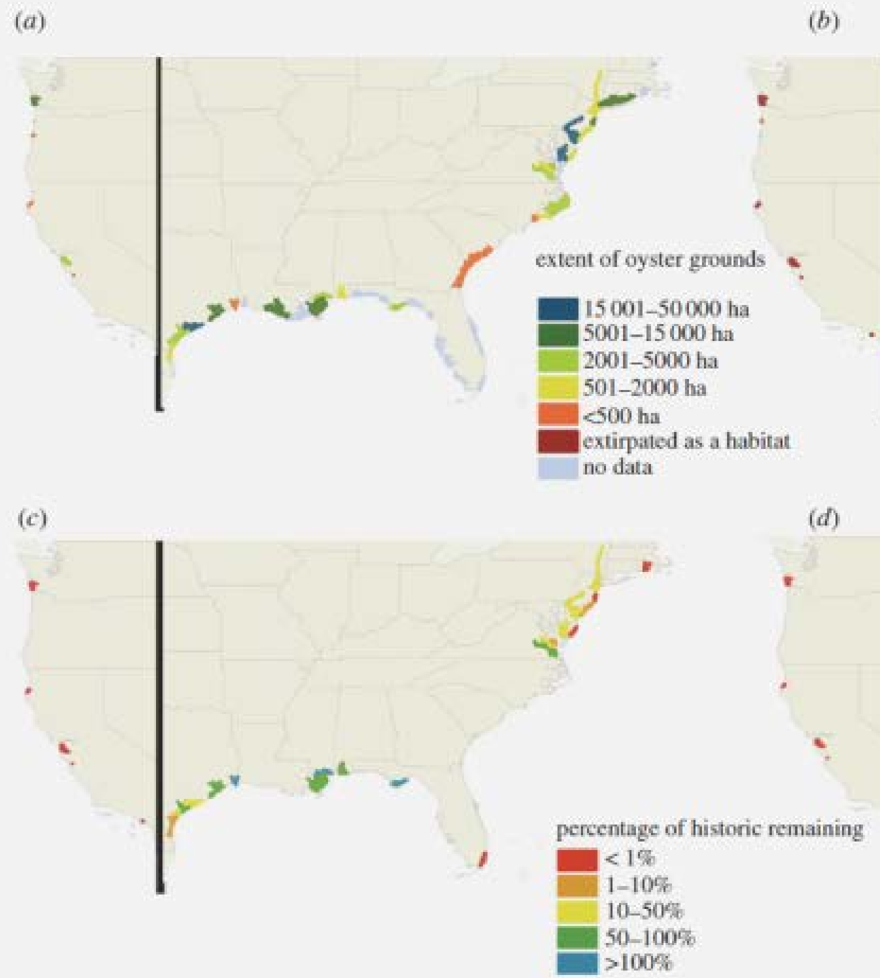


Figure 1. Maps illustrating: oyster ground areal extent (*a*) historically and (*b*) presently in estuaries in the US and the percentage change in (*c*) oyster ground extent and (*d*) oyster biomass in estuaries for which comparable historic and modern data were available.

Overall

REEF AREA

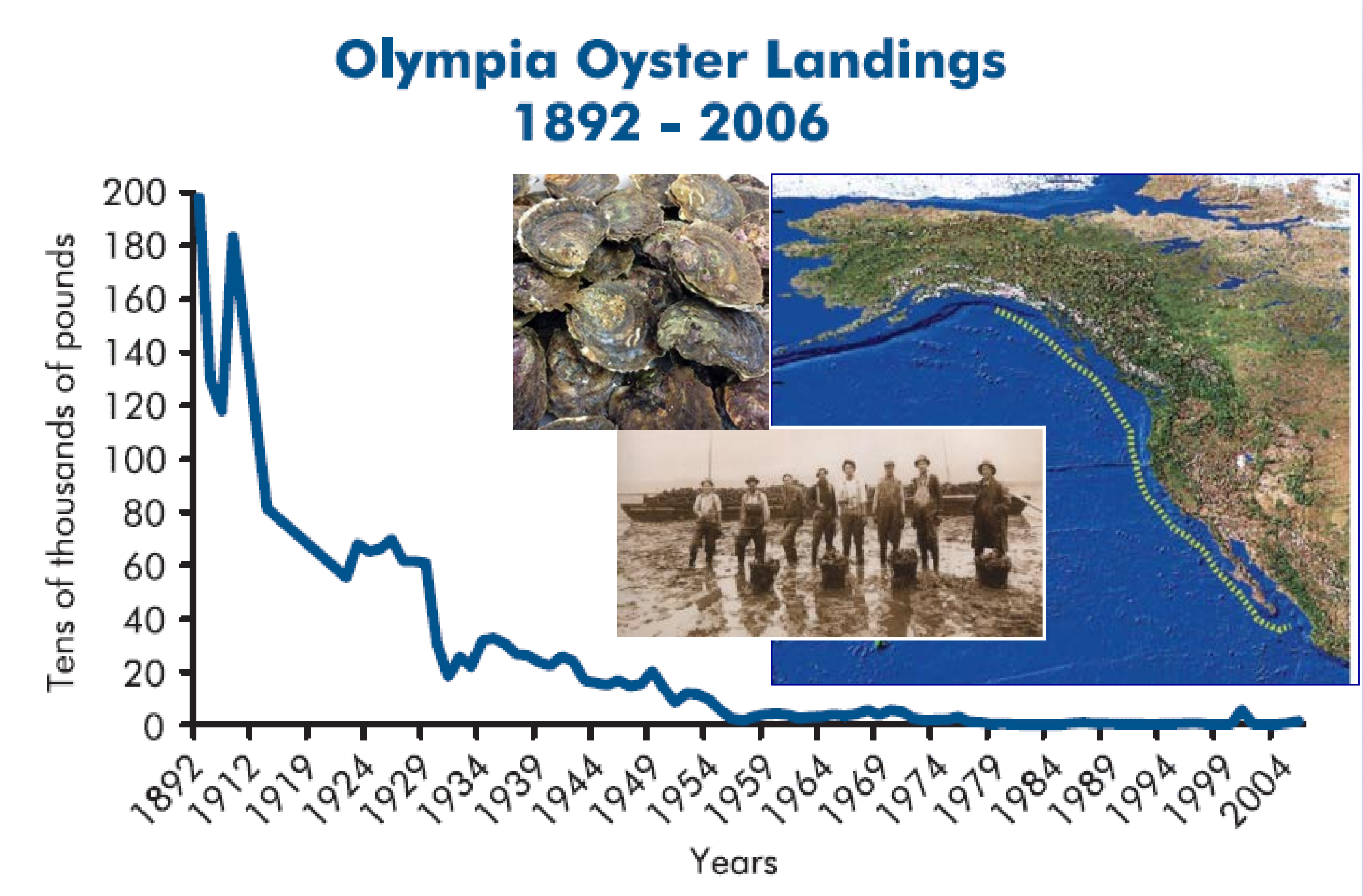
↓ ***64%***

BIOMASS

↓ ***88%***

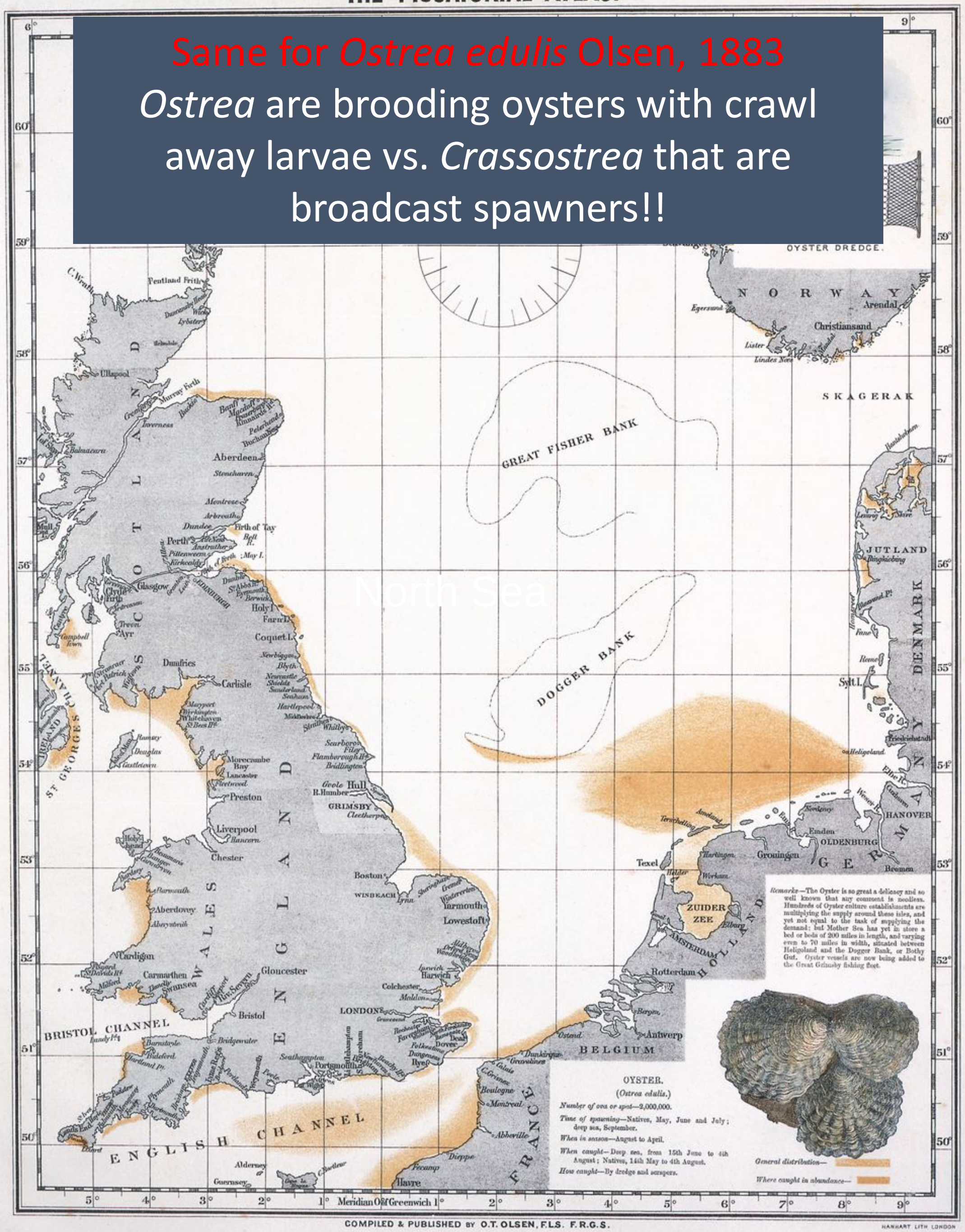
From: Zu Ermgassen et al. 2012, Proc. Royal Soc. B 279:

WA Oyster, *Ostrea lurida* Landings

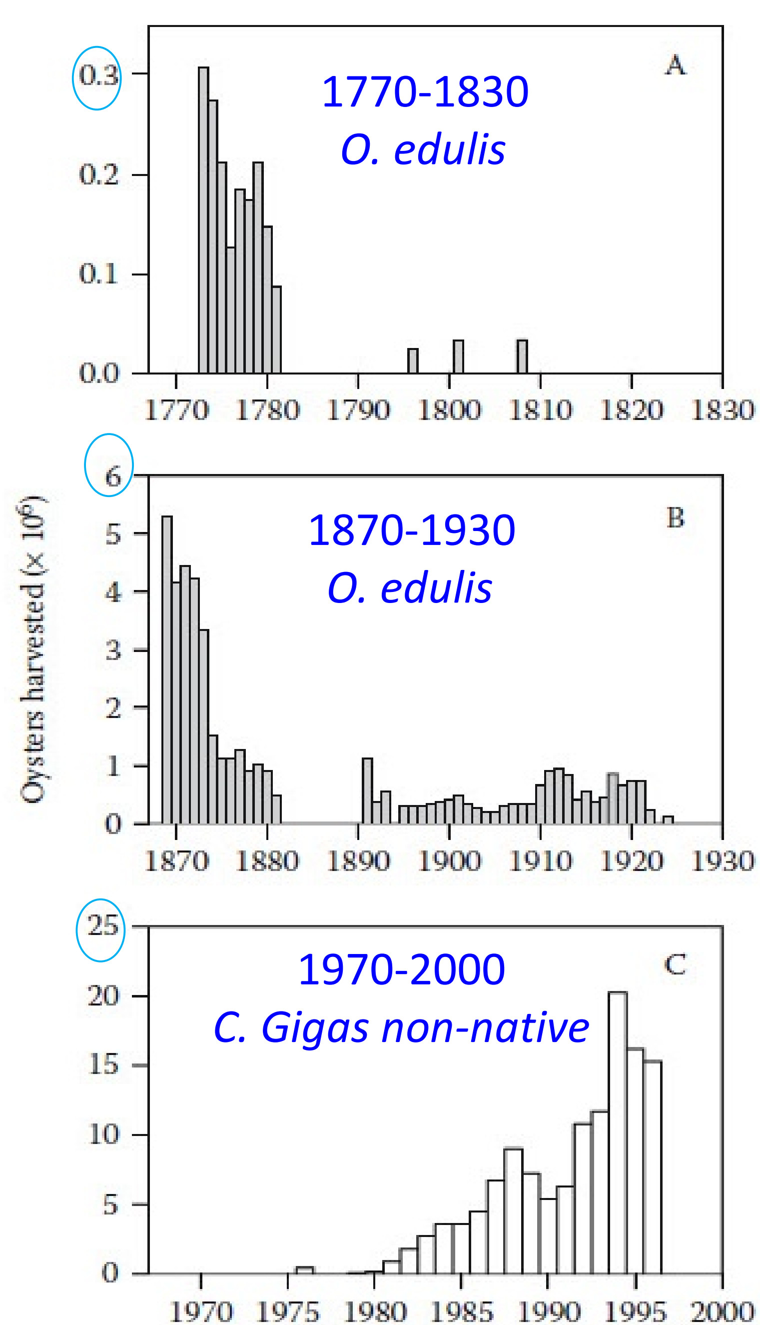


Same for *Ostrea edulis* Olsen, 1883

Ostrea are brooding oysters with crawl away larvae vs. *Crassostrea* that are broadcast spawners!!



Ann. Landings *O. edulis* & *C. gigas* in Frisian Wadden Sea

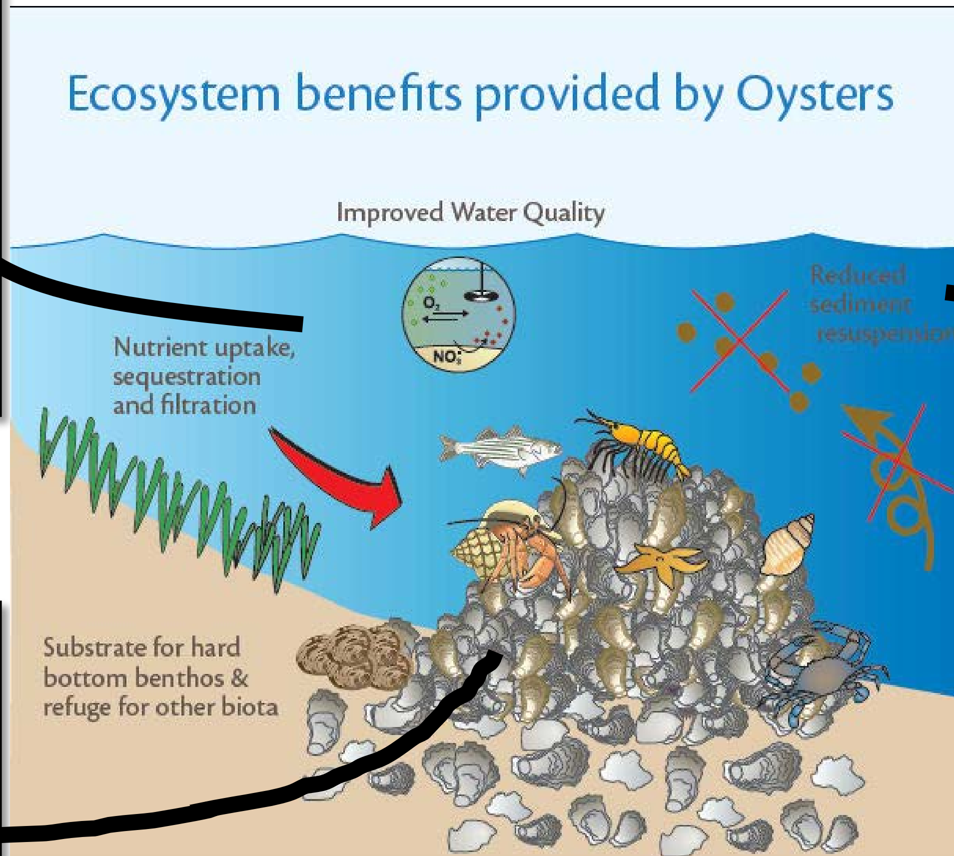


Now All on Same Page as to the Role of Oysters

- Foundation species
- Habitat engineer
- Nutrient cycling and storage
- Important commercial species

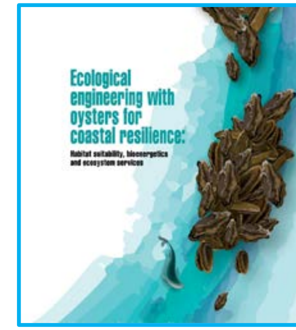
Water quality
- Filter up to 190 l per day
- 286 oysters m^{-2} can remove:
  - 378 kg TN
  - 54 kg TP
  - 10,934 kg TC ha^{-1}

Higgins et al. 2011, JEQ 40



http://chesapeakebay.noaa.gov/oysters/oyster-reefs

Modified from: 2015 NAS talk: La Peyre Pollack, Geiger



Shore protection
- Trap sediments
- Alter energy
- Affect other habitats

Meyer et al. 1997; Piazza et al. 2005; Chowdhury et al. 2019

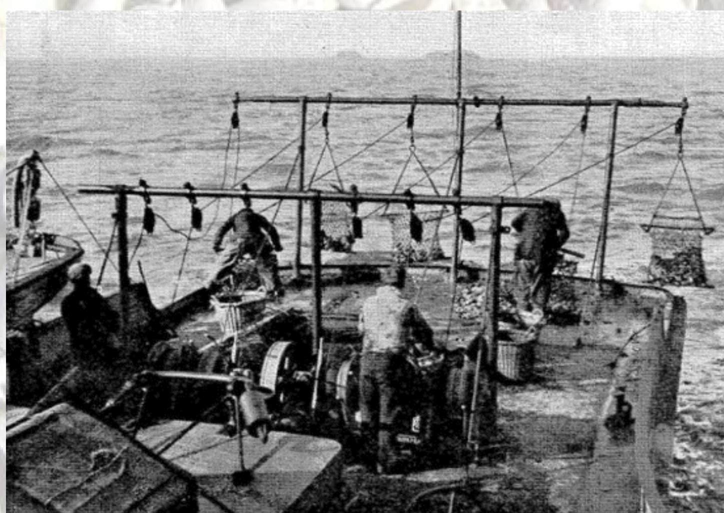
Habitat
- 10 m^2 of oysters = 2.6 kg yr^{-1} augmented 2° production

Peterson et al. 2003

Total Services: $5.5-99k ha/yr.

Grabowski et al. 2012

Now Impetus to Protect, Enhance, and Restore Oysters, Shorelines



"The preservation of oyster beds is as much the role of the State as preservation of forests."(K.A. Möbius,1877)

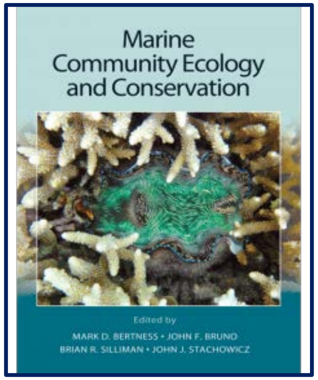
Photos from : Heaven on a Half Shell; FL Archives; Gercken & Schmidt; Chowdhury

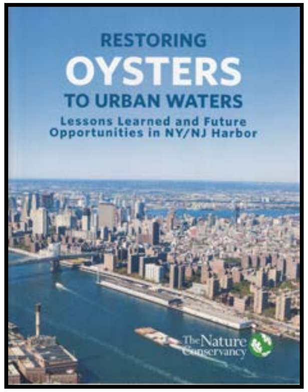
Need to Agree on Definition for "Restoration"

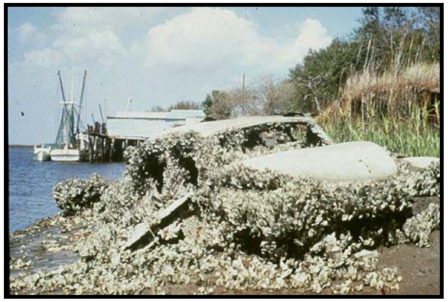
TNC-NOAA's "restoration" definition close to the National Research Council's definition in its '*Restoration of Aquatic Ecosystems*' doc:

1. "Restoration" defined as: *the return of an ecosystem to a close approximation of its condition prior to disturbance.*
2. If restoration is to be successful, both the structure and the function(s) must be recreated.
3. Recreating "form" without "function(s)" is not "restoration".
4. **However, we lack clear definitions of either operational or functional success at this level. Failure easy, success harder to define and quantify.**

Recent Definition
Ecological restoration (Gann et al., Rest. Ecol. 2019). The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.







Want to Avoid at All Costs!

Recruit- vs. Substrate-limited Oyster Populations

- Numerous factors come into play as a function of where sites sit on this continuum
- Two not mutually exclusive (or both)
- No clear guidelines/data for evaluating sites
- One relatively low tech, the other a high tech, land-based capital investment (hatcheries, dedicated vessels, personnel, etc.)





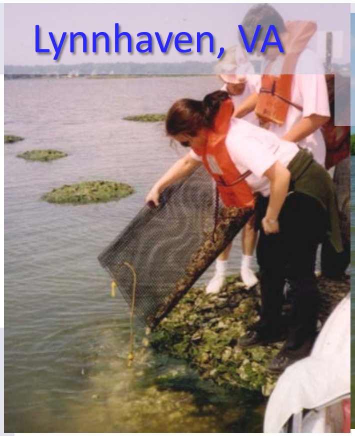


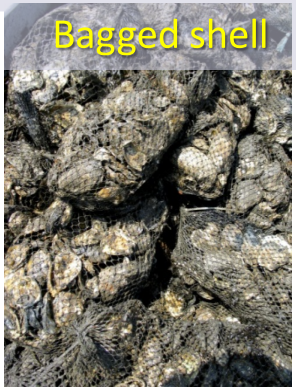
Restoration Scale

Large-Scale

Medium-Scale

Small- (Comm.) Scale



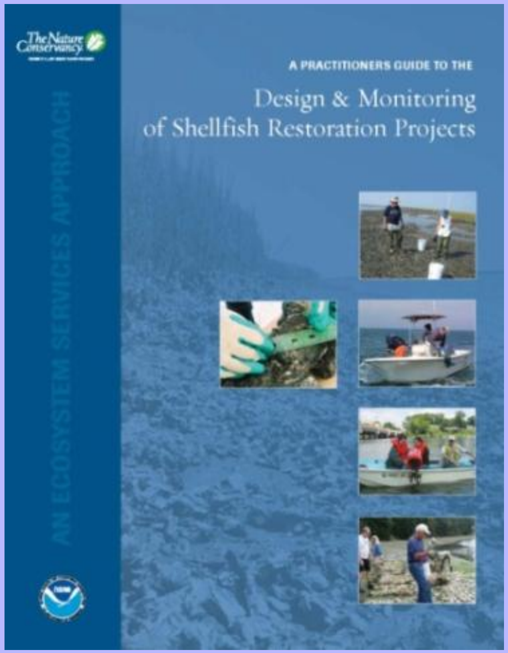


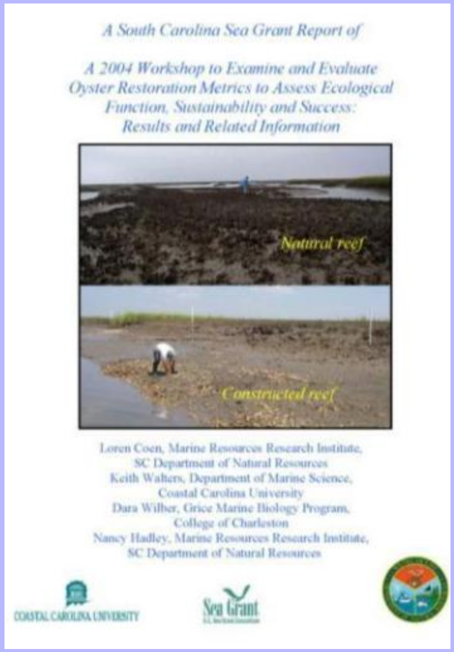
Numerous Restoration Approaches

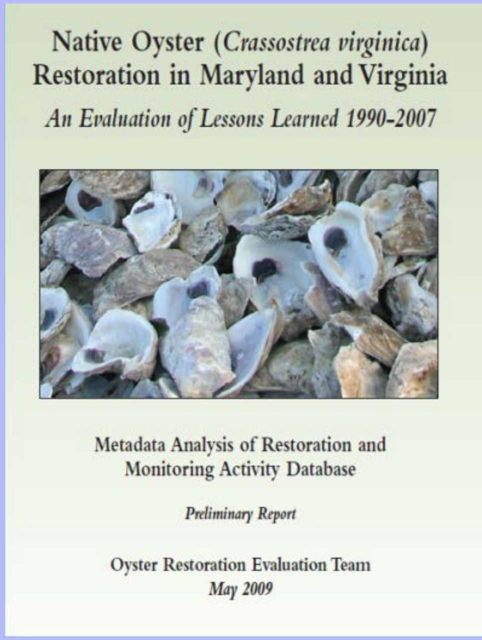
Oyster Restoration Might Include:

- Addition of appropriate substrate for natural settlement and growth (most places)
- Seeding reefs with juvenile oysters or spat-on-shell (=SOS) to jump start restoration (e.g., NYC)
- Creation of “spawner” sanctuaries in closed areas (e.g., Great Wicomico River, VA) for oysters, scallops, conch, etc.

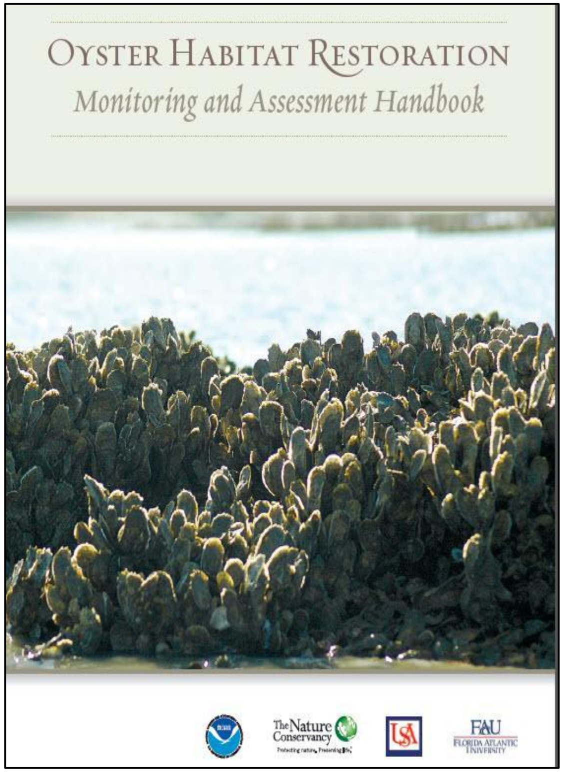
Now Extensive Literature in U.S. for Oyster Restoration & Monitoring: Please Read Them!

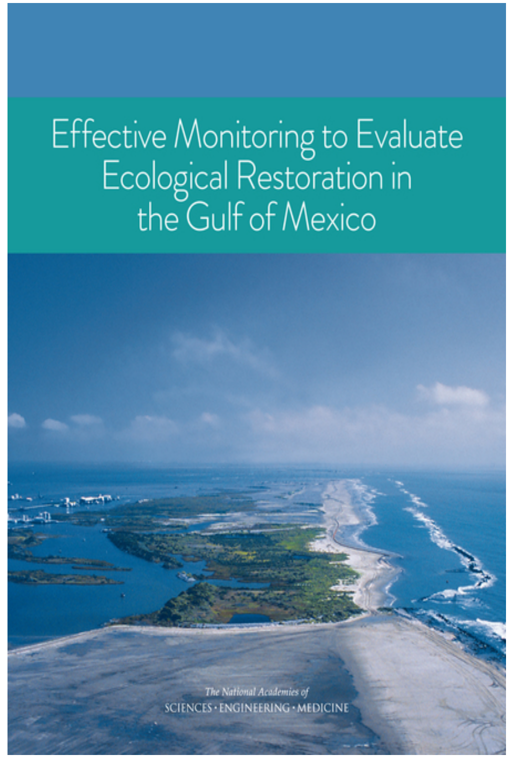


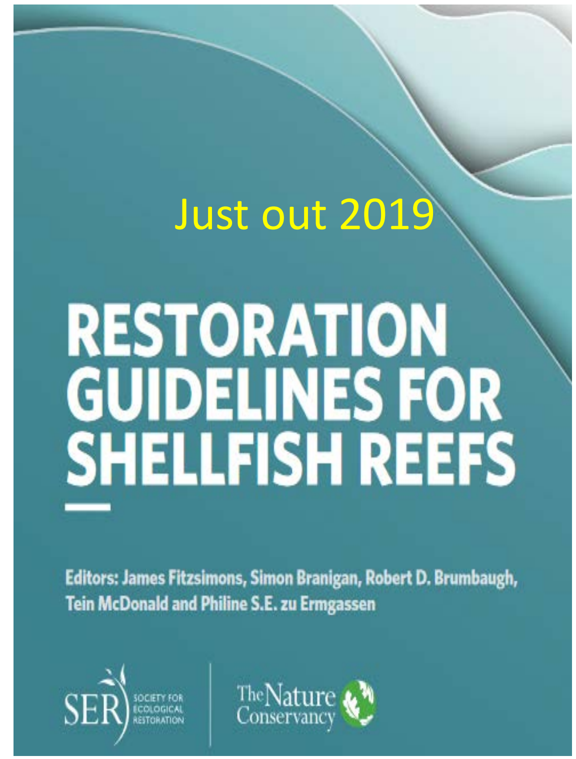




Now Extensive Literature in U.S. for Oyster Restoration & Monitoring: Cont. Please Read Them!







Journal of Shellfish Research, Vol. 30, No. 3, 719–731, 2011.

LESSONS LEARNED FROM EFFORTS TO RESTORE OYSTER POPULATIONS IN MARYLAND AND VIRGINIA, 1990 TO 2007

VICTOR S. KENNEDY,[1*] DENISE L. BREITBURG,[2] MARY C. CHRISTMAN,[3] MARK W. LUCKENBACH,[4] KENNEDY PAYNTER,[5] JONATHAN KRAMER,[6] KEVIN G. SELLNER,[7] JODI DEW-BAXTER,[8] CHERIE KELLER[9] AND ROGER MANN[10]
[1]*Horn Point Laboratory, University of Maryland Center for Environmental Science, Box 775, Cambridge MD 21613;* [2]*Smithsonian Environmental Research Center, Edgewater, MD 21037;* [3]*MCC Statistical Consulting LLC, Gainesville, FL 32605;* [4]*Eastern Shore Laboratory, Virginia Institute of Marine Science, Wachapreague, VA 23480;* [5]*Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Box 38, Solomons, MD 20688, and Department of Biology, University of Maryland, College Park, MD 20742;* [6]*Maryland Sea Grant, University System of Maryland, College Park, MD 20740;* [7]*Chesapeake Research Consortium, Inc., Edgewater, MD 21037;* [8]*Versar Inc. ESM, Columbia, MD 21045;* [9]*University of Florida, Department of Biology, Gainesville, FL 32611;* [10]*Virginia Institute of Marine Science, Gloucester Point, VA 23062*

ABSTRACT A century-long decline of the fishery for the Eastern oyster *Crassostrea virginica* (Gmelin, 1791) in Maryland and Virginia stimulated numerous efforts by federal, state, and nongovernmental agencies to restore oyster populations, with limited success. To learn from recent efforts, we analyzed records of restoration and monitoring activities undertaken between 1990 and 2007 by 12 such agencies. Of the 1,037 oyster bars (reefs, beds, or grounds) for which we obtained data, 43% experienced both restoration and monitoring, with the remaining experiencing either restoration or monitoring only. Restoration activities involved adding substrate (shell), transplanting hatchery or wild seed (juvenile oysters), bar cleaning, and bagless dredging. Of these, substrate addition and transplanting seed were common actions, with bar cleaning and bagless dredging relatively uncommon. Limited monitoring efforts, a lack of replicated postrestoration sampling, and the effects of harvest on some restored bars hinders evaluations of the effectiveness of restoration activities. Future restoration activities should have clearly articulated objectives and be coordinated among agencies and across bars, which should also be off limits to fishing. To evaluate restoration efforts, experimental designs should include replication, quantitative sampling, and robust sample sizes, supplemented by pre- and postrestoration monitoring.

KEY WORDS: Chesapeake Bay, management, Maryland, monitoring, oyster fishery restoration, Virginia, *Crassostrea virginica*

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Monitoring is Critical to Evaluate Project Effectiveness

Project-Level Monitoring Plan

Process Guidance
Determine:

Restoration Goals

Measurable Restoration Objectives

Research/Management Question(s)

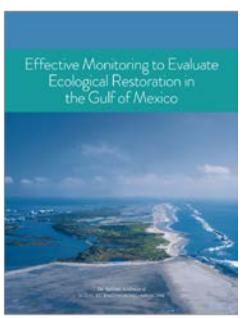
Using Conceptual Models as Guide

Purpose for Monitoring:

- Construction Monitoring
- Performance Monitoring
- Monitoring for Adaptive Management

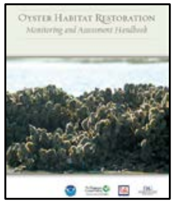
Has been suggested that projects allocate at least 10% of project budget to monitoring!



Modified from: NAS, 2017. Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico, The National Academies of Sciences, Engineering, and Medicine. Washington, D.C., 219pp.

“Universal” Monitoring Metrics



“Universal” metrics are useful to assess project performance, as well as comparisons between projects & regions. Need to assess both natural (=reference), as well as constructed (= restored) sites (= reefs, footprints).

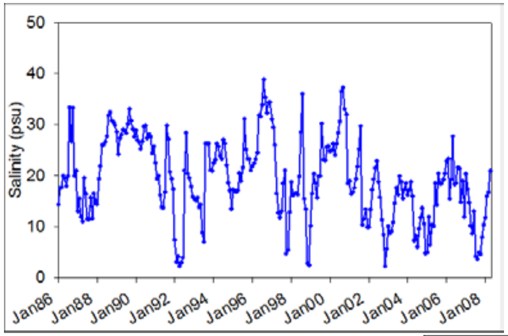
✓ Primary Oyster Metrics

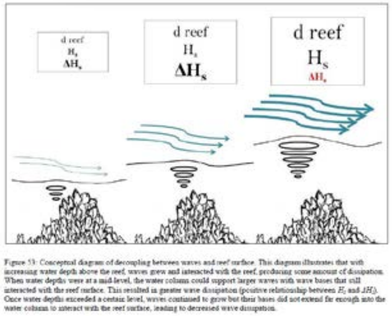
1. Presence/absence
2. Spatial extent
3. Density
4. Size-frequency

Photos: L. Coen

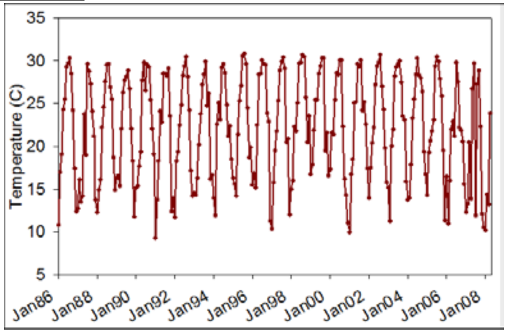
✓ Environmental Metrics

1. Salinity Regime (high freq., not just means)
2. Temperature (interactive)
3. Sediment Budget (incl. burial, accret., loss)
4. Dissolved Oxygen (as an aperiodic limiter for subtidal primarily)
5. Wind, waves, exposure (esp., intertidal oysters), tidal range





TPWD data for Aransas Bay, TX

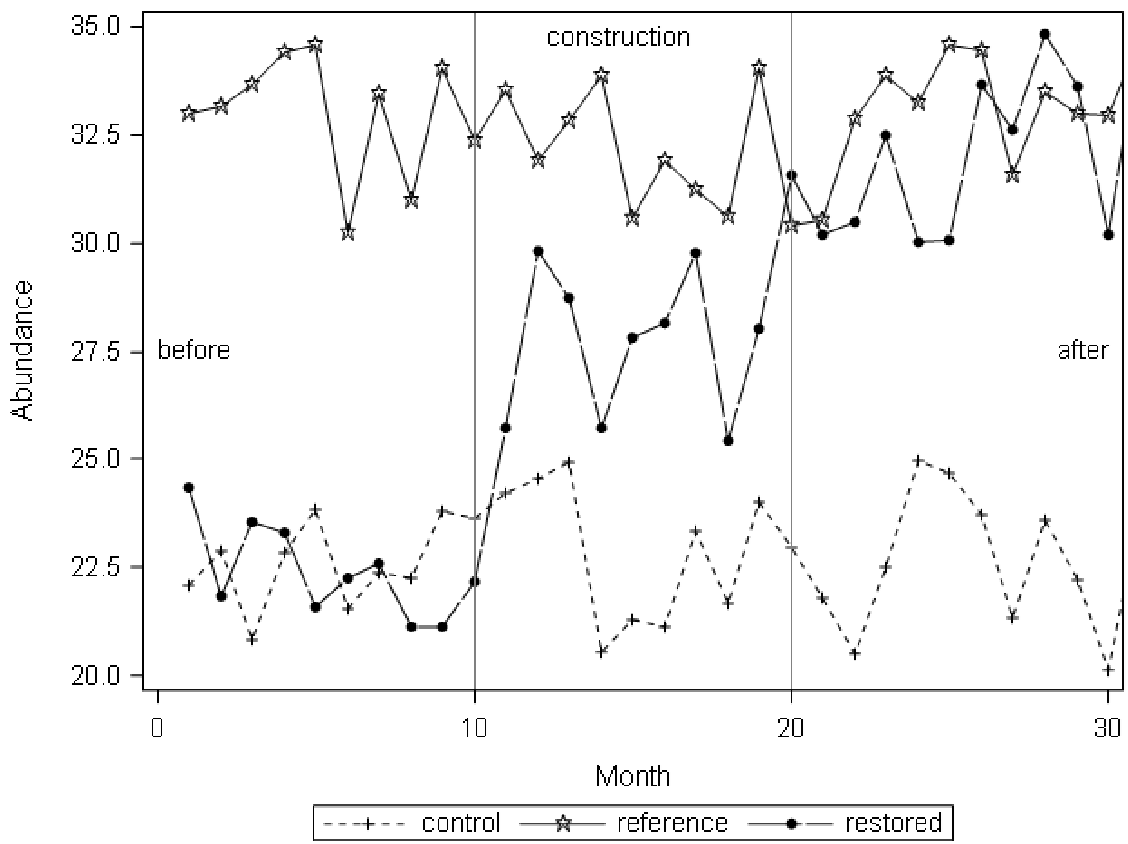


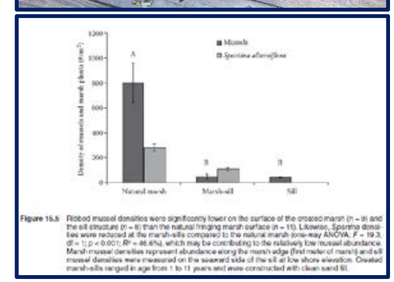
✓ Reef Attributes

1. Reef Areal Dimension
   a. Project footprint
   b. Reef area
2. Reef Height over time

Modified from: Taube 2013; **Baggett et al., 2014;** 2015 NAS talk: La Peyre Pollack, Geiger; NAS 2017

A Hypothetical Example of a Performance Monitoring Dataset (C, E, R) Through Time

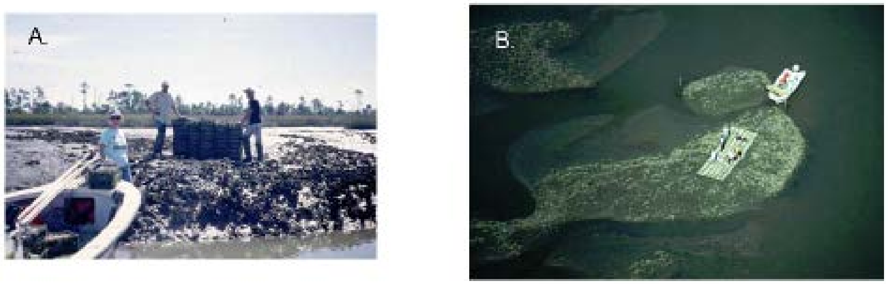




Tracking three ‘areas’ or treatments: Control, Reference, and Restored

Intertidal Oyster Recruitment Trajectory

Assessing oysters over time: natural (ref.) vs. experimental (=restored) through time



Appendix 1. A., reef construction; B, Inlet Creek aerial during construction in 1994; C., Toler's Cove aerial immediately after reef construction (arrows indicate reefs D-F); D., Inlet Creek aerial at time of reef construction (arrows indicate reefs A-C).

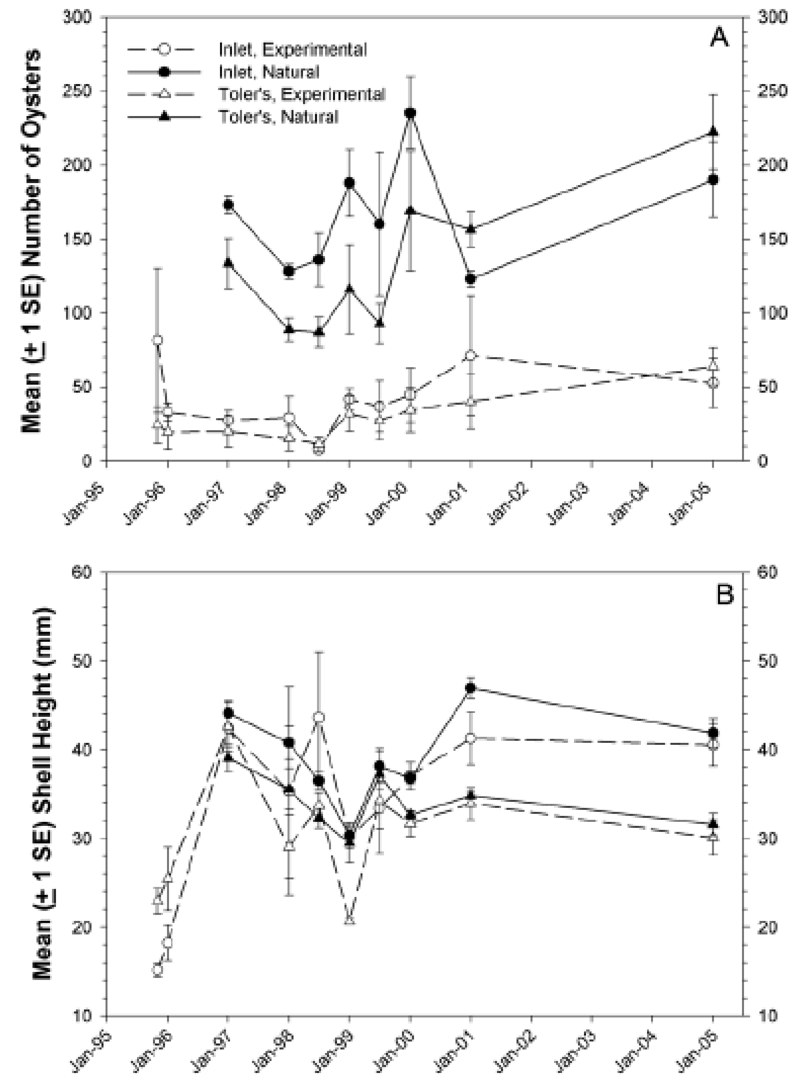


Figure 24. A: Mean (+ 1 SE) number of oysters (N = 9 per treatment) at both sites from 1995 through 2005 on natural and experimental reefs. B: Mean (+ 1 SE) oyster shell height.

Coen et al. Unpublished data, ORP SC

Reef Restoration Assessments: Powers et al. 2009 (MEPS)

Vol. 389: 159–170, 2009
doi: 10.3354/meps08164

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published September 4

OPEN ACCESS

Success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration

Sean P. Powers[1,*], Charles H. Peterson[2], Jonathan H. Grabowski[3], Hunter S. Lenihan[4]

- 94 reefs: 23 intertidal, 63 subtidal, ages 3 to 30 yrs.
- 88 constructed; 6 were 'natural'
- Very different reef footprint sizes also

Table 2. Success of North Carolina oyster reef sanctuaries as judged by the minimum criteria (vertical structure, live oysters, and 1 yr successful recruitment) and mean density of all oysters >25 mm shell height (SH), oyster biomass, and market-sized oysters (>75 mm SH)

Sanctuary	Minimal: Successful reefs	Minimal: Failed reefs	Minimal: Overall sanctuary	Mean oyster density (no. m^{-2})	Mean oyster biomass (kg m^{-2})	Mean market-size oysters (no. m^{-2})
Intertidal						
Bird Shoals	6	0	Success	210	7.2	142
Middle Marsh I	12	0	Success	205	9.6	105
Middle Marsh II	11	0	Success	227	[illegible]	[illegible]
Subtidal						
Bogue	0	1	Failure	0	[illegible]	[illegible]
Neuse River shallow	14	10	Success	95	[illegible]	[illegible]
Neuse River mid-depth	0	12	Failure	0	[illegible]	[illegible]
Neuse River deep	9	15	Failure	0.25	[illegible]	[illegible]
West Bay	1	0	Success	92	[illegible]	24
Deep Bay	1	0	Success	27	[illegible]	9
Crab Hole	0	1	Failure	0	[illegible]	0
Wanchese	1	0	Success	23	[illegible]	11
Total %	60 % success	40 % failure	64 % success			

Reef Restoration Assessments:
Powers et al. 2009 (MEPS) cont.

Findings

- All intertidal reefs judged ‘successful’; all had oyster densities > subtidal reefs
- Subtidal reefs all deemed failures, either buried or in areas of low DO

However, Metrics Used May be Potentially Flawed

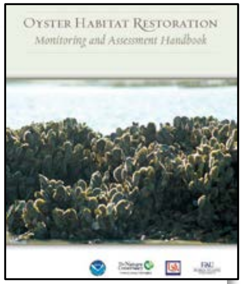
- Biomass estimates included shell wgt., problematic for subtidal vs. intertidal comparisons
- ‘Reference’ reefs or other controls missing
- Reef ages quite variable (3 to 30 yrs.) and confounded

Ancillary or Goal-Oriented Monitoring Metrics

- **Ancillary or Goal-oriented metrics** link to desired endpoints for restored functions or services. Need to assess both natural (= reference), as well as constructed (restored) sites (reefs, footprints).

✓ Ancillary Metrics

1. Shell budget
2. Predators
3. Competitors
4. Condition
5. Reproduction, sex ratio
6. Disease (dermo can be lethal for subtidal oysters if salinities >~20)
7. Non-Natives

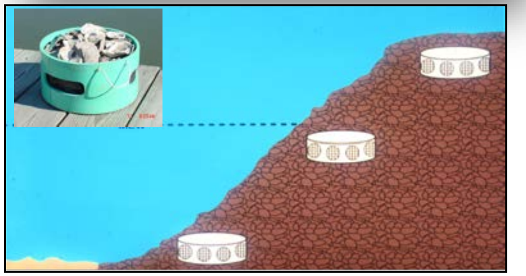


Baggett et al., 2014

Photo: Coen 2014

✓ Goal-Oriented (Services) Metrics

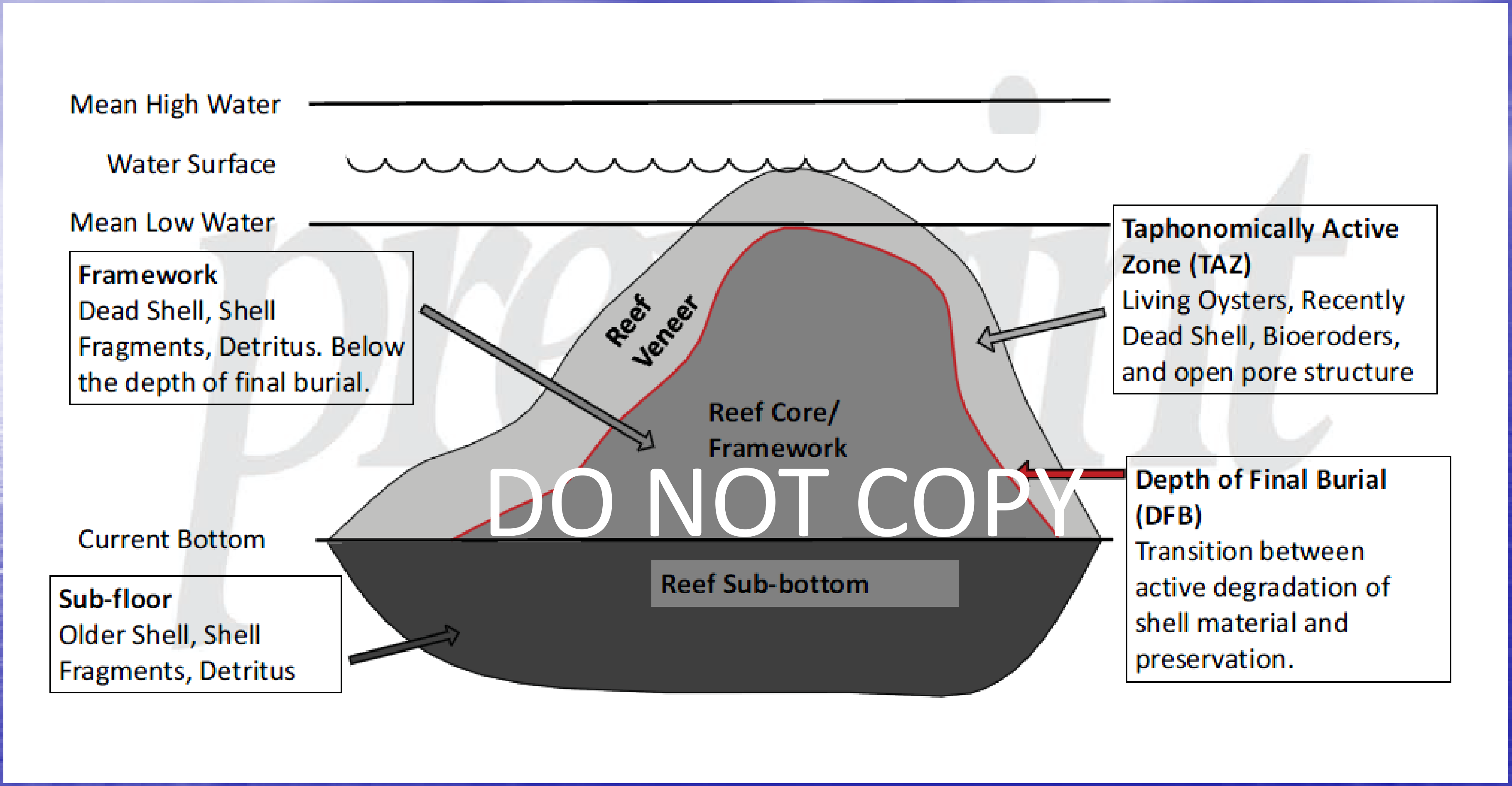
1. Landings oysters or fish (if fisheries goal)
2. Neighboring reef dynamics
3. Community data – faunal
4. Seagrass or marsh growth
5. Water clarity/quality, etc. (filtration, *in situ* fluor.)
6. Waterfowl usage
7. Shoreline budget/elevation (erosion or accretion)
8. Sediment stabilization, erosion facilitate adjacent (vegetated) habitats
9. Human use – for recreation



Modified from: Baggett et al., 2014; 2015 NAS talk: La Peyre Pollack, Geiger; NAS 2017; Walles et al. 2016a,b; Coen, Unpubl., Chowdhury et al. 2019

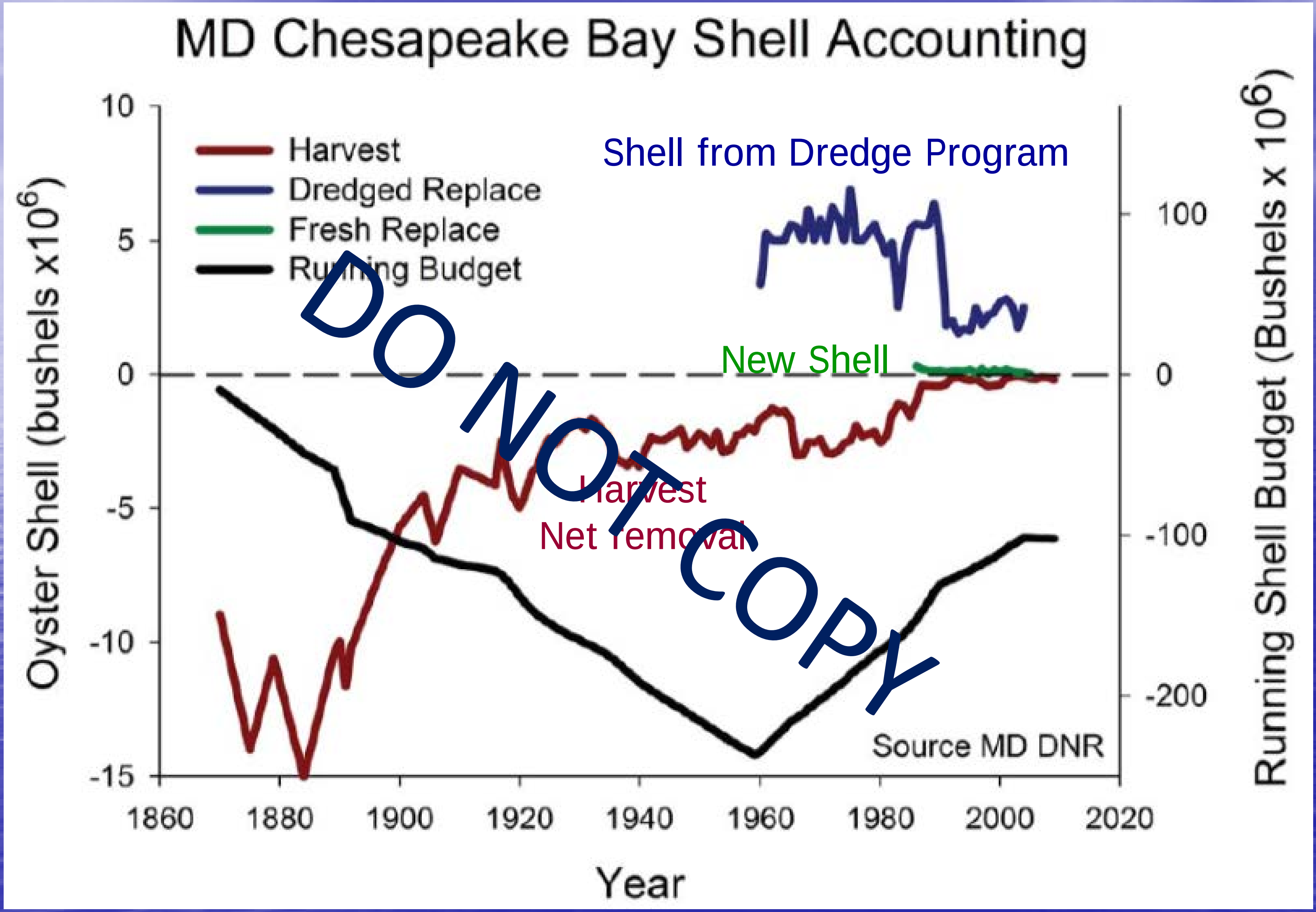
All started with 1 shell in the mud, perhaps a decade or more ago?

Conceptual Depiction of Oyster Reef Structure



From: Waldbusser et al. 2013, Ecology; adapted from Hargis and Haven, 1999

Oyster Shell Accounting of Harvest/Replacement in MD



Removed vs. Replaced

From: Waldbusser et al., 2013. Ecology 94:895-903.

The GEMS Project

Gulf of Mexico Ecosystem Service Logic Models and Socio-Economic Indicators

Linking project impacts to economic, health and wellbeing benefits for people

Lydia Olander[1], Chris Shepard[2], Heather Tallis[2], David Yoskowitz[3], **Kara Coffey[3]**, Jill Hamilton[1], Lauren Hutchison[3], Sara Mason[1], Katie Warnell[1], Katya Wowk[3]

[1]Nicholas Institute for Environmental Policy Solutions at Duke University, [2] The Nature Conservancy, [3] Harte Research Institute for Gulf of Mexico Studies at Texas A&M University- Corpus Christi

Introduction to the project

Challenge

Billions of dollars will be spent on restoration of Gulf ecosystems over the coming decades, but there is no shared platform to guide assessment and reporting of restoration progress and effectiveness for the broad set of environmental, social, and economic goals shared by the many institutions working in the Gulf.

Solution

Effective project planning and evaluation can be facilitated by a set of common logic models and socio-economic indicators and metrics relevant across projects, programs, and locations.

Goals

- Help streamline and simplify application and reporting processes
- Simplify and improve reporting of impacts of projects
- Create a transferable tool for implementation of restoration approaches to extend the consistency, efficiency, and reporting benefits of this approach

Process

This project will use Ecosystem Service Logic Models (ESLMs) as a framework to think about ecosystem services and how they can be monitored in relation to Gulf restoration projects. These models, developed for common restoration techniques, will form the basis for a series of workshops held at 5 sites across the Gulf (Figure 4), where participants will use model outcomes to develop socio-economic indicators and metrics important at their site. Regional Gulf workshops will collate information from all local workshops, and produce ESLMs and indicators that are relevant across the Gulf. We will cover two different restoration strategies during the course of the project.

This research is supported by the Gulf Research Program of the National Academy of Sciences, Engineering, and Medicine under award number 2000008884.

Ecosystem Service Logic Models

Ecosystem Service Logic Models represent the way a management action cascades through an ecological system and results in ecosystem services and other human welfare impacts. (Figure 1). These models can:

- Provide a consistent platform for multiple restoration approaches
- Help increase monitoring efficiency, when standardized
- Help identify uncertainties and knowledge gaps

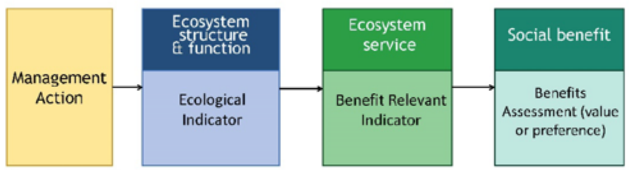


Figure 1. Ecosystem Service Logic Model Framework

Socio-Behavioral-Economic Indicators

A socio-behavioral-economic indicator (Figure 2):

- Describes characteristics, attributes, and/or behaviors of individuals, social groups or communities
- Is defined as a single measurable variable that quantifies the state or quality of an attribute in the world (e.g. recreational fish landing → number or pounds of oysters harvested)

Figure 2. Socio-behavioral-economic indicator model

Oyster Reef Restoration: Ecosystem Service Logic Model

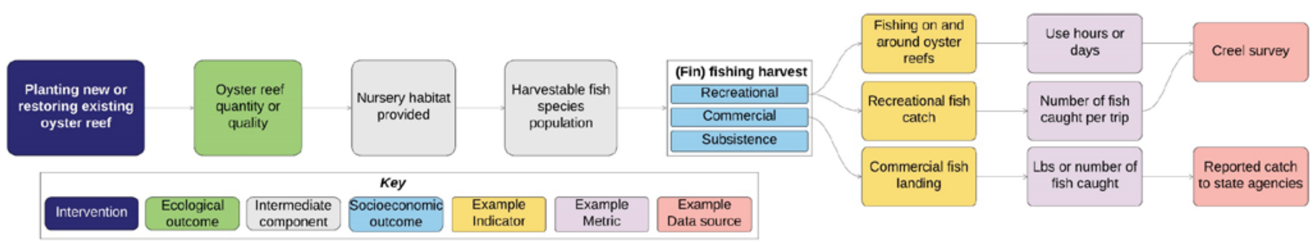


Figure 3. Draft component of Ecosystem Service Logic Model

Study Sites

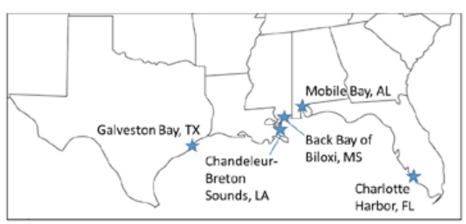


Figure 4. Map of GEMS project locations

Timeline

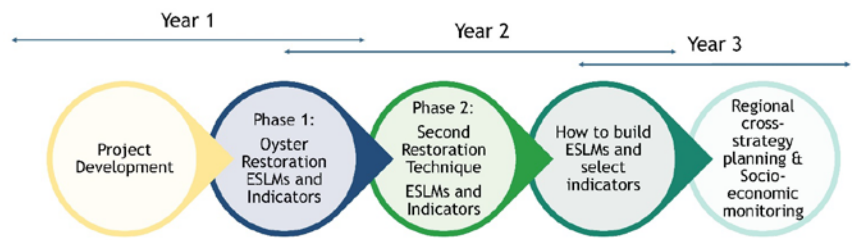


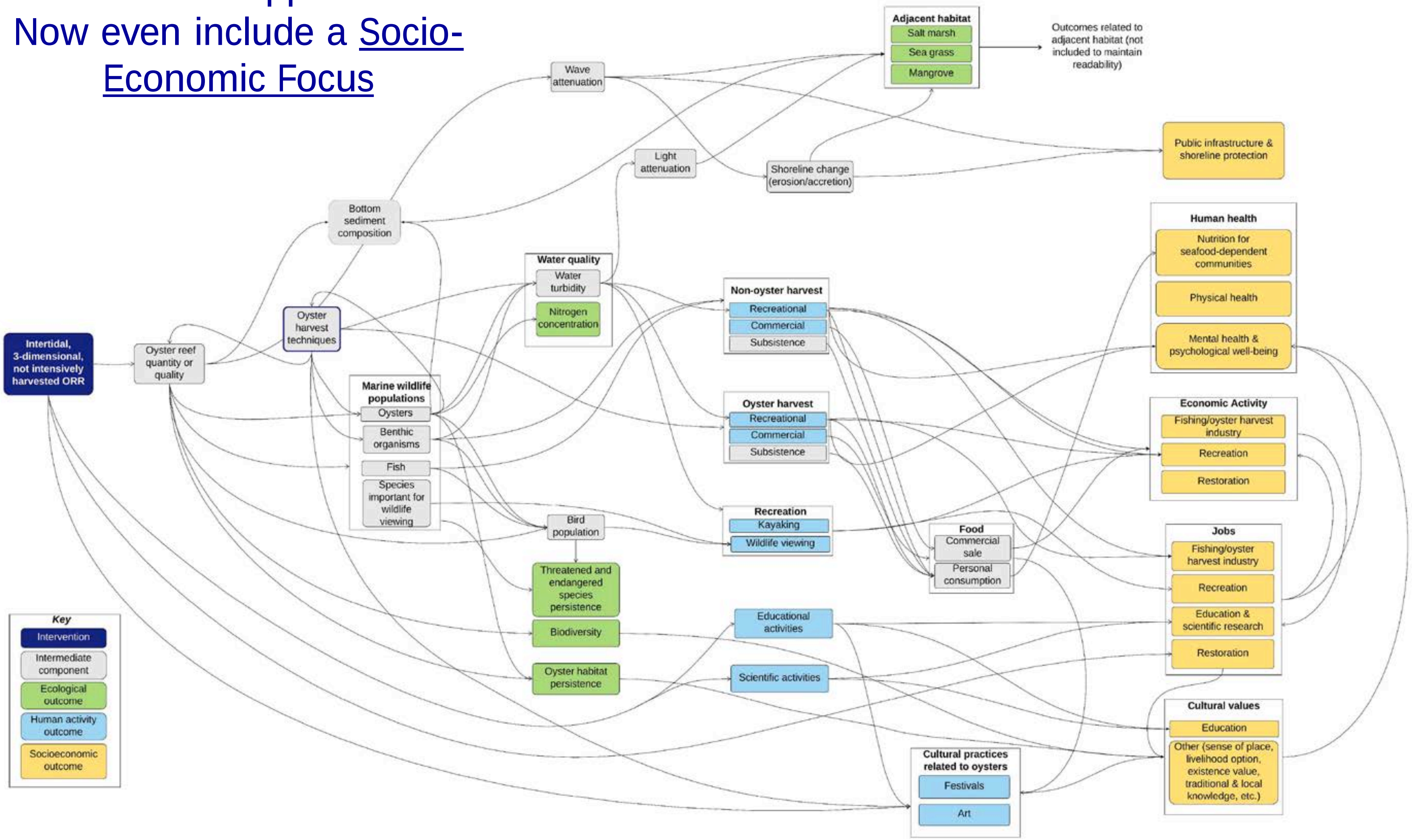
Figure 5. Timeline of GEMS Project

Gulf of Mexico Ecosystem Service Logic Models and Socio-Economic Indicators (GEMS)

Ecosystem Service Logic Model (ESLM) for Oyster Reef Restoration

Technique 4: Intertidal, 3-dimensional, not intensively harvested
Implemented in all focal estuaries

Intertidal Approach
Now even include a Socio-Economic Focus



See https://nicholasinstitute.duke.edu/project/gems/oyster-reef-restoration/oyster-ecosystem-service-logic-model

Oyster Reef Restoration Trajectories for Resident Fauna and Oysters VA and SC

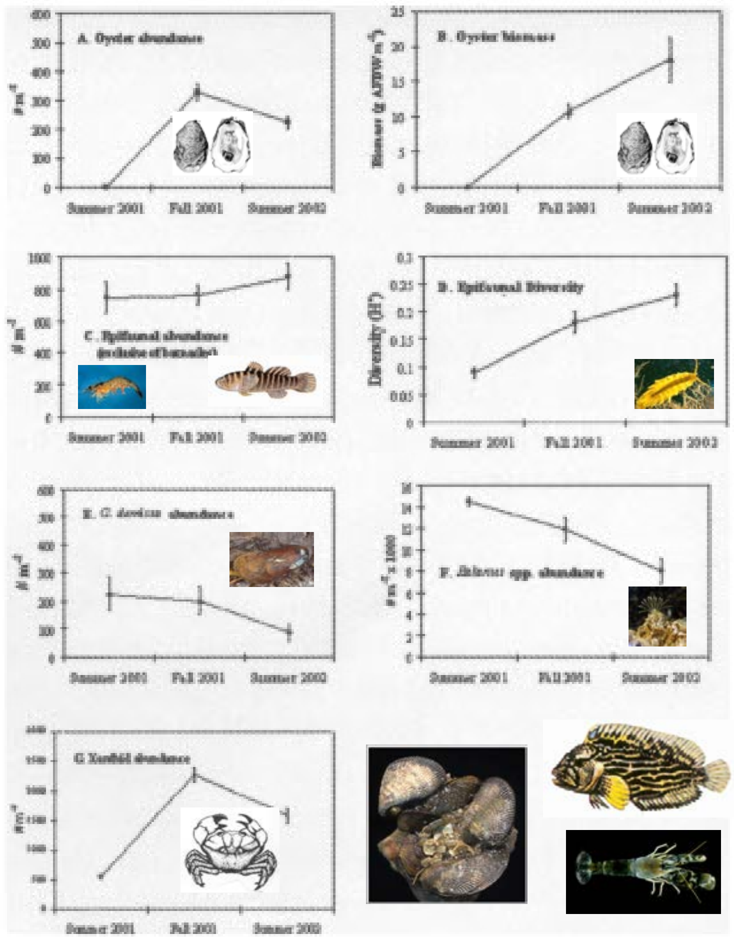


Figure 5. Temporal patterns of (A) oyster abundance, (B) oyster biomass, (C) epifaunal abundance, (D) epifaunal diversity, (E) *Geukensia demissa* abundance, (F) *Balanus* spp. abundance, and (G) xanthid crab abundance on the reefs in the Rappahannock River, Chesapeake Bay, Virginia. Values are means ± SE by reef site.

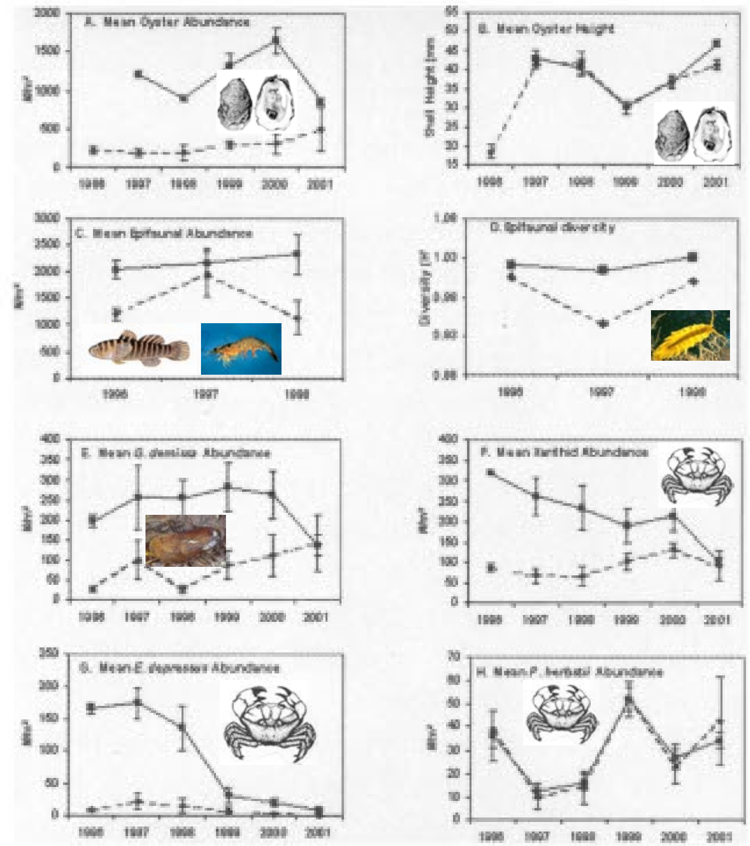


Figure 7. Temporal patterns for (A) mean oyster abundance, (B) mean oyster height, (C) mean epifaunal abundance, (D) epifaunal diversity, (E) mean *Geukensia demissa* abundance, (F) mean xanthid crab abundance, (G) mean *Eurypanopeus depressus* abundance, and (H) *Panopeus herbstii* abundance for experimental (dashed lines) and natural (solid lines) reefs in Inlet Creek, Charleston Harbor, South Carolina. All values are means ± SE by reef type (experimental vs. natural) except for D, epifaunal diversity.

From: Luckenbach et al. 2005, J. Coastal Res. SI 40:

Large-Scale Bay-Wide Effort: 1000s of acres, and Billions $$$

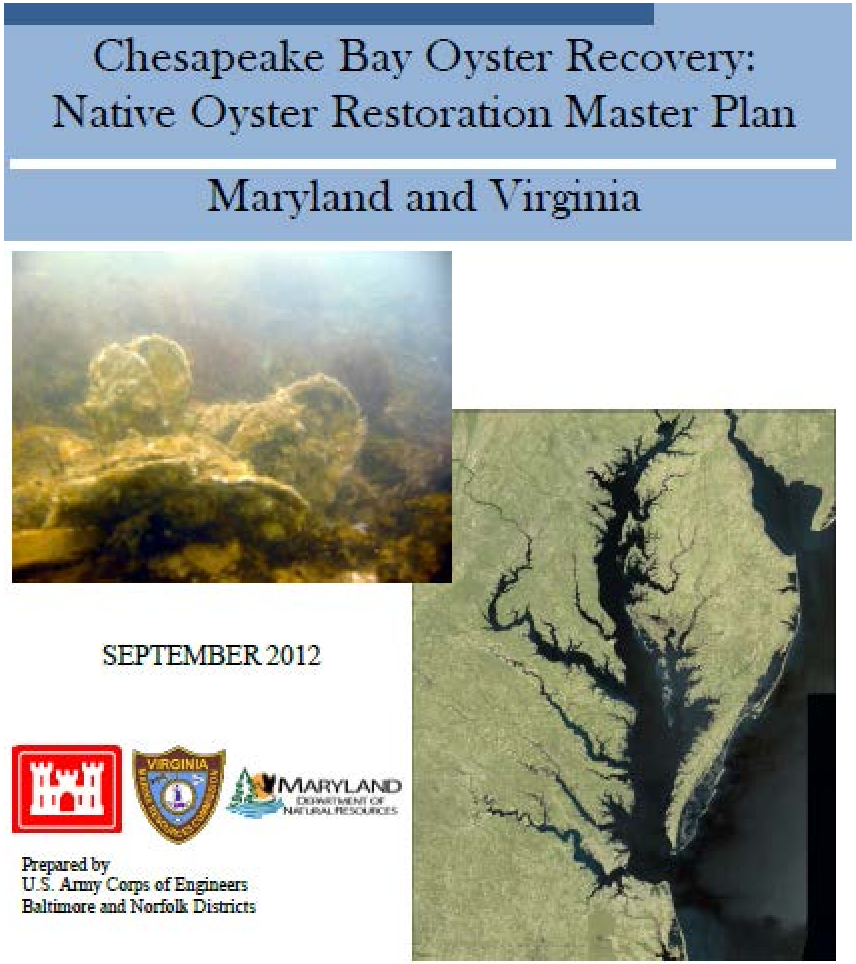


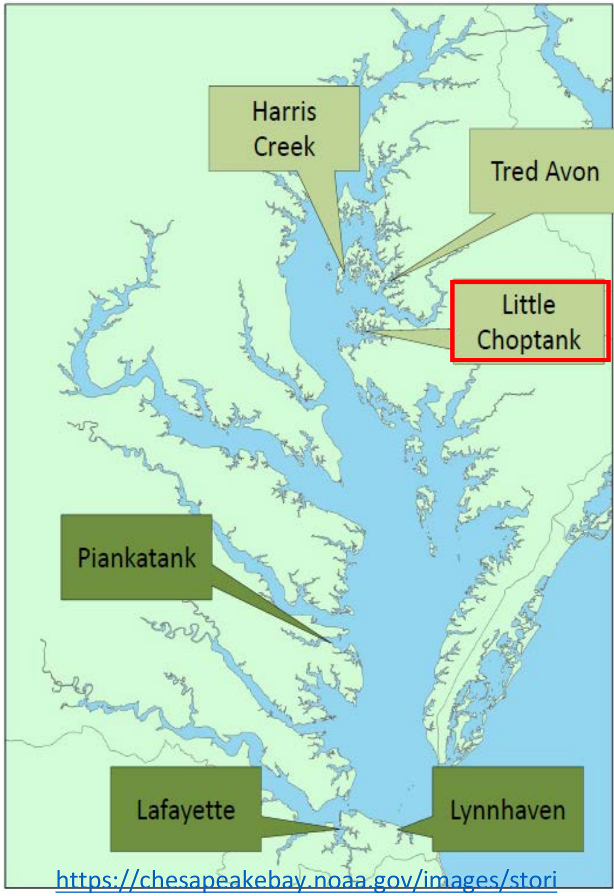
Table ES-2. Projected Restoration Costs

	Number of Tier 1 Tributaries	Oyster Reef Restoration Target (acres)	Total Estimated Low Range Cost	Total Estimated High Range Cost
Maryland Tier 1	14	7,300-14,600	$0.87 billion	$2.85 billion
Virginia Tier 1	10	10,100-20,400	$0.97 billion	$3.63 billion
Scenario 1- All Tier 1 Tributaries	24	17,400–35,000	$ 1.85 billion	$ 6.50 billion
Scenario 2- Salinity-based restoration	24	18,200	$ 1.99 billion	$ 3.42 billion
Scenario 3- E.O. Implementation	20	14,400–28,400	$ 1.56 billion	$ 5.38 billion

Planting fossil shell for restoration in the Lynnhaven River, VA. Shell is blown from barges using high-powered water cannons. Photograph provided by USACE-Norfolk.

Chesapeake Bay Oyster Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success of Restored Oyster Reef Sanctuaries by the Oyster Metrics Workgroup (OMW)

- USACE projected that 8-16% of 'historic' oyster bottom needs to be restored per tributary to effect significant change.
- Oyster restoration (i.e. planting of substrate or spat-on-shell) occurs at the level of a reef (= oyster bar).
- Lack clear definitions of either operational or functional success at this level.
- **Complete failure** is easily observed as a lack of recruitment to planted shell, high mortality of planted seed, or the degradation and burial of shell before a population becomes established.
- **Success,** is harder to define and quantify.



https://chesapeakebay.noaa.gov/images/stories/habitats/icsrwestby.pdf

Overall Goal:

MD-VA agreed to large-scale oyster restoration efforts in 20 tributaries. At this large-scale, should see effects.

Submitted to: the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program, Dec. 2011
see https://chesapeakebay.noaa.gov/images/stories/fisheries/keyFishSpecies/oystermetricsreportfinal.pdf

For Example, Little Choptank River (MD), Reference Assessment Large-scale Oyster Restoration (Reef L68): Universal” Monitoring Metrics

Biological Metrics (oyster density, biomass, multiple year class, shell budget) data for Little Choptank reefs for 2017

Treatment Name	Reef-building substrate added?	Substrate Material	Cap Material	Reef seeded?	Notes
Reference	No	None	None	No	Did not meet oyster density success criteria; would typically require restoration, but none was undertaken so reefs could serve as reference sites.
Premet	No	None	None	No	Assumed to have met the oyster density success criteria prior to restoration, so no restoration activities undertaken.
Seed Only	No	None	None	Yes (spat-on-shell)	null
Florida fossil shell	Yes	Fossil shell	None	Yes (spat-on-shell)l	null
Stone topped with mixed shell	Yes	Amphibolite (stone)	Mixed shell (scallop, conch, and clam)	Yes (spat-on-shell)	null

Table 1: Description of restoration treatment types for reefs monitored in 2017.

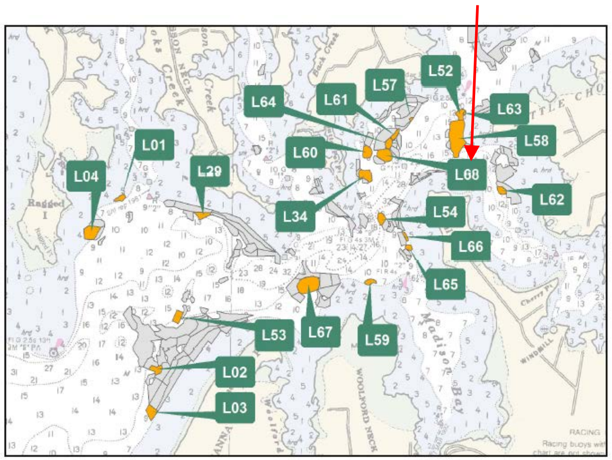
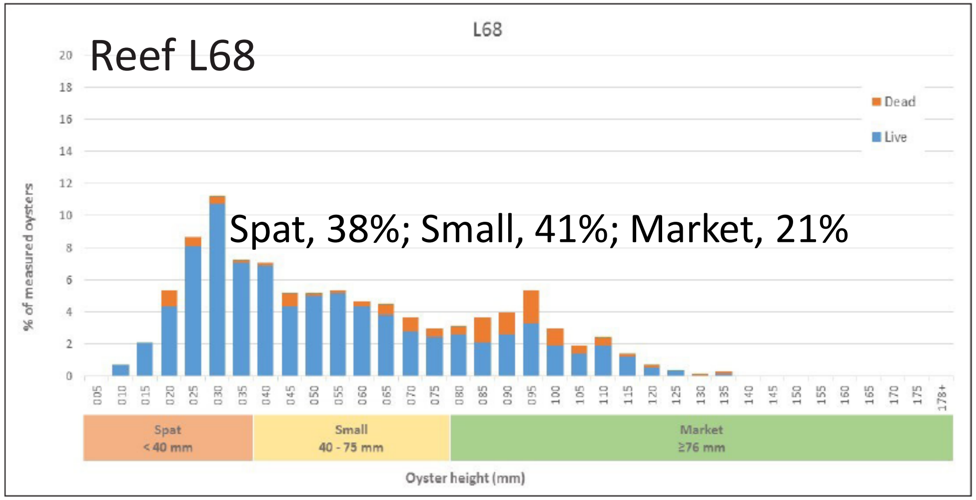
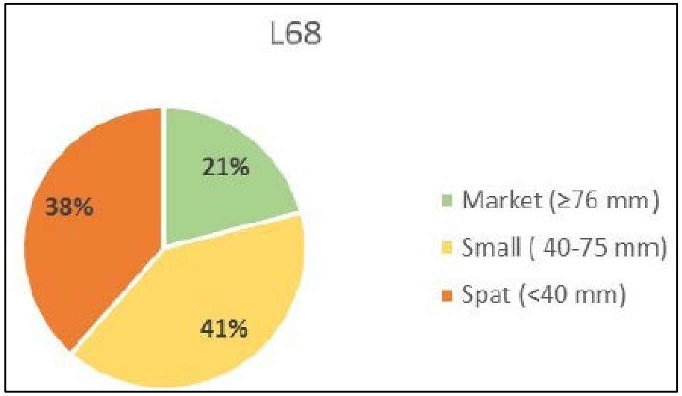


Figure 11: Reefs monitored in the Little Choptank River in 2017.

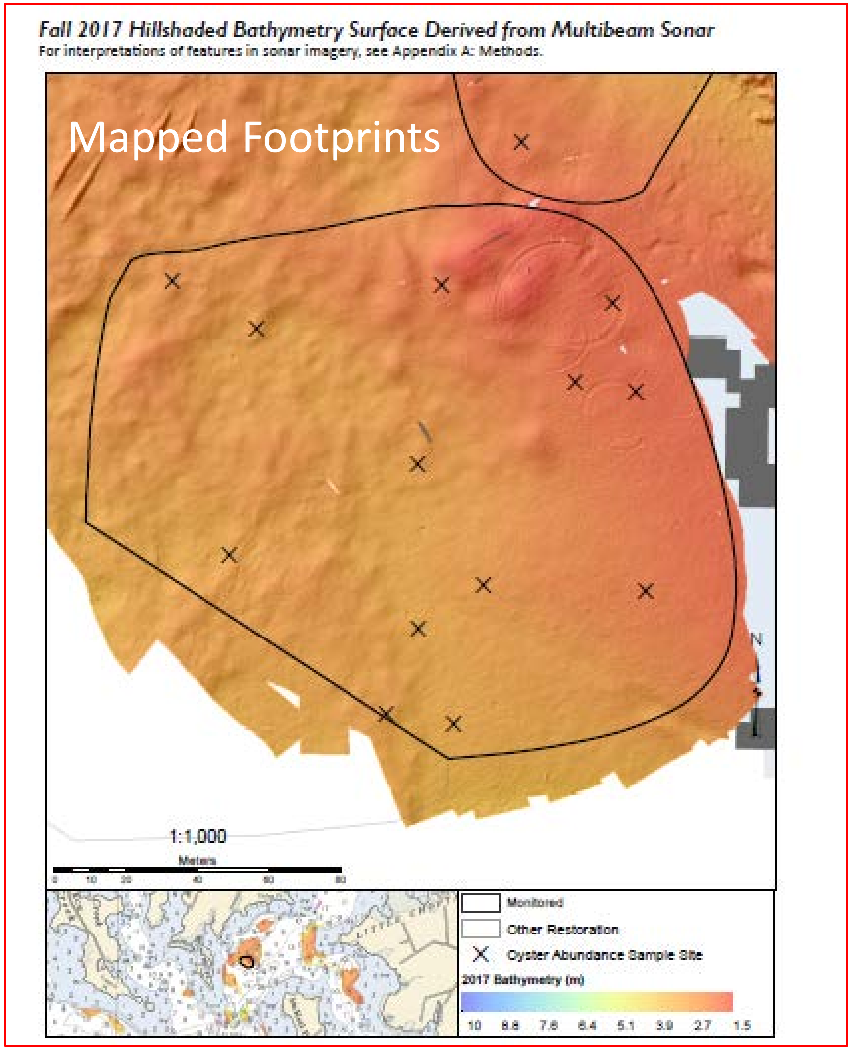
Shell Height of Oysters Measured on Reef



% measured oysters in three size categories



Little Choptank River (MD), Reference Assessment Large-scale Oyster Restoration (Reef L68): Universal" Monitoring Metrics
Mapping Reef Footprints



Submitted to: the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program, Dec. 2011
see https://chesapeakebay.noaa.gov/images/stories/fisheries/keyFishSpecies/oystermetricsreportfinal.pdf

Specific Oyster Metrics Success Criteria

There are six explicit criteria: (1) oyster density; (2) oyster biomass; (3) occurrence of multiple year classes; (4) positive shell budget; (5) reef height; and (6) reef footprint (area). Note: thresholds and definitions provided!

Biological Metrics	Oyster density	Minimum threshold = 15 oysters per m^2 over 30% of the reef area Target = 50 oysters per m^2 over 30% of the reef area
	Oyster biomass	Minimum threshold = 15 grams dry weight per m^2 over 30% of the reef area Target = 50 grams dry weight per m^2 over 30% of the reef area
	Multiple year classes	Presence of multiple year classes on the reef, as defined by oysters in at least two of the following size classes: market (>76 mm); small (40-75 mm); spat (<40 mm).
	Shell budget	Stable or increasing shell budget on the reef
Structural Metrics	Reef footprint	Stable or increasing reef footprint compared to baseline
	Reef height	Stable or increasing reef height compared to baseline

Table 6: The Oyster Metrics reef-level success criteria.

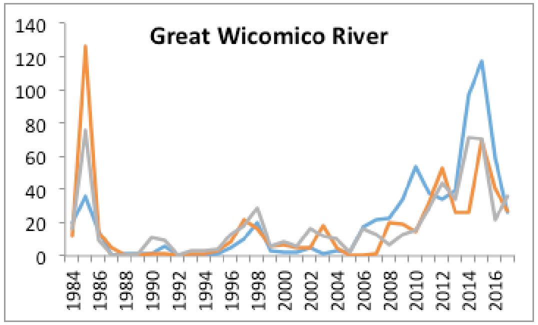
Future Factors that Need to be Considered

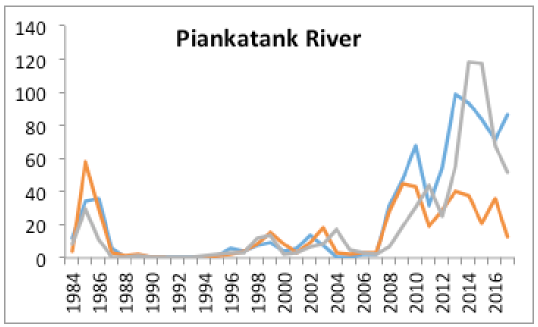
- Future water-quality issues such as extreme low DO events or other water-quality issues in the future could result in substantial oyster mortality. Upstream and upland activity, or watershed-wide water-quality degradation, could also affect oysters.
- Oyster diseases: Dermo has been prevalent in this part of Maryland, but at a very low (sublethal) intensity. Dry weather could result in higher salinities, resulting in increased Dermo intensity, leading to significant oyster mortality.

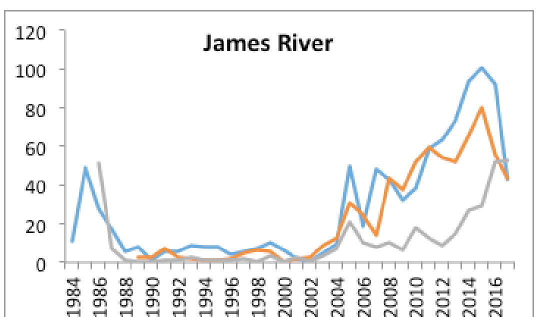
the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program, Dec. 2011
see https://chesapeakebay.noaa.gov/images/stories/fisheries/keyFishSpecies/oystermetricsreportfinal.pdf

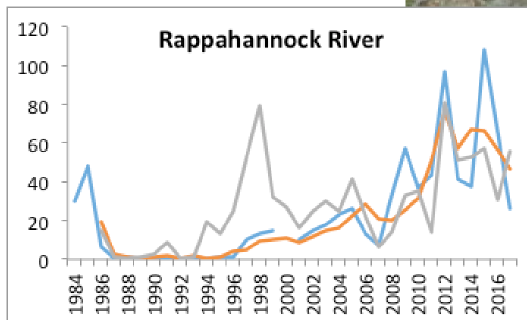
The Scope of Restoration Success in Chesapeake

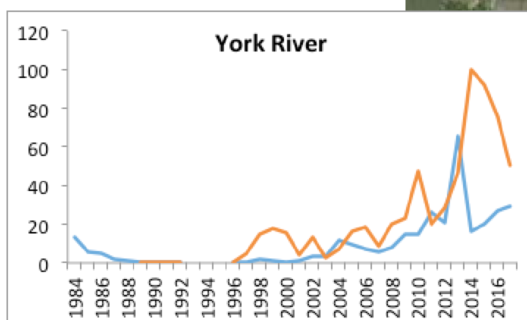
of Market oysters (3” SH) bushel -1



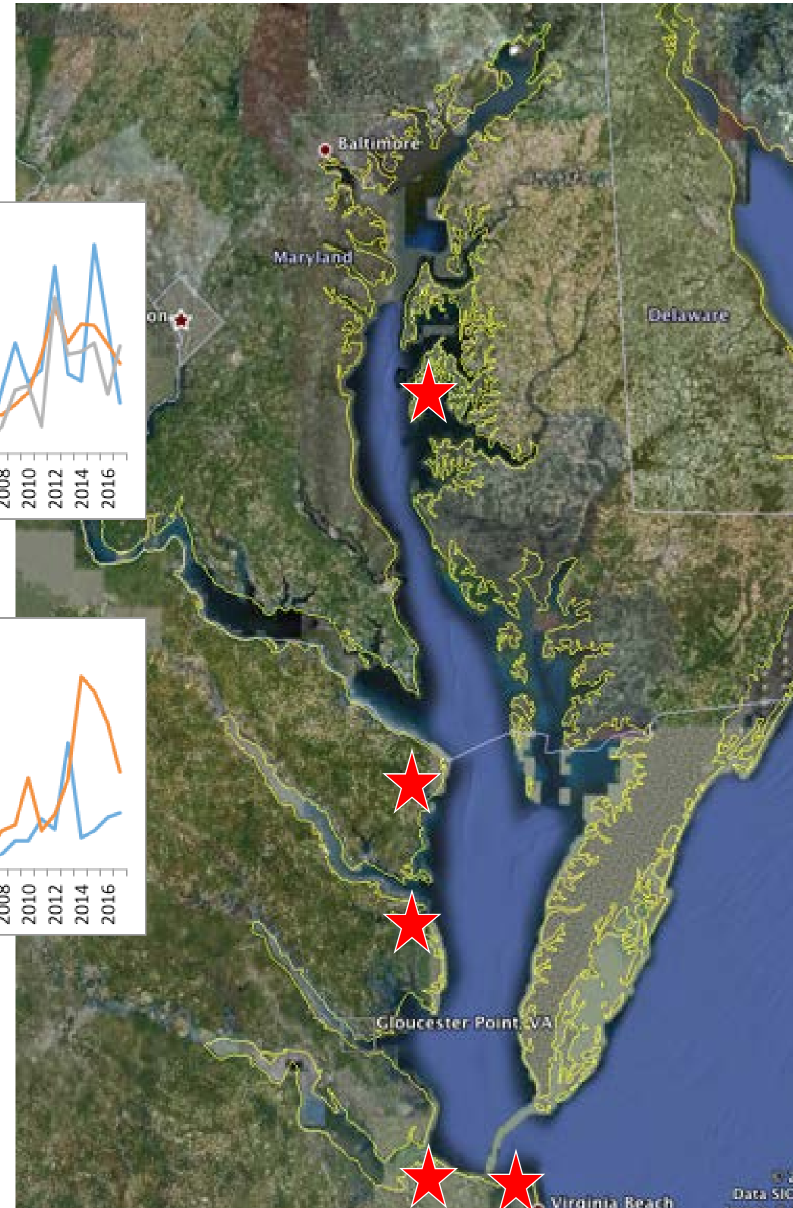








Repl. Reef Samples
1
2
3



Data: Market-sized (3” SH) oysters from VIMS Molluscan Ecology Lab (Mann/Southworth) dredge survey

A Different Perspective, Ryan Carnegie, VIMS

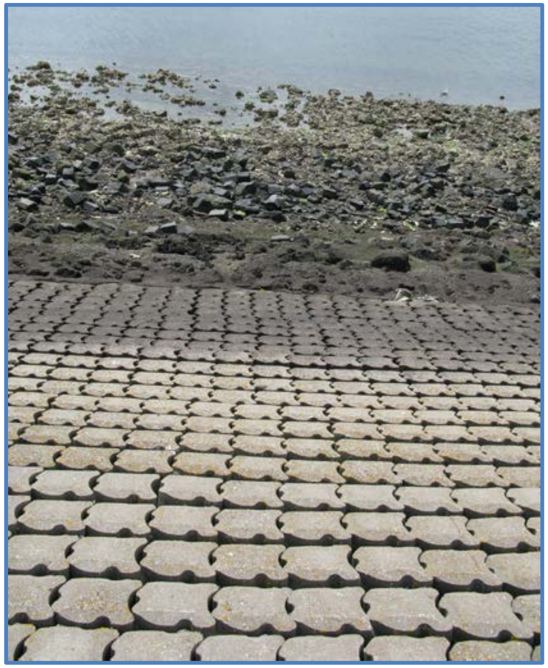
- In Chesapeake Bay, some suggest that the 'success' we are seeing (at tributary scale), with these massive expenditures (e.g., material, SOS, labor) means we have finally figured out how to do large-scale oyster restoration 'correctly'. **But are we?**
- However, oysters in Bay are increasing everywhere, regardless of whether restoration occurred nearby. **So what's going on?**
- Practitioners of these large-scale efforts suggest finally making a real difference. **So significant $$ should continue.**

But, perhaps something more fundamental occurring?

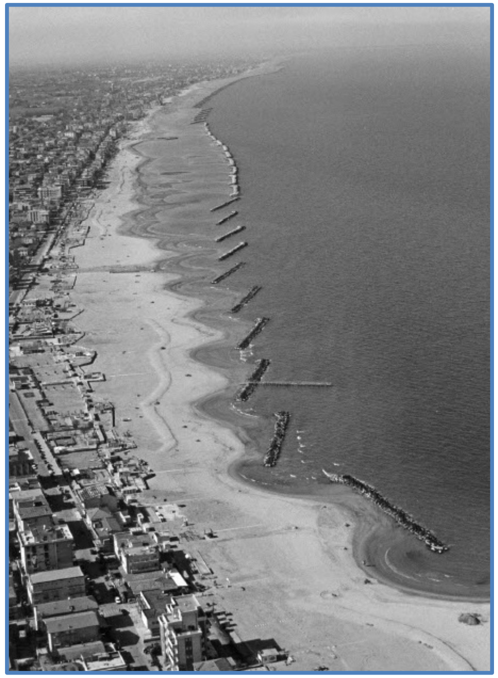
1) Overall, the Bay's restored reef footprint is relatively small, both spatially and temporally.
2) Perhaps the oyster itself is contributing, by way of **resistance-tolerance evolution** to diseases?
3) Hence a conundrum, is the success**: (a)** from a few high profile, but very localized mega-projects **or (b)** that the highly dispersed, restoration efforts are just a better way to broadcast these disease resistance-tolerance ('adapted') oysters???

Whether one or both of these hypotheses is the explanation a major question!

Engineering Our Coastlines Facing Erosion



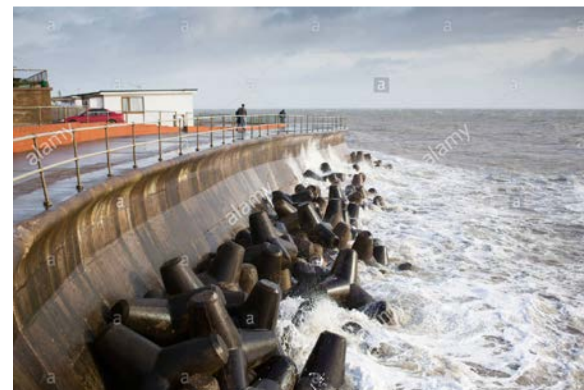
Defenses along Netherland's dikes
tiles above, asphalt below



Defenses along
Italian's Adriatic coast

Superfund site, Charleston, SC

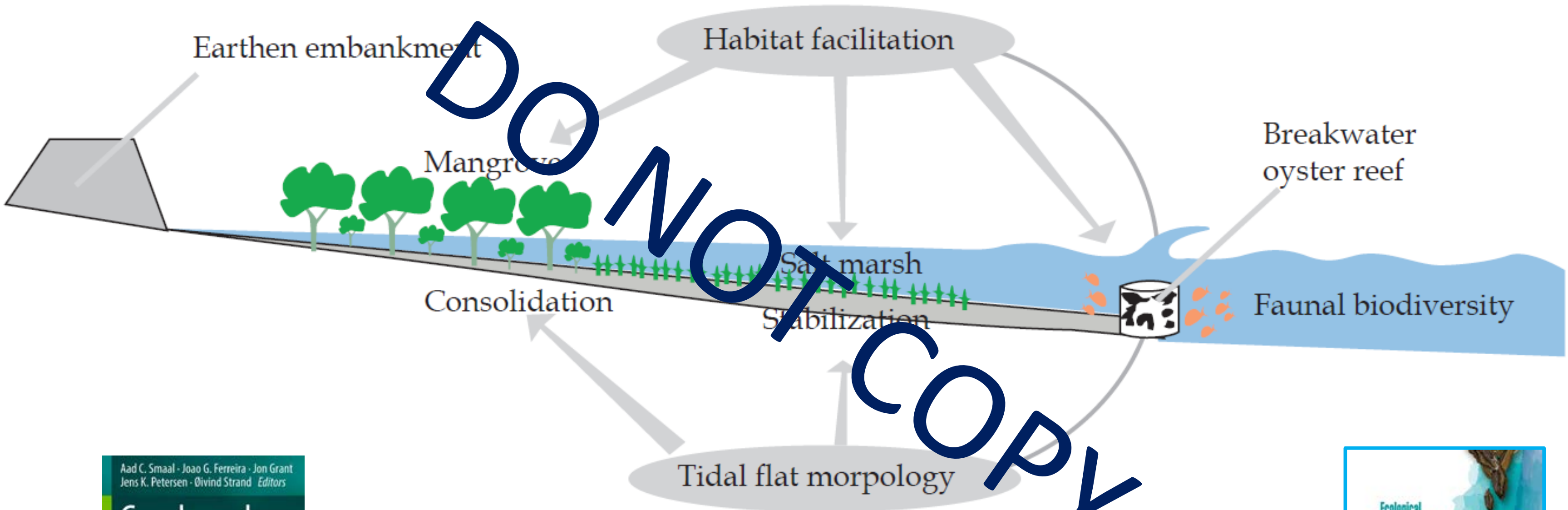
Manhattan's future?

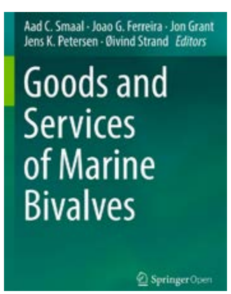


Weston's WannaB Inn, Lemon Bay, FL
https://wusfnews.wusf.usf.edu/post/artificial-mangroves-could-bring-back-vanishing-habitats-florida

Ecological Engineering

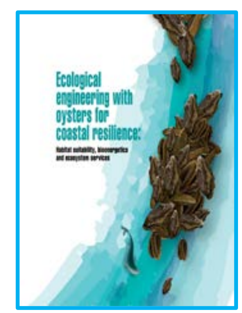
"The design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both" (Mitsch 2012)





Goods & Services of Marine Bivalves

(BTW, free download at Springer)



WAGENINGEN UNIVERSITY & RESEARCH

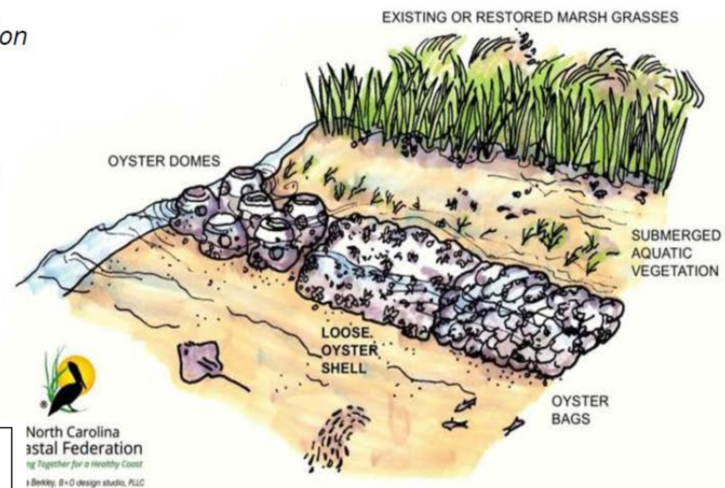
100years 1918 — 2018

Chowdhury 2019

INSTITUTE OF MARINE SCIENCES AND FISHERIES
UNIVERSITY OF CHITTAGONG

Now Living Shorelines Being Promoted as "More Natural" Approaches to Protecting/Stabilizing Shorelines

<u>LIVING SHORELINE</u>: "*a shoreline management practice that provides erosion control; protects, restores or enhances natural shoreline habitat; and maintains coastal processes through strategic placement of plants, stone, sand fill, and other structural and organic materials*" (NOAA).



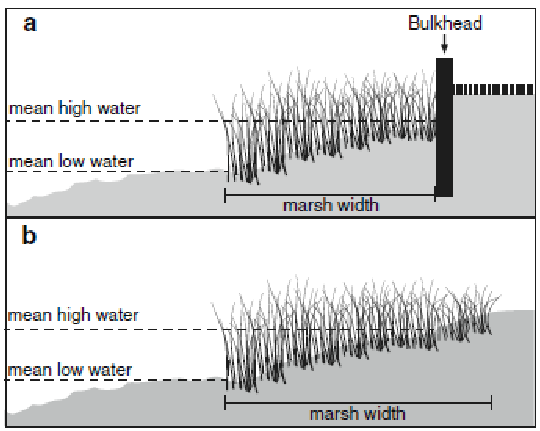
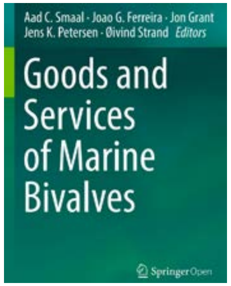


Fig. 1 Marsh cross section for bulkheaded (a) and reference (b) sites. Note that the bulkhead is a physical barrier to marsh migration

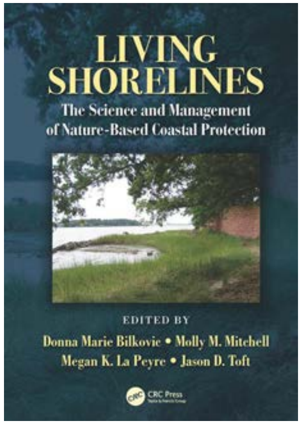
O'Meara et al. Wet. Ecol. Mgmt. 15

<u>Ecological Engineering:</u>
"The design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both" (Mitsch 2012)



Goods & Services of Marine Bivalves

(BTW, free download at Springer)



2017

Various Living Shoreline "Breakwater" Configurations

Modified from B. Bloomberg et al., DISL; S. Douglass 2014; Gittman et al. 2015; L. Coen

Various Living Shoreline "Breakwater" Configurations

<u>Engineered breakwaters might include 'Green' to 'Gray'</u> <u>options</u>:

- Rock, loose material, shell bags, reef balls, gabion mats, ReefBLKs, HESCO cages (e.g., Bilkovic et al. 2017, Living shorelines vol., others)

Rethinking Living Shorelines

A "Living Shoreline" at the North Carolina Center for the Advancement of Teaching
Ocracoke, North Carolina

Orrin H. Pilkey* Rob Young
Norma Longo* Andy Coburn

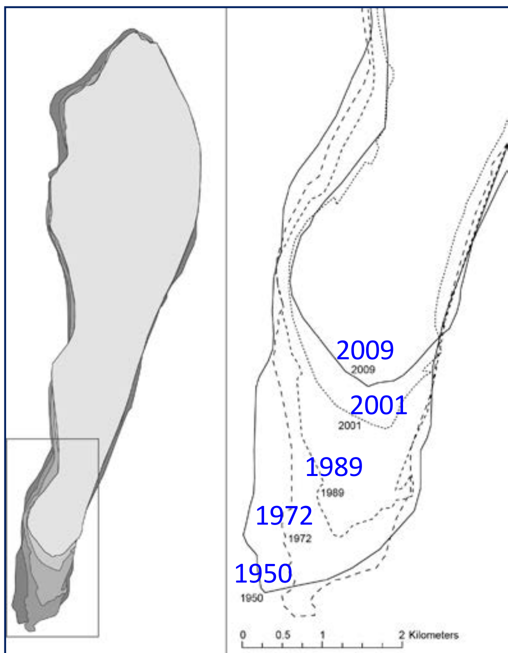
The New York Times
2018

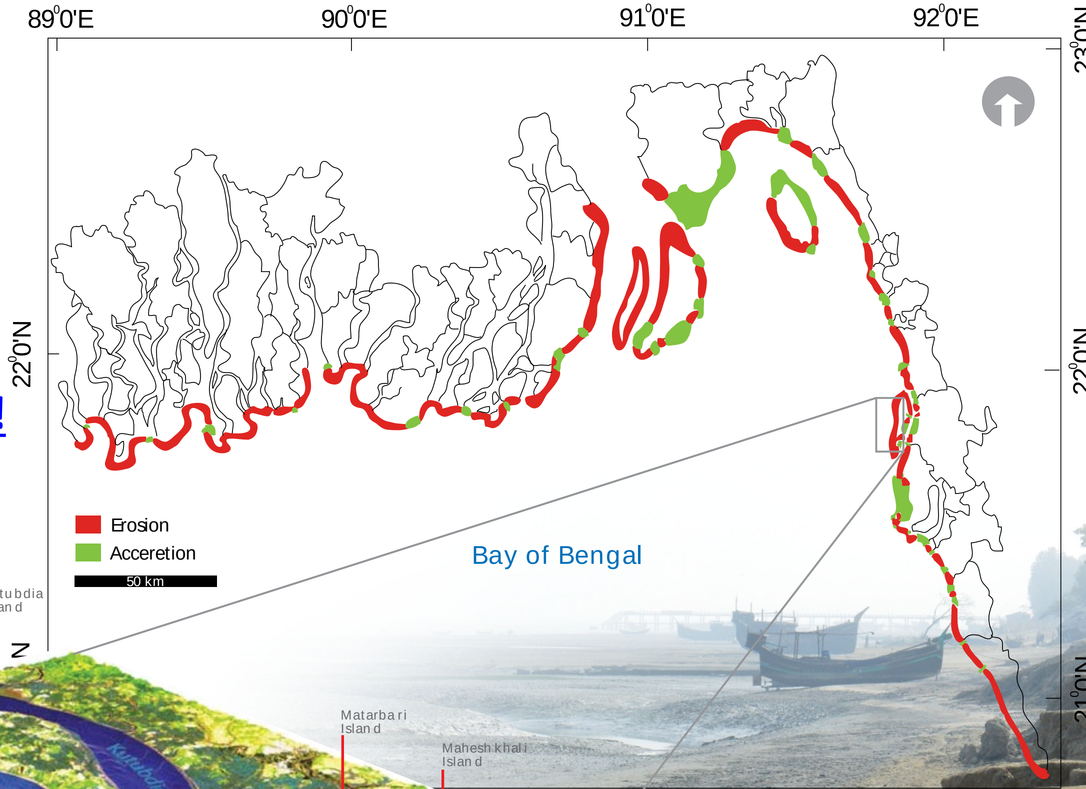
Kutubdia Island, Bangladesh: Erosion & Accretion

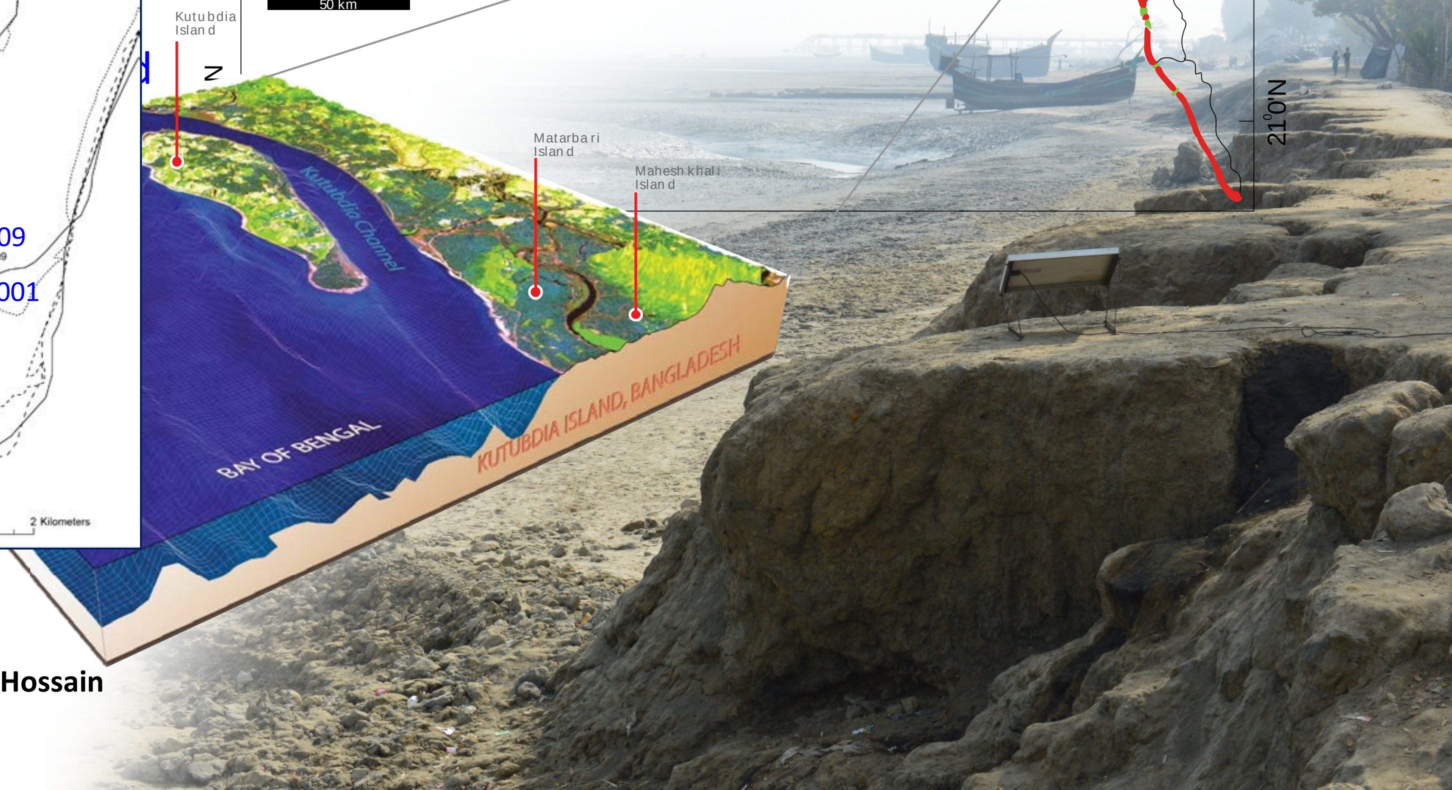
Modified from Chowdhury 2019.

Sarwar & Woodroffe, 2013. Rates of shoreline change along the coast of Bangladesh. J. Coastal Conserv. 17:515-526.

Lost >300 km² in last 20 years!!

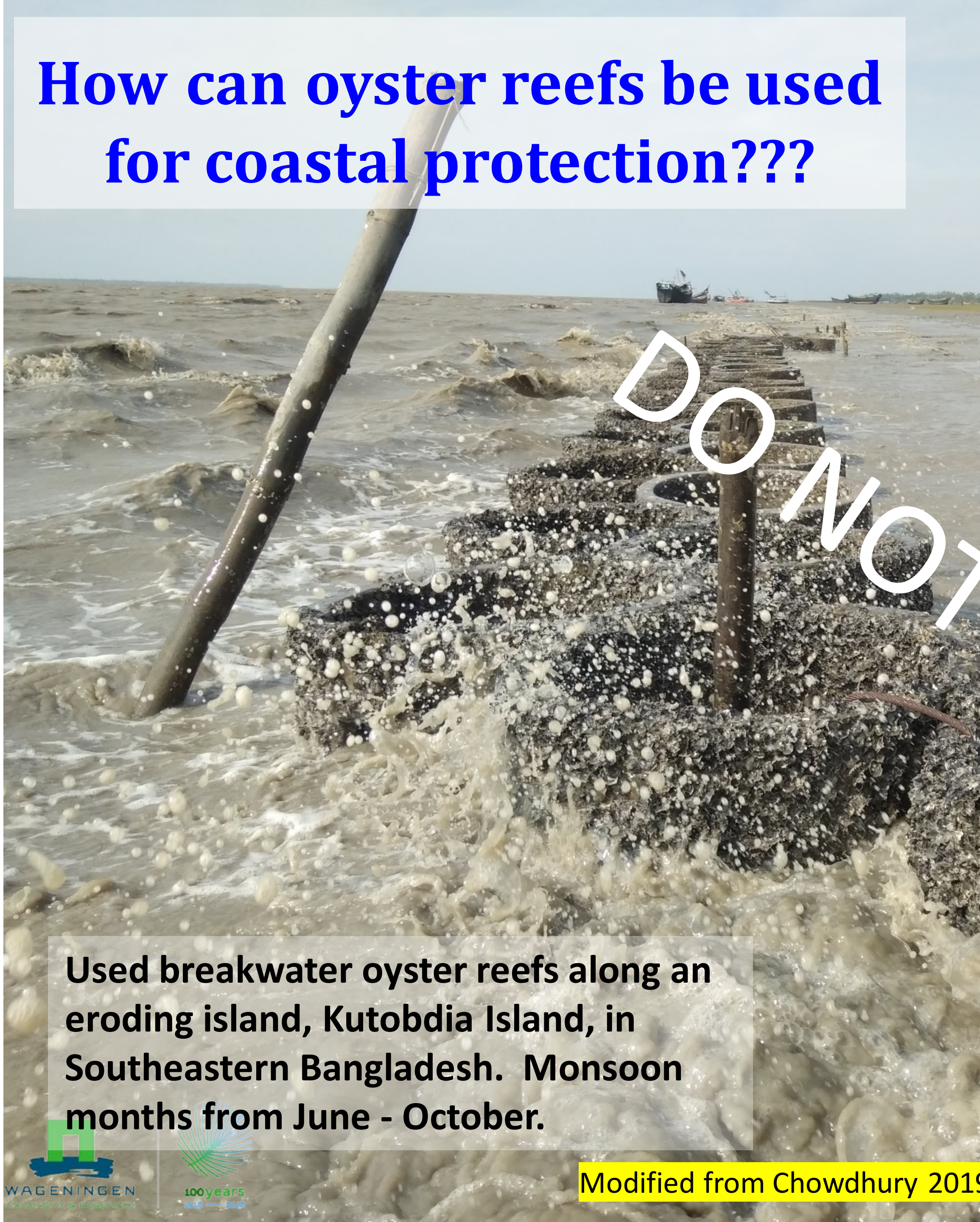


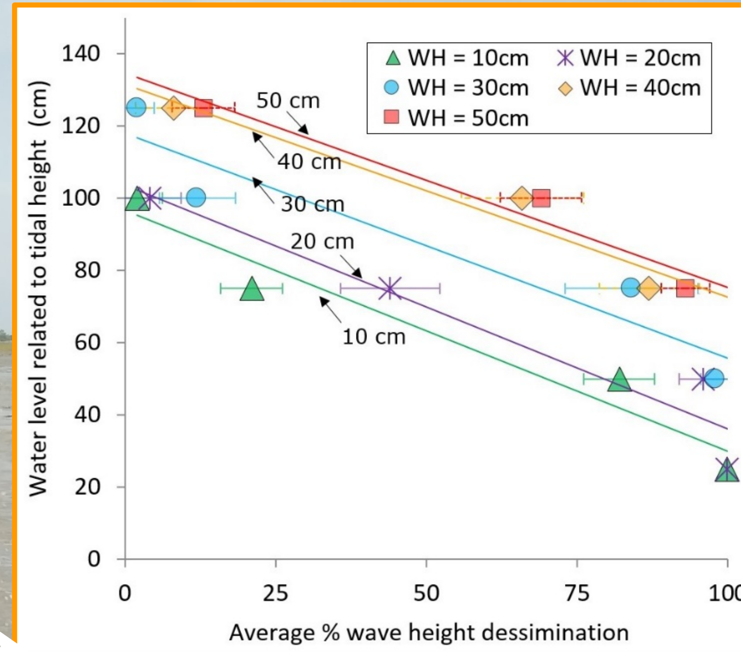




Modified From: M. Shahadat Hossain

How can oyster reefs be used for coastal protection???

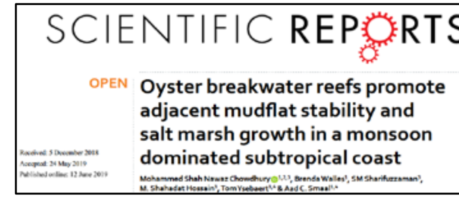




Used breakwater oyster reefs along an eroding island, Kutobdia Island, in Southeastern Bangladesh. Monsoon months from June - October.

Modified from Chowdhury 2019, et al. 2019.

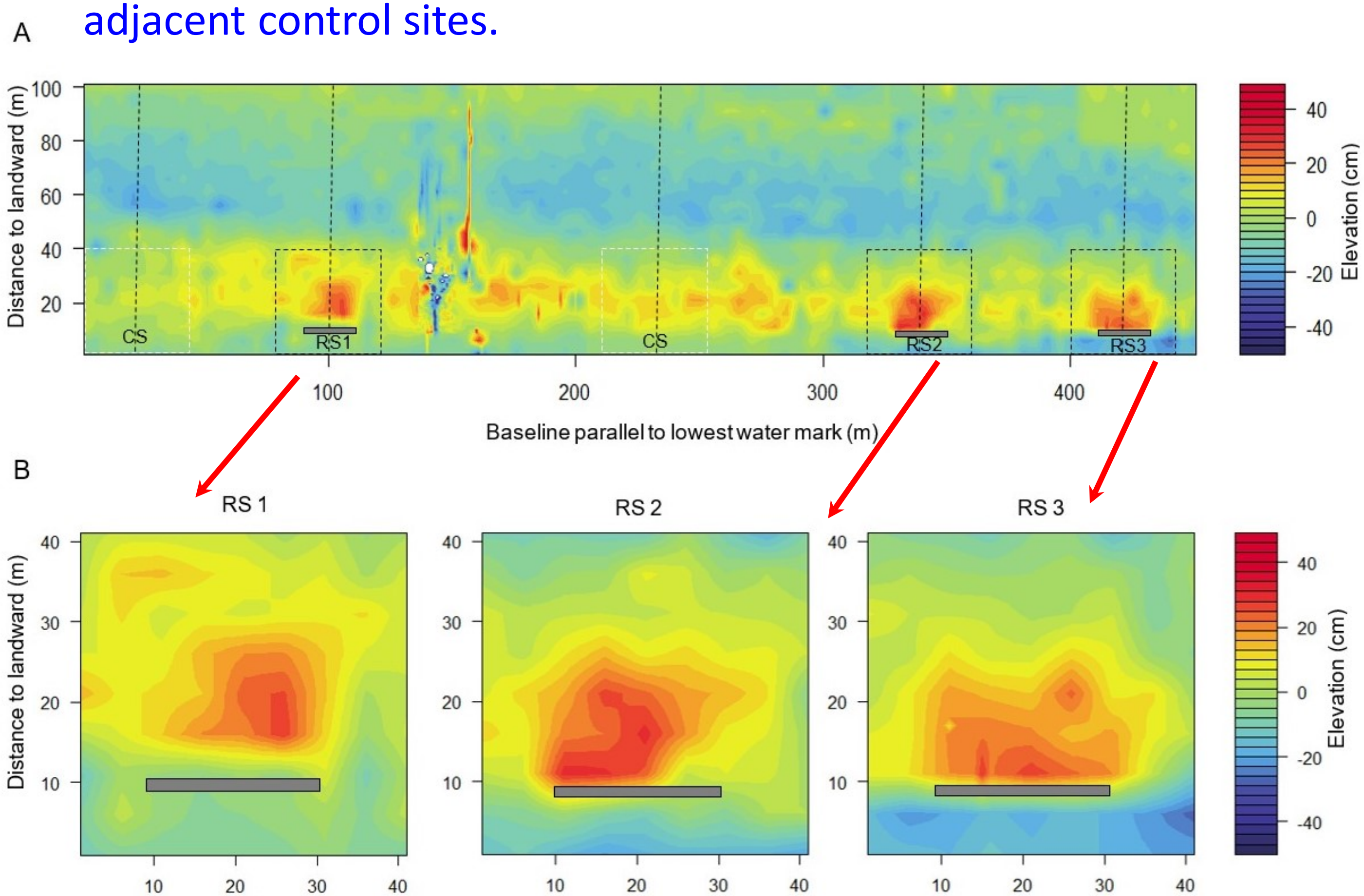
How? oysters used for coastal protection


SCIENTIFIC REPORTS
OPEN
Oyster breakwater reefs promote adjacent mudflat stability and salt marsh growth in a monsoon dominated subtropical coast

Chowdhury 2019, Chowdhury et al. 2019

From Digital Elevation Model (DEM)

1. Leeward side of reef had > mean sediment accretion, as high as 29 cm.
2. Erosion was further reduced by 54% vs. adjacent control sites.



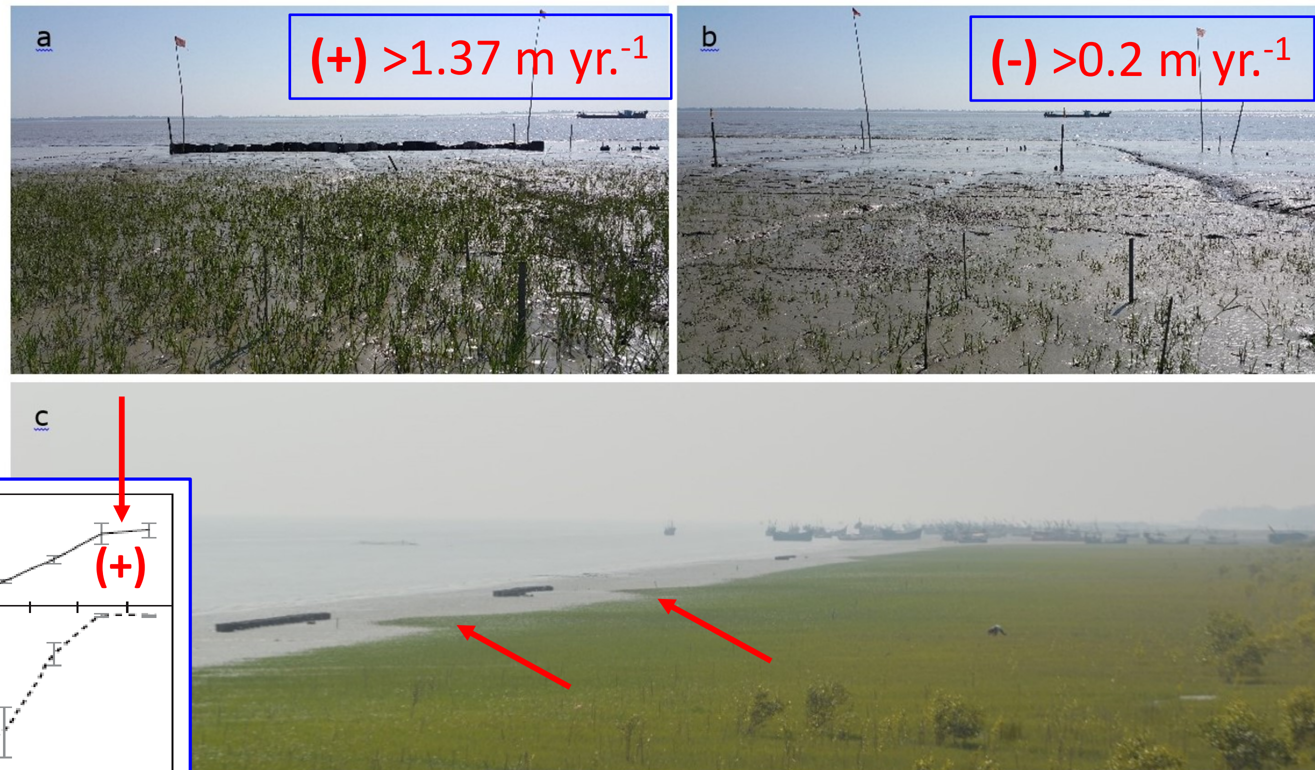
Modified from Chowdhury 2019, et al. 2019.

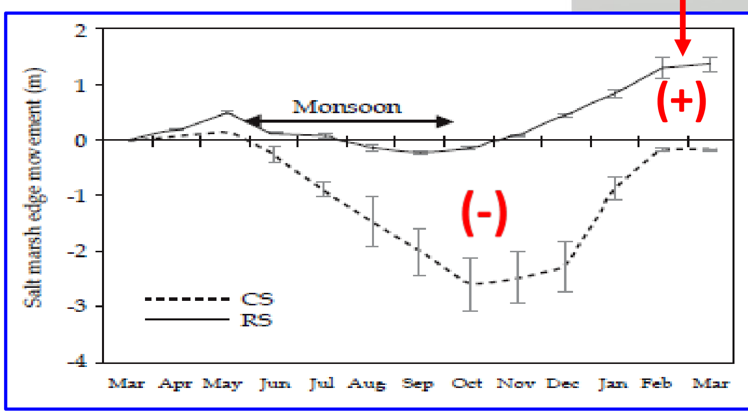
Using R software (version 3.3.0) using the packages grDevices and graphics.

WAGENINGEN UNIVERSITY & RESEARCH
100years 1918 — 2018

How oysters Can used for coastal protection ?

- Observed marsh loss both trts. during monsoon season, but with retreat significantly lower behind reefs vs. controls.
- Reefs facilitated marsh expansion, >1.37 m $yr.^{-1}$ vs. a loss of >0.2 m $yr.^{-1}$ landward of the control areas. Moreover, saltmarsh regeneration rates were >36% at the reef vs. the control site.





Seasonal dynamics in the movement of salt marsh edge at control (CS) and reef (RS) sites.

Modified from Chowdhury 2019, et al. 2019

Oyster: Marsh Shoreline Stabilization In SC

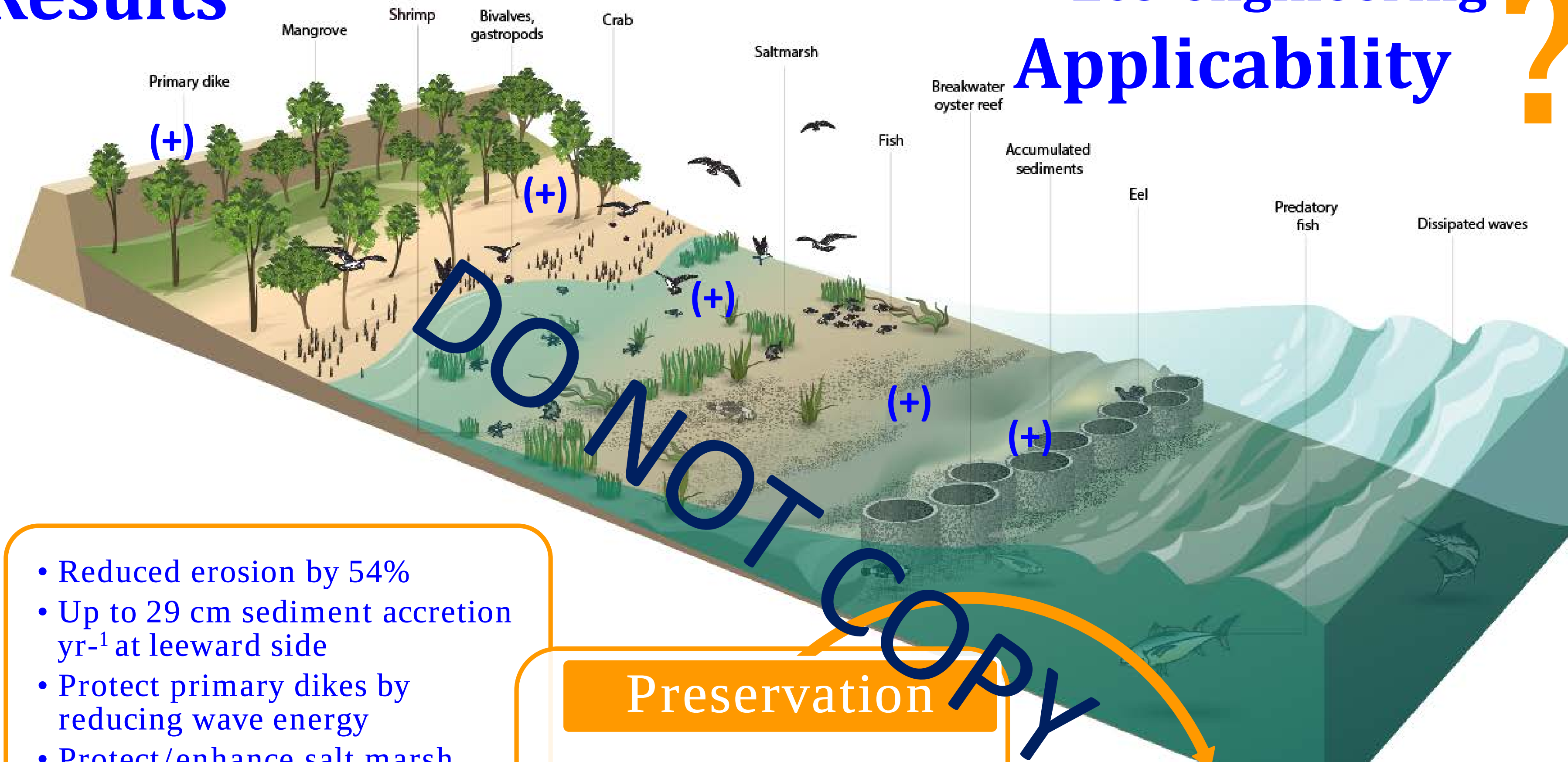
Modified from Coen and Hadley, SCORE

After 16 months, constructed shellbag reef's note marsh regrowth/expansion

After 34 months

Results

Eco-engineering Applicability ?



- Reduced erosion by 54%
- Up to 29 cm sediment accretion yr^{-1} at leeward side
- Protect primary dikes by reducing wave energy
- Protect/enhance salt marsh
- Protect/enhance mangroves

Protection

Preservation

- Supports 32 species of fish
- 18 shrimp species
- Crab 9 species
- 19 molluscan species
- ~30 polychaetes species
- Enhanced marsh, mangrove footprints

Production

- 228 g crab trap^{-1} day^{-1}
- 640 g fish haul^{-1} net^{-1}
- 300 g shrimp haul^{-1} reef^{-1}
- 1-5 kg oyster m^{-2} yr^{-1}

Chowdhury 2019, unpublished

WAGENINGEN UNIVERSITY & RESEARCH

100years 1918 — 2018

LA: Intertidal Oyster Restoration/Shoreline Protection

GOM Living Shorelines: From: Melancon and Curole

Triton™ Gabion Mats (filled w/ limestone rocks) (an on-shore structure)

5'W x 20'L x 1'Deep

geotextile grid material formed into a basket and interconnected to form a mat.

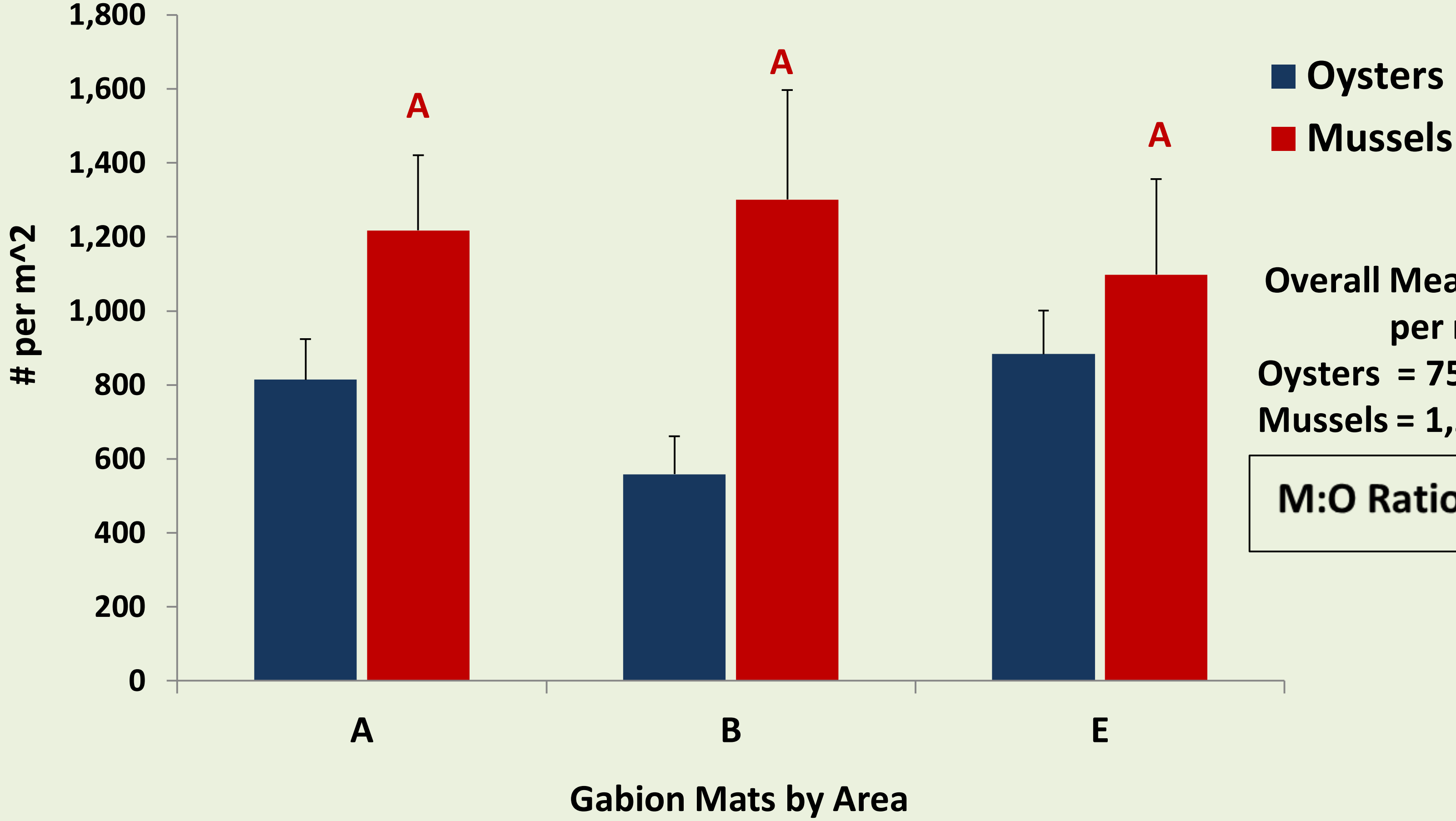
Weight @ 10,000-15,000 lbs each

Cost per Linear Foot = $536

Winter 2011-12 Assessment

Sometimes Oyster Restoration Begets A Different Result Than Planned!

Surficial Live Oyster & Mussel Densities
Winter 2011-12 Assessment



Overall Mean Density per m^2
Oysters = 752±67
Mussels = 1,213±143

M:O Ratio = 1.6:1

LA: At What Temporal Scale Do You Assess Success or Failure?

When has a reef been 'restored' or 'created'? Results at year 1 or 2 <u>may not</u> match those in years 3, 4 or 5 and beyond.

LA project considered <u>highly successful</u> based on oyster density/pop. size <u>at year 2,</u> post-construction (La Peyre et al. 2017)

Project <u>a failure</u> based on same metrics <u>at year 5</u>, post-construction!

Why?

Stone crabs!

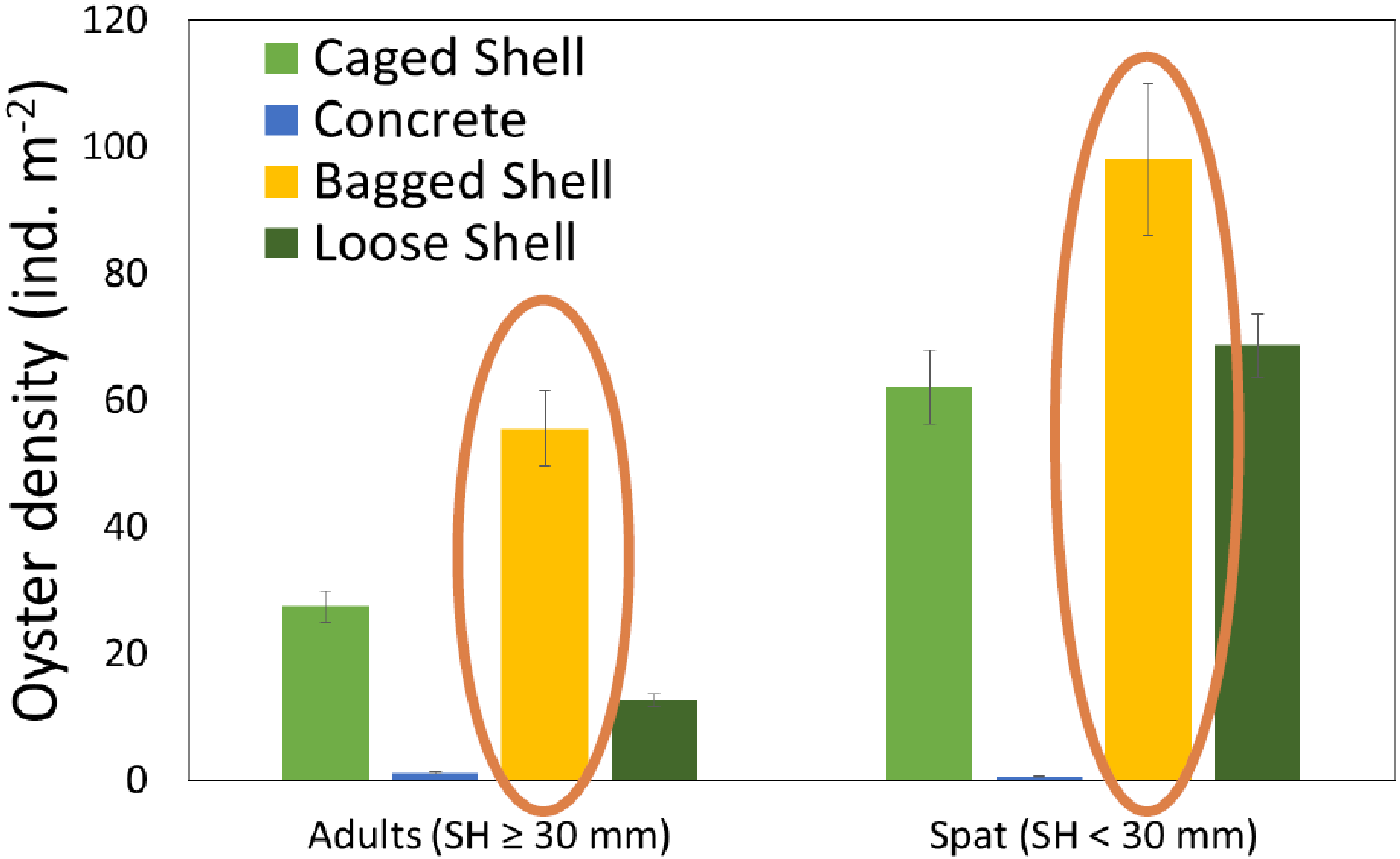
Adapted from: 2015 NAS talk: La Peyre Pollack, Geiger

Alabama Living Shoreline Synthesis



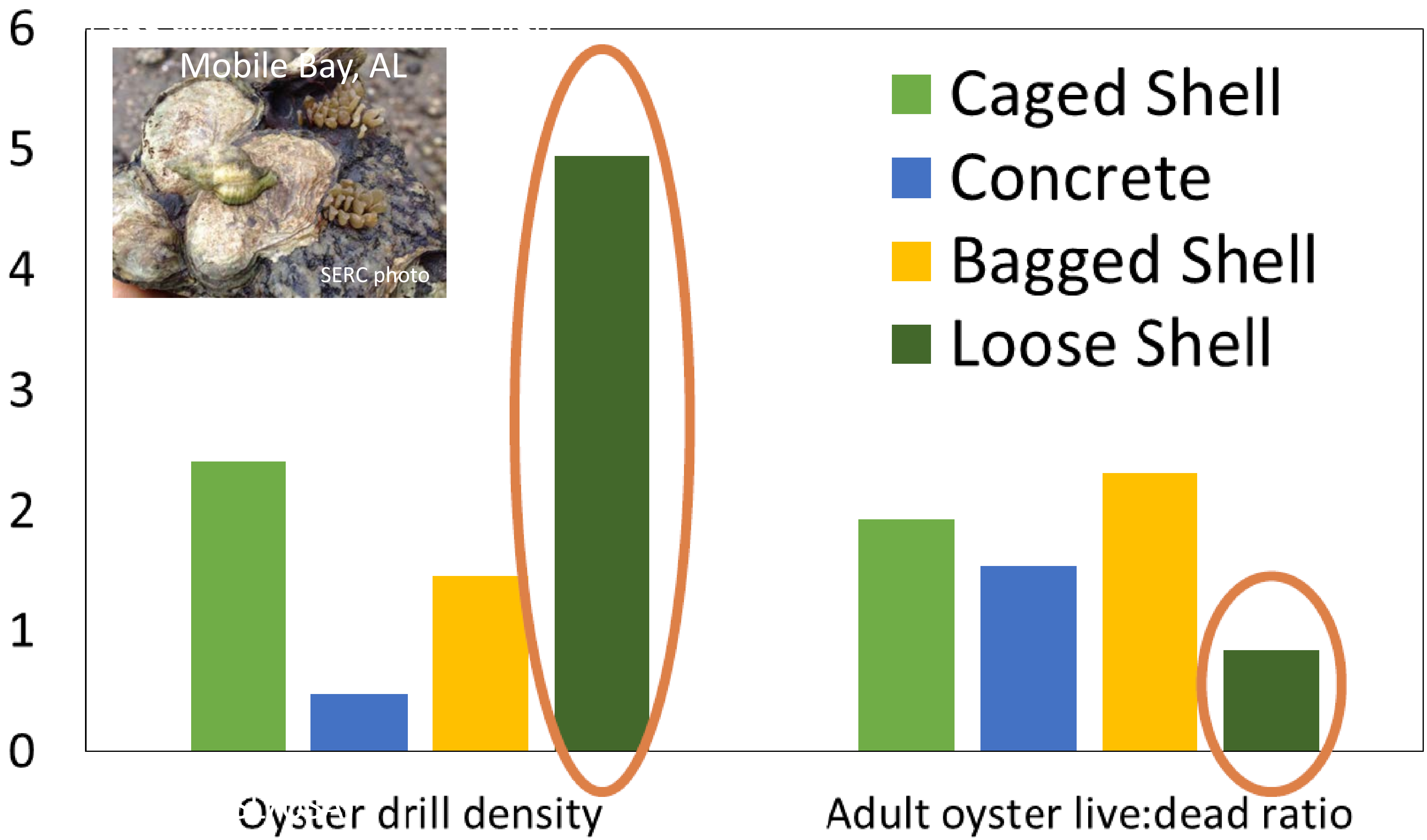
Modified from: B. Bloomberg et al., DISL

Oyster densities were highest on oyster shell (bagged best) reefs as compared to other materials.

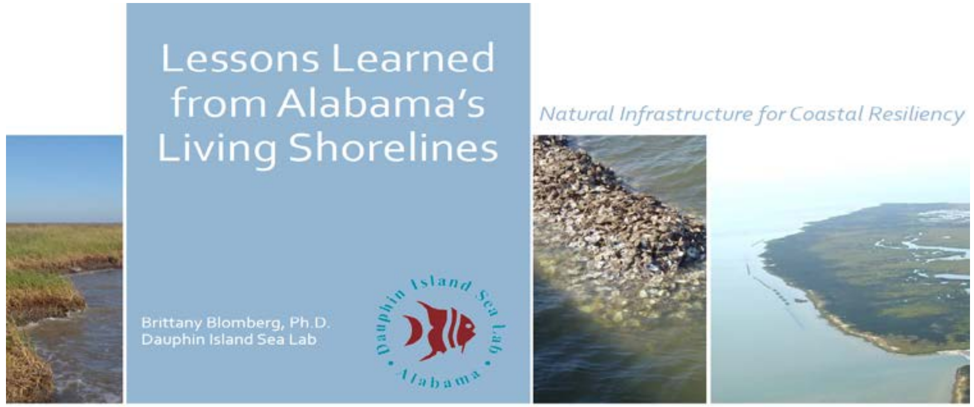


Modified from B. Bloomberg et al., DISL

Oyster drills like loose shell.



Modified from B. Bloomberg et al., DISL



- Reefs constructed of loose shell spread resulting in low profile reefs.
- ReefBLKs lost contained shell
- Bagged shell reefs had the highest live oyster densities
- Demersal fishes saw greatest enhancement on various reef types
- Grabowski et al. (2012) predicted that LS most valuable service would be shoreline protection
  - However, significant reductions in shoreline erosion <u>have not been observed to date</u>!

Modified from B. Bloomberg et al., DISL

West Coast U.S.: Living Shoreline Effort

Using Native Oysters & Eelgrass

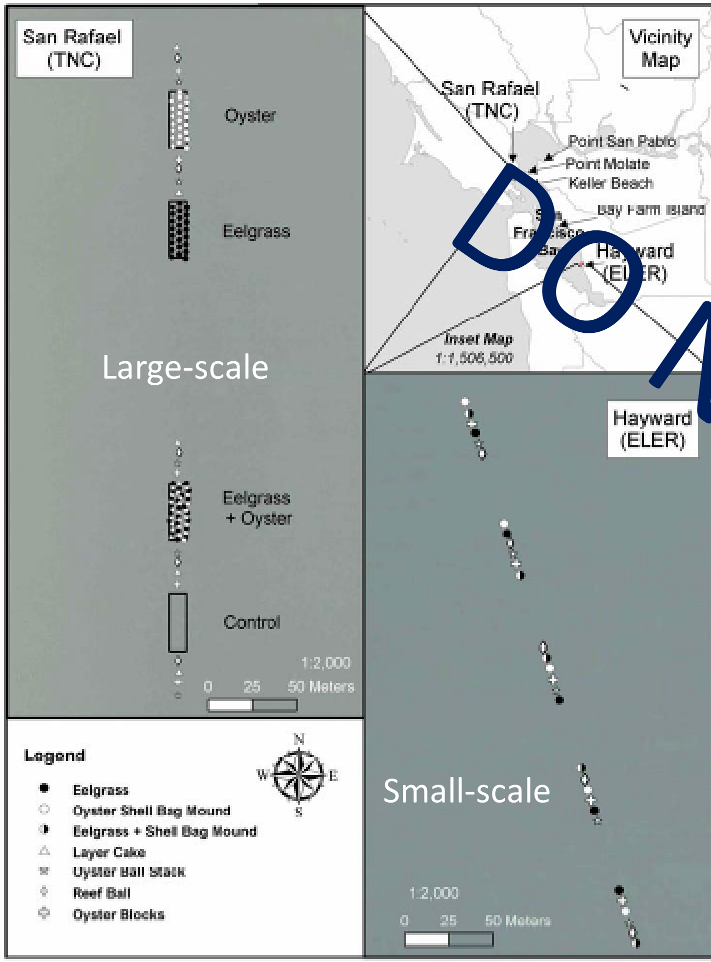


Figure 1. Maps showing the location and configuration of (left) the larger-scale and small-scale experiment designs at San Rafael (property of The Nature Conservancy [TNC]) and (right) the small-scale design at Hayward (offshore of Eden Landing Ecological Reserve [ELER]). Space was left at the center of the San Rafael project for preexisting test plots of eelgrass. Eelgrass transplants were collected from Point San Pablo and Point Molate for the San Rafael site and from Bay Farm Island and offshore of ELER for the Hayward site (top right map). Point Molate and Keller Beach eelgrass beds were used as reference sites for epibenthic invertebrate community development at San Rafael.

Figure 3. Top: Photos of treatments used in the project. Bottom: Eelgrass planting using bamboo stake technique, including, on the right, a schematic of planting design within an eelgrass unit at San Rafael and Hayward. Two donors were used to plant each site, as indicated by shading in the schematic. For San Rafael, the donor in the center alternated in each patch.

From: T. Grosholtz et al.

Few Selected Results: San Rafael LS Site (TNC)

Native (*O. lurida*) Oyster Abundance by Treatment

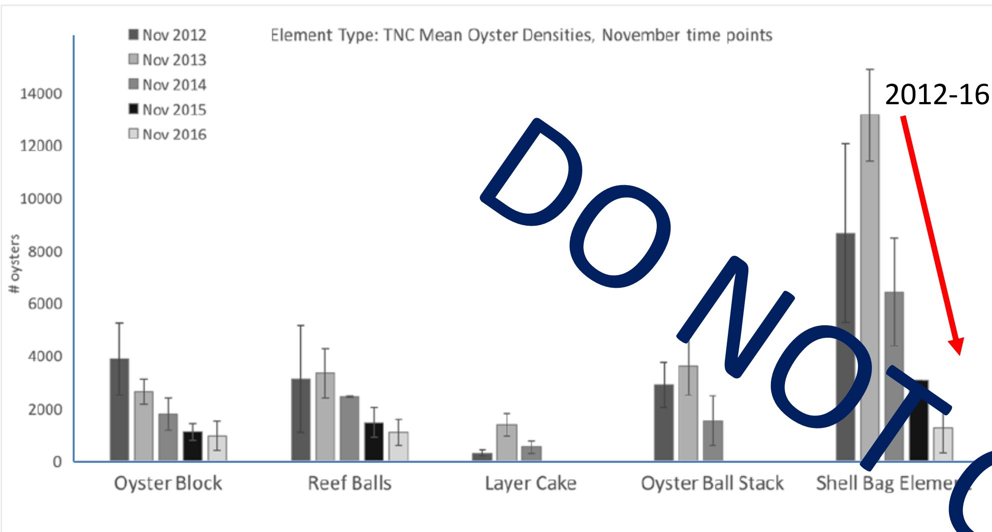
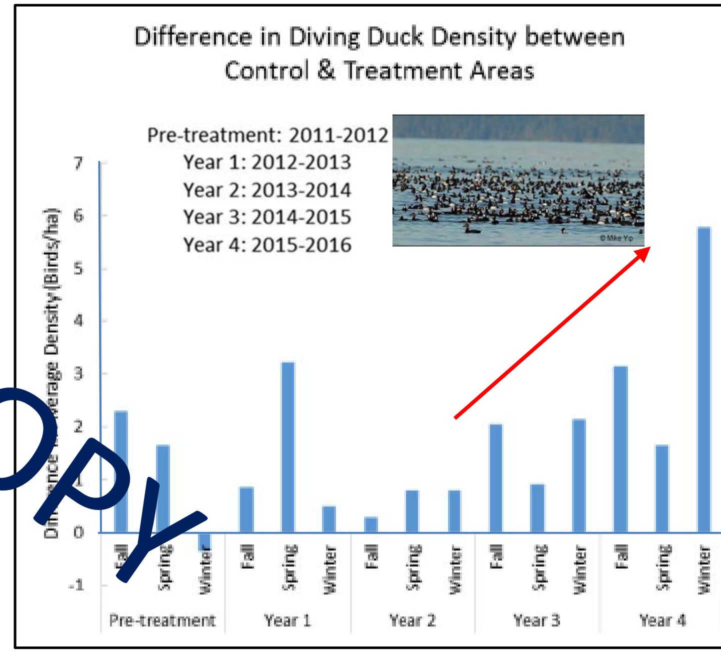


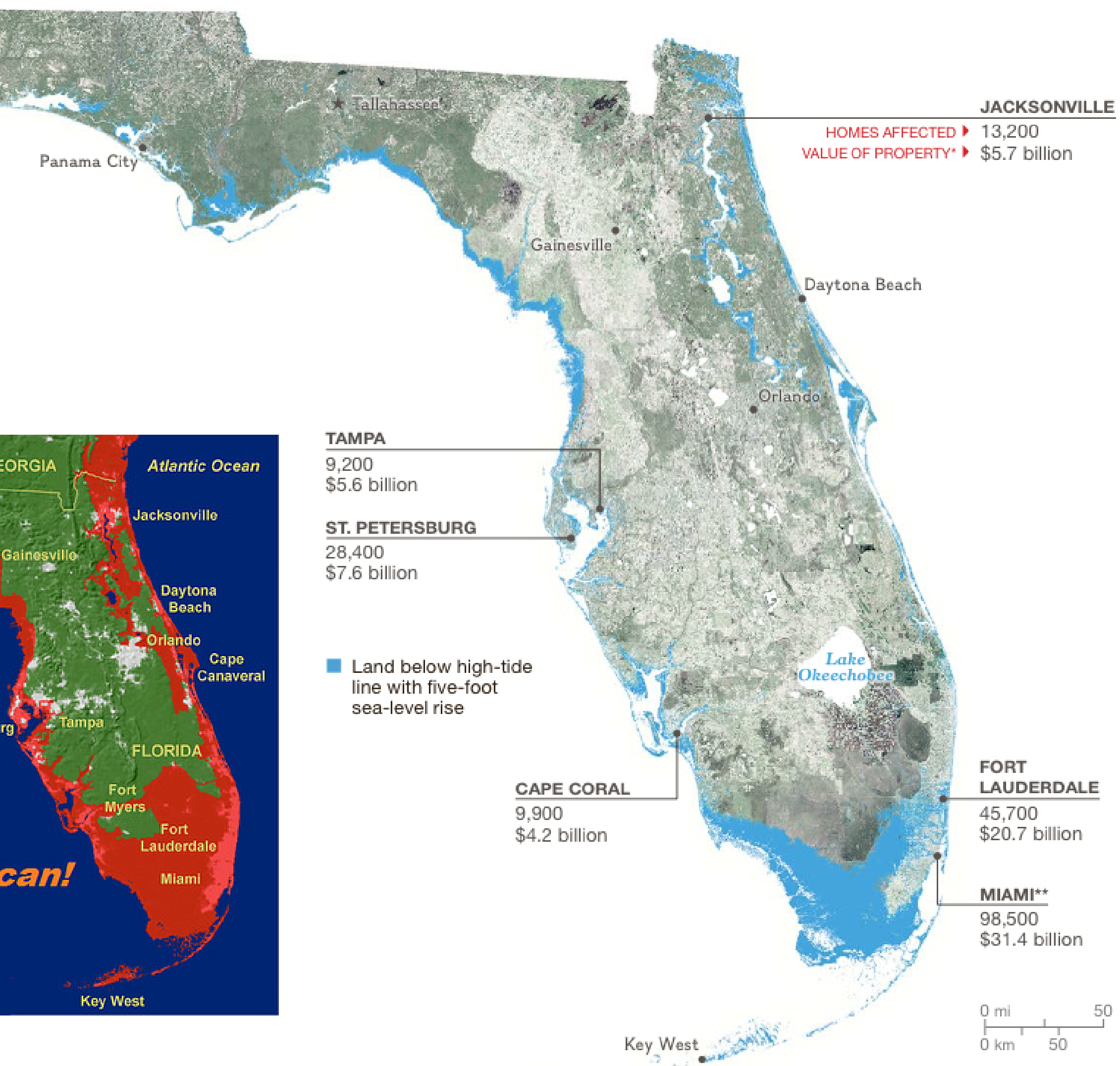
Figure 8. Estimated native oyster abundance per baycrete or shell bag element, November time points, at the San Rafael site (TNC). Means (±95% CI) were generated by scaling up from 10 small replicate shell bags (five each from oyster-only and oyster–eelgrass treatment plots) or from six 100-cm^2 quadrats placed on each of five replicate baycrete elements at the San Rafael site. Given their relatively poor performance (see text), layer cakes and oyster ball stacks were not monitored in 2016.

Mean Diving Duck Densities at Low Tide: Zone B: Control-Treatment



From: SF Bay Living Shorelines Project, Grosholtz et al.

Moot? Predictions for Florida with SLR into the Future: New Oyster Hard Substrate??



M.S.N. Chowdhury, Ph.D.

Instit. Mar. Sci., Univ. of Chittagong, Bangladesh

Chowdhury, M.S.N., J.W.M. Wijsman, M.S. Hossain, T. Ysebaert, A.C. Smaal, 2018. DEB parameter estimation for *Saccostrea cucullata* (Born), an intertidal rock oyster in the Northern Bay of Bengal. J. Sea Res. 142:180-190.

Chowdhury, M.S.N., 2019. Ecological engineering with oysters for coastal resilience: Habitat suitability, bioenergetics, and ecosystem services. Ph.D., WIAS, Wageningen University, Netherlands, 196pp.

Chowdhury, M.S.N., J.W.M. Wijsman, M.S. Hossain, T. Ysebaert, A.C. Smaal, 2019a. Growth potential of rock oyster (*Sacosstrea cucullata*) exposed to dynamic environmental conditions simulated by a Dynamic Energy Budget model. J. Sea Res. 147:19-27.

Chowdhury, M.S.N., B. Walles, S.M .Sharifuzzaman, M.S. Hossain, T. Ysebaert, and A.C. Smaal, 2019b. Oyster breakwater reefs promote adjacent mudflat stability and salt marsh growth in a monsoon dominated subtropical coast. Nature Sci. Reports 9:8549 see https://doi.org/10.1038/s41598-019-44925-6

Chowdhury, M.S.N., J.W.M. Wijsman, M.S. Hossain, T. Ysebaert, and A.C. Smaal, 2019c. A verified habitat suitability model for the intertidal rock oyster, *Saccostrea cucullata*. PLoS ONE 14(6):e0217688. see https://doi.org/10.1371/journal.pone.0217688

Special Thanks For Their Input

David Bushek (Rutgers), Ryan Carnegie (VIMS), Mike Beck (TNC), Steve Geiger (FWC), Ted Grosholz (UC Davis), Ken Heck (DISL), Megan La Peyre (LSU-USGS),Lisa Kellogg (VIMS), Mark Luckenbach (VIMS), Earl Melancon (NSU), Jen Pollack (TAMU-CC), Keith Walters (CCU), and many others….

Thanks especially to OIMMP and organizers for invitation

https://www.gofundme.com/f/oyster-restoration-website

FLORIDA ATLANTIC UNIVERSITY

COLLEGE OF CHARLESTON
FOUNDED 1770
CHARLESTON, SOUTH CAROLINA

PMS 877 (metallic silver)
HARBOR BRANCH
FLORIDA ATLANTIC UNIVERSITY

INSTITUTE OF MARINE SCIENCES AND FISHERIES
UNIVERSITY OF CHITTAGONG