ShARES: Shellfish Aquaculture in Reserves – Ecosystem Services

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NERRS Science Collaborative

Project Summary Slides

Outline

- Project objectives
- Project findings
  - Environmental impacts: sediment, water
  - Nitrogen sequestration by oysters (FARM model)
  - Wild oyster impacts: gene expression
  - Wild oyster impacts: condition, demographics
  - Habitat: reef-associated & transient fauna
- Summary of stakeholder discussion

1. Develop priorities for further research on ecosystem services and impacts of shellfish aquaculture
2. Develop priorities for considerations for management for shellfish aquaculture in Reserves

Shellfish aquaculture in National Estuarine Research Reserves

Masonboro Island NCNERR

- New oyster leases – 2015
- Moratorium on leases in Reserves – 2016
- Project funded – 2016
- Stakeholder group developed - 2017

Shellfish Aquaculture in Reserves: Ecosystem Services

NOAA NERRS Science Collaborative

Project Objectives

Assess the environmental impacts, including ecosystem services of shellfish aquaculture in the NC National Estuarine Research Reserve and other areas in SE North Carolina

Use stakeholder input to select parameters and sites of interest, guide research questions

Provide information to end users that will be useful for decision-making

ShARES
Shellfish Aquaculture in Reserves: Ecosystem Services

Stakeholder Concerns

A. Public access for traditional recreational and commercial activities

B. Seston depletion – adequate food for cultured oysters & wild organisms

C. Other changes to water and sediment characteristics (oxygen, nutrients, organic enrichment)

D. Impacts on wild oyster populations

E. Habitat

F. Impacts due to additional substrate (plastic pollution, viewscape)

- Now: real/perceived user conflicts are an important issue
- "Social carrying capacity" – an important topic for future study

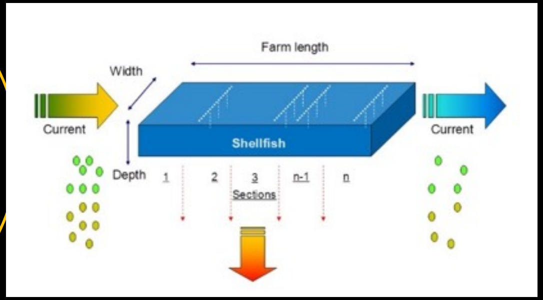
Objectives Addressed by this Project

State & Federal
NCNERR, NC Management agencies, NOAA

Shellfish leasing program
- Protect benthic resource (shellfish, seagrass)
- Manage user conflicts
- Assess long-term water quality/ecosystem effects

Habitat protection & Coastal management
- Balance research, education, recreation, and commercial fishing/aquaculture uses
- Ecosystem service valuation
- How management decisions impact water quality, using SWMP data.

Sustainable growth
- Economic opportunity
- Minimal financial risks
- Maximal output/profit
- High-quality production
- Aquaculture benefits (water quality, habitat)



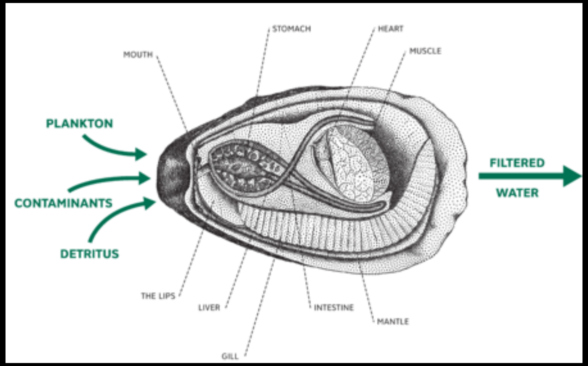
Industry: Shellfish growers (local and regional)

Project outputs include data and models that will aid decision-making.
Outcomes include relationship-building between managers and industry.

What do we mean by ecosystem services & environmental impacts, and how were parameters selected?

Ecosystem services – benefits people obtain from the regulation of ecosystem processes, e.g.,

- Improve water quality through filtration
- Provide habitat & nursery functions



Although there is increasing recognition that shellfish provide multiple ecosystem services, management of shellfish and their habitats for objectives beyond recreational and commercial harvest has not yet become widespread (Brumbaugh & Toropova 2008).

Ecosystem services

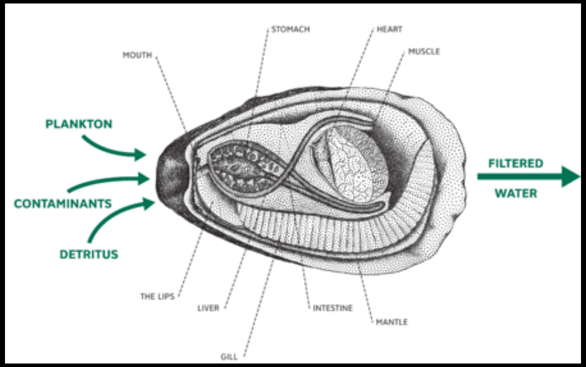
Models can calculate how much nitrogen farmed oysters can remove

Value: costs to prevent/remove nitrogen pollution

Great Bay, NH: 150 – 172 kg^{-1} N yr^{-1}

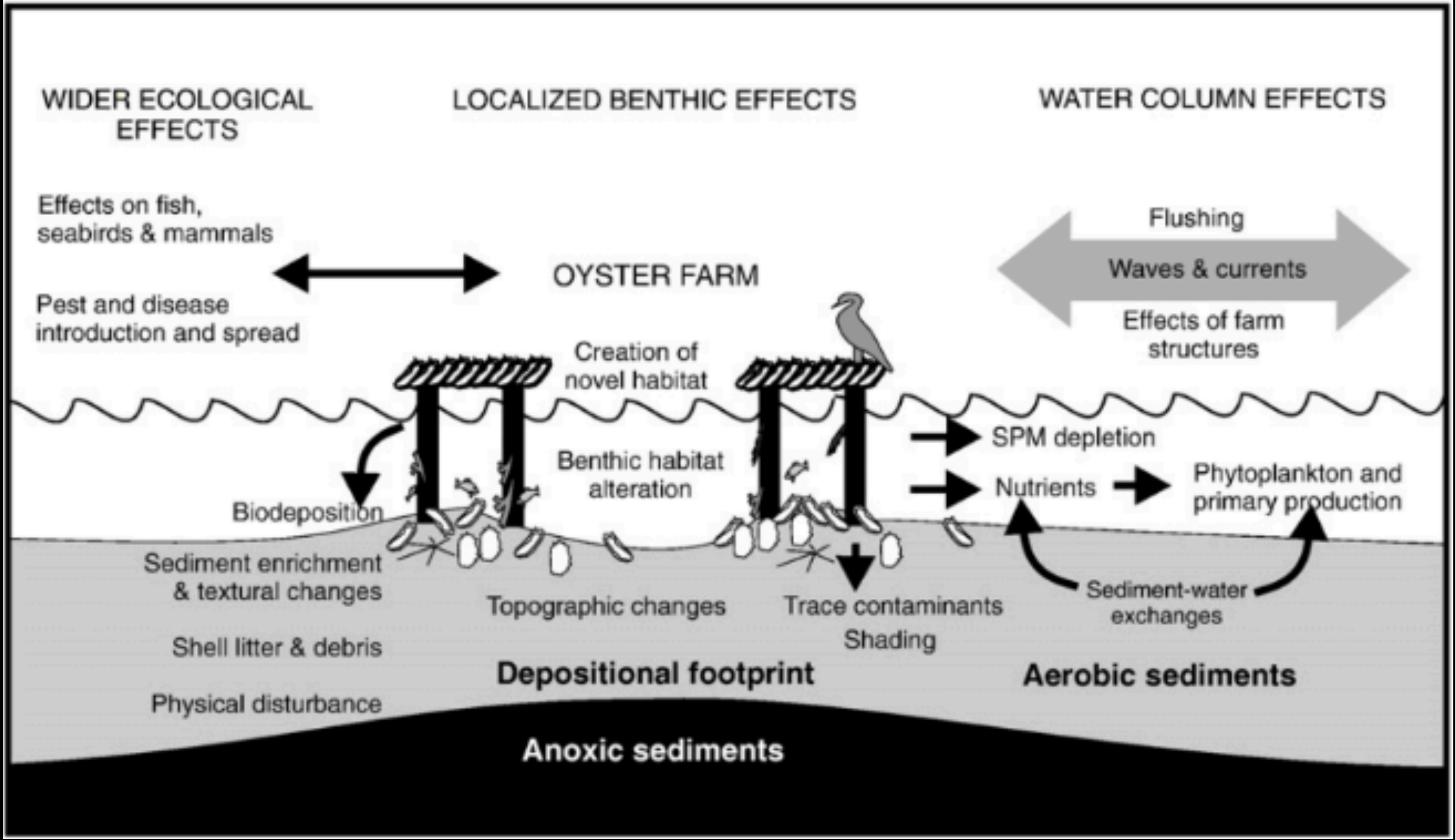
Avoided cost = \$3,600 – 4,100 $acre^{-1}$ yr^{-1}

Quantify nitrogen mitigation and habitat function



Bricker, S.B. et al. 2020. Estuaries & Coasts 43:23–38

Potential Impacts



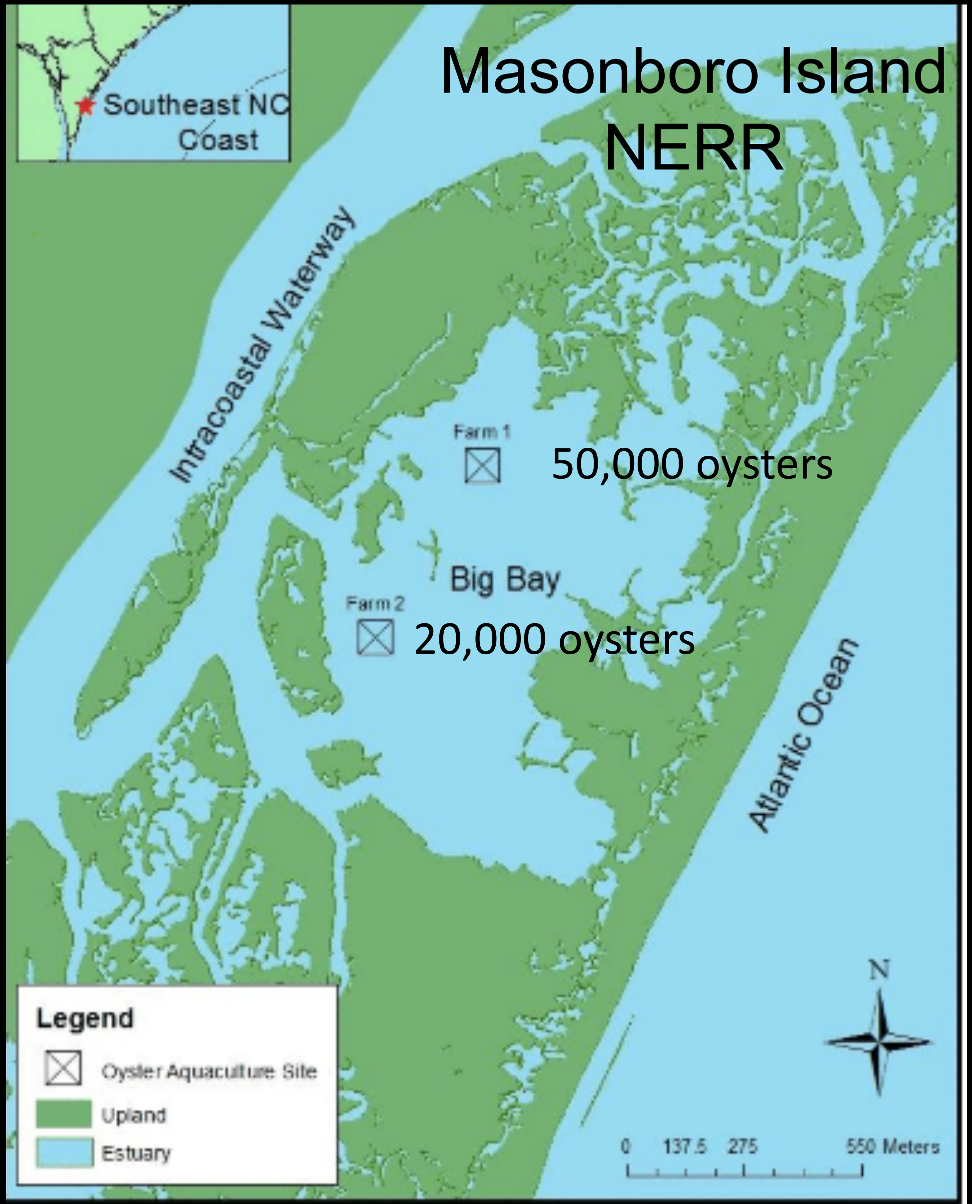
Quantify alterations to sediment and water column

Forrest, B.M. et al., 2009. Aquaculture 298:1-15

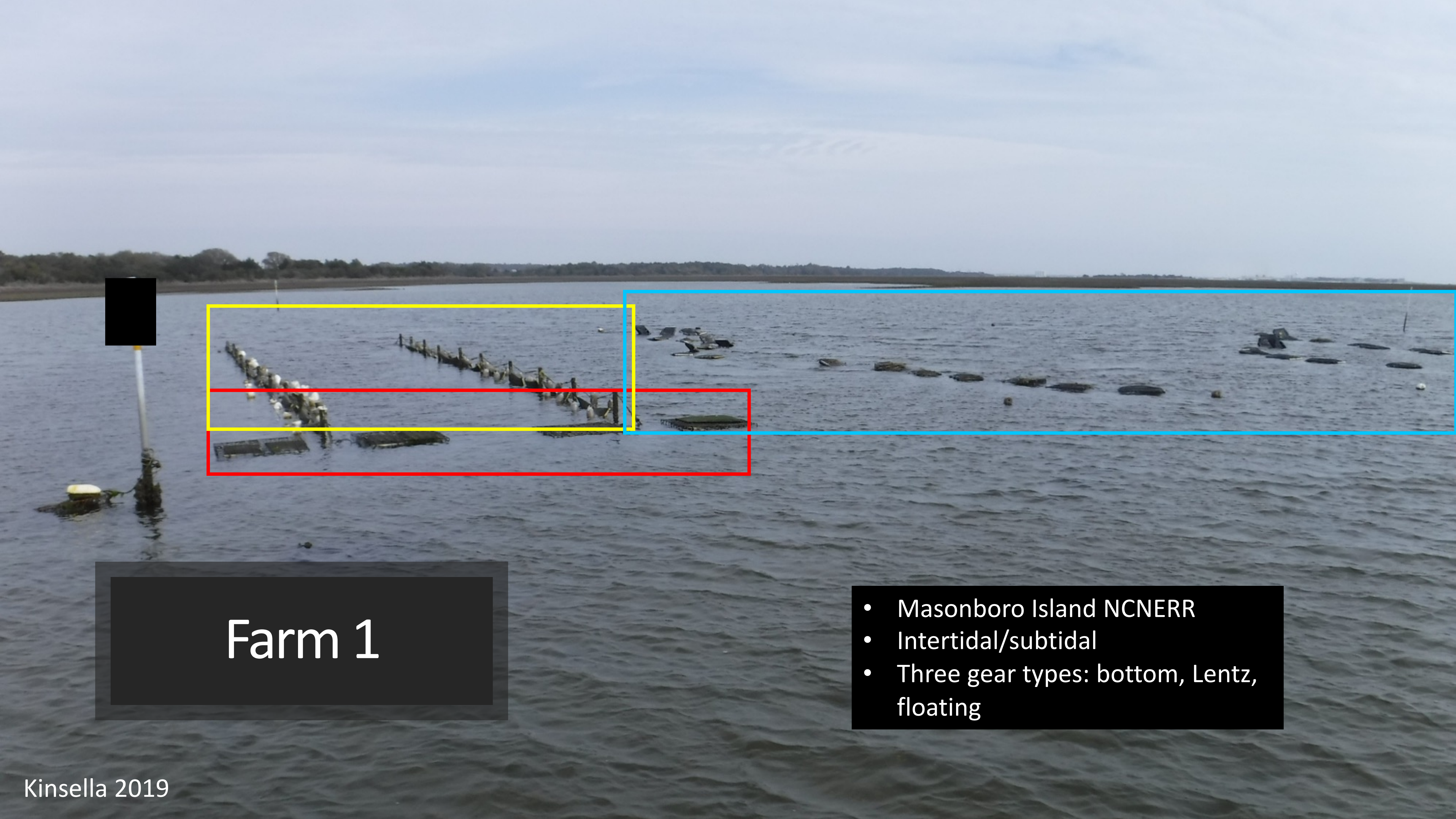
Choosing parameters: Stakeholder collaboration

Through open communication, diverse perspectives, and shared goals, the Stakeholder Group will advise research on the questions of shellfish cultivation impacts on: wild oyster resource, habitat, and water quality change; leading to a better understanding of the environmental influences of shellfish cultivation to ensure the development of an informed policy and a common language.

Study Sites



Kinsella 2019


Farm 1
Masonboro Island NCNERR
Intertidal/subtidal
Three gear types: bottom, Lentz, floating
Kinsella 2019

Farm 2

Farm 3

- New River Estuary
- Subtidal
- Three gear types
  - “Cage w/ bag” – Nov 2017
  - “Tray” – July 2017
  - “Cage” – July 2017

Kinsella 2019

Timeline

- Year 1: March 2017 – Feb 2018: Masonboro
  - wild oyster, sediment, water
  - Farm practices, oyster growth, physiology
- Year 2: March 2018 – Feb 2019: Masonboro & New River
  - wild oyster, sediment, water, habitat
  - Farm practices, oyster growth, physiology
  - Delays due to Hurricane Florence
- Year 3: March 2019 – Feb 2020
  - Incorporate physiology & farm practice into FARM model
  - Data analysis
  - No-cost extension to present due to Hurricane Florence delays

Timeline

- Year 1: March 2017 – Feb 2018: Masonboro
  - wild oyste
  - Farm prac
- Year 2: Marc
  - wild oyste
  - Farm prac
  - Delays due

2017: A determination was made by the NC Department of Natural & Cultural Resources – Natural Heritage Program finding that this activity is inconsistent with the site's purpose as a nature preserve.

The Division of Marine Fisheries sent leaseholders letters stating that leases would not be renewed based on this determination.

- Year 3: March 2019 – Feb 2020
  - Incorporate physiology & farm practice into FARM model
  - Data analysis
  - No-cost extension to present due to Hurricane Florence delays

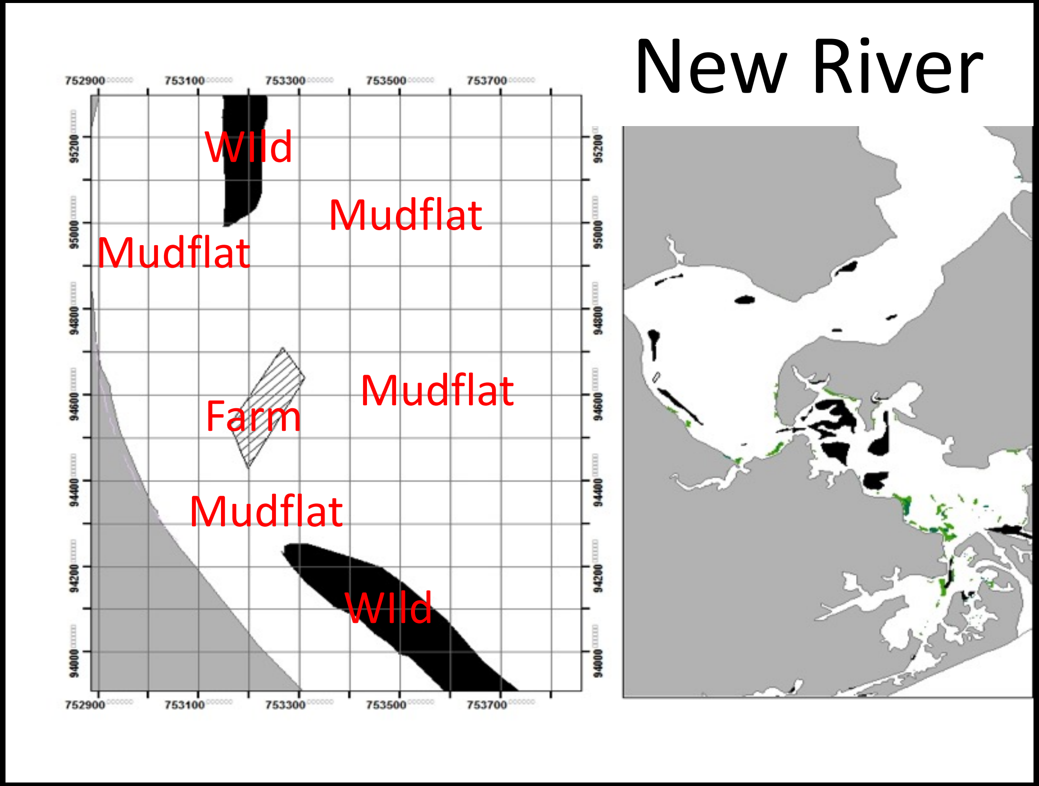
Selected Results

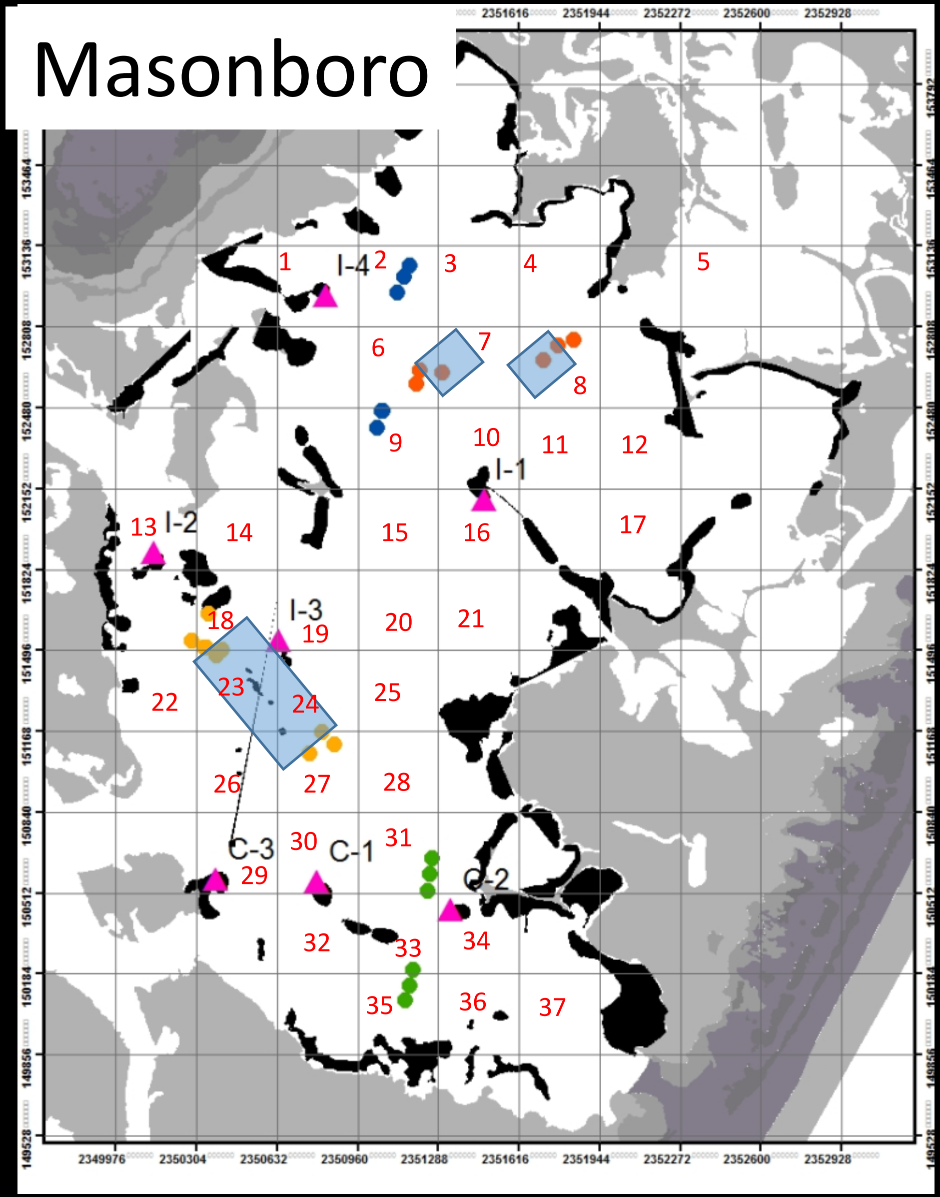
(Our undergrads were the best)

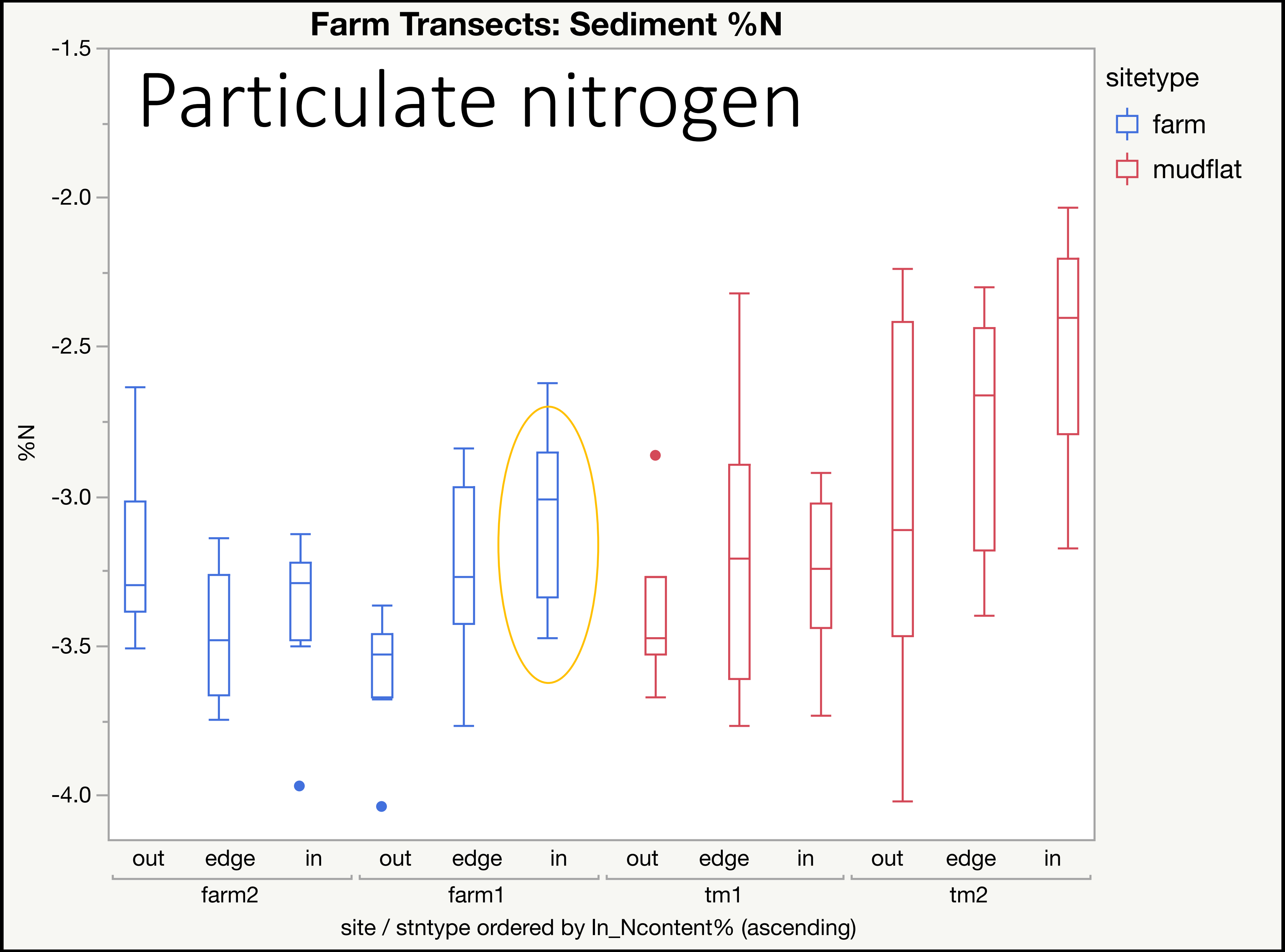
SHARES

Sediment Sampling

- Comparison of farm footprint to mudflat and wild oyster or shell management area
- Evidence of nutrient/organic matter changes? Toxic levels of sulfide/ammonium?

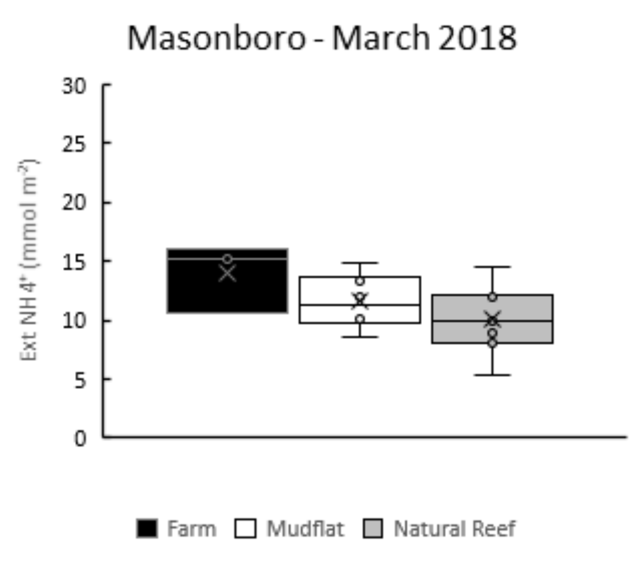


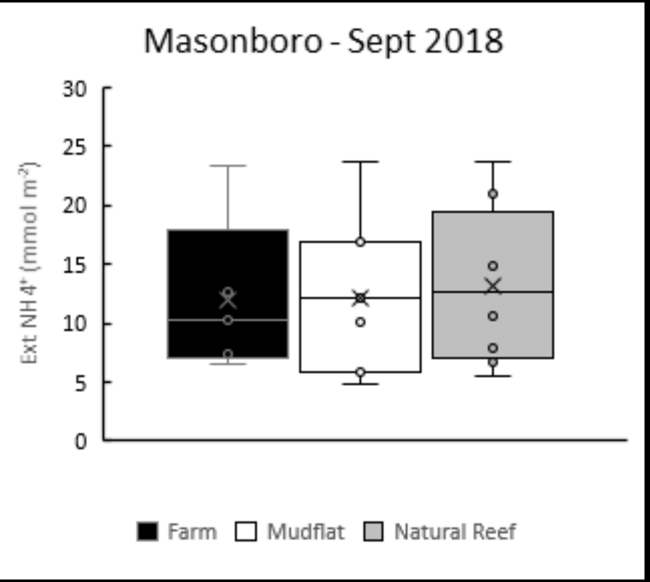


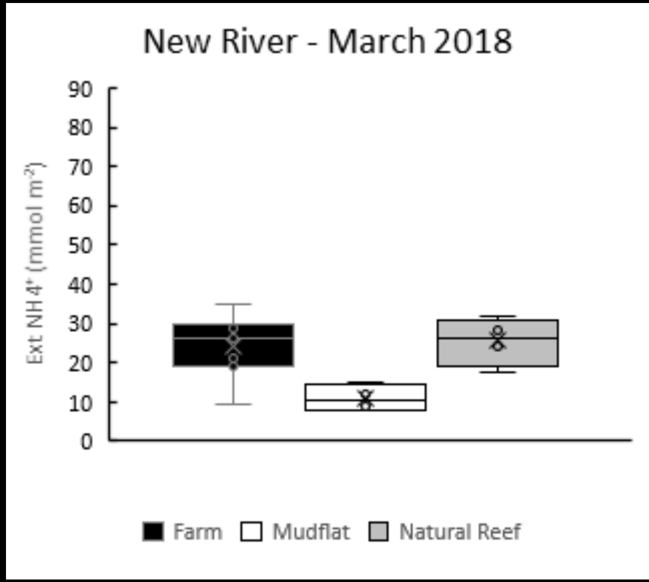


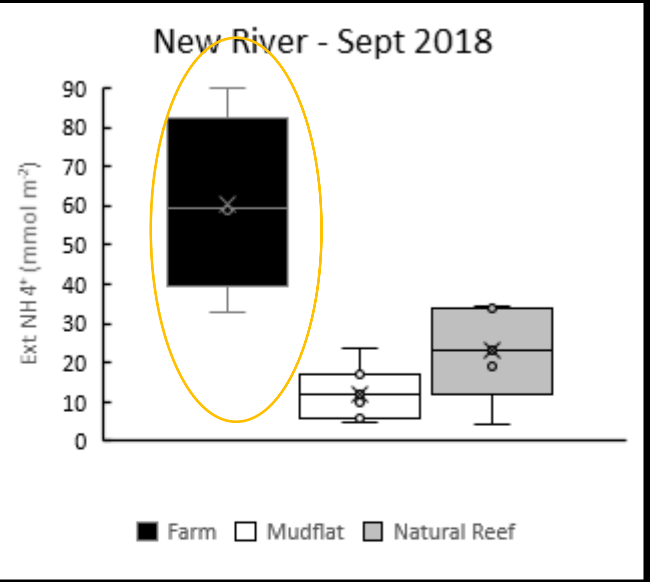
Farm Transects: Sediment %N
Particulate nitrogen
sitetype
farm
mudflat
%N
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
out
edge
in
out
edge
in
out
edge
in
out
edge
in
farm2
farm1
tm1
tm2
site / stntype ordered by ln_Ncontent% (ascending)

Extractable ammonium







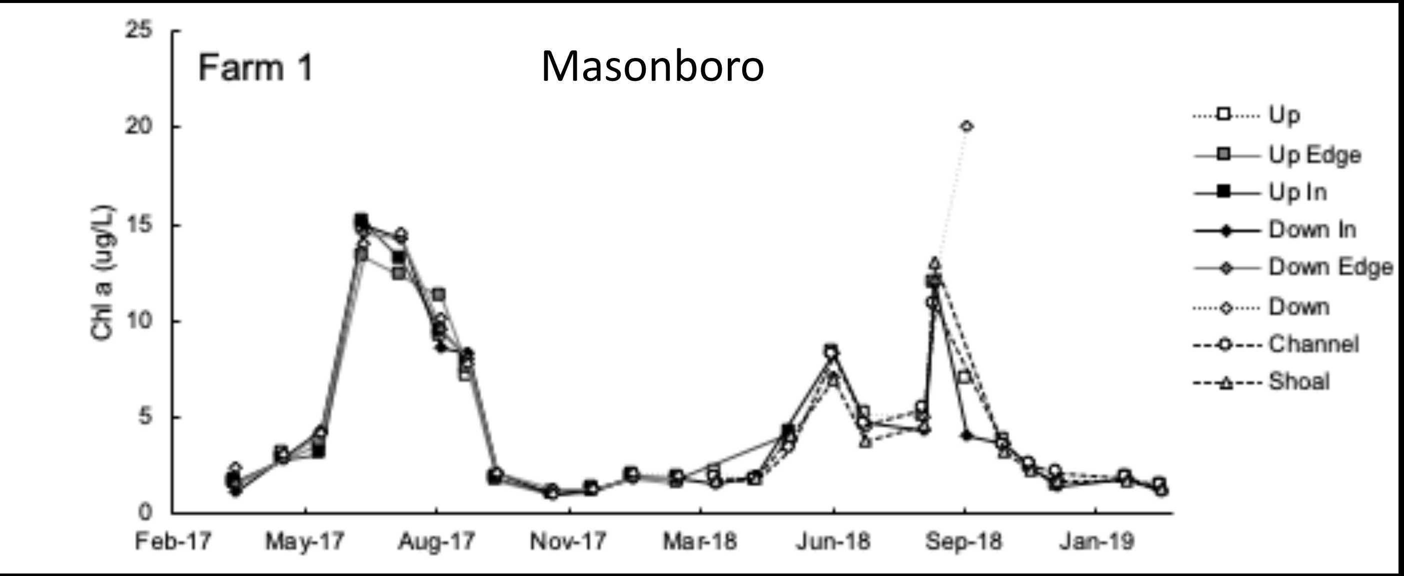


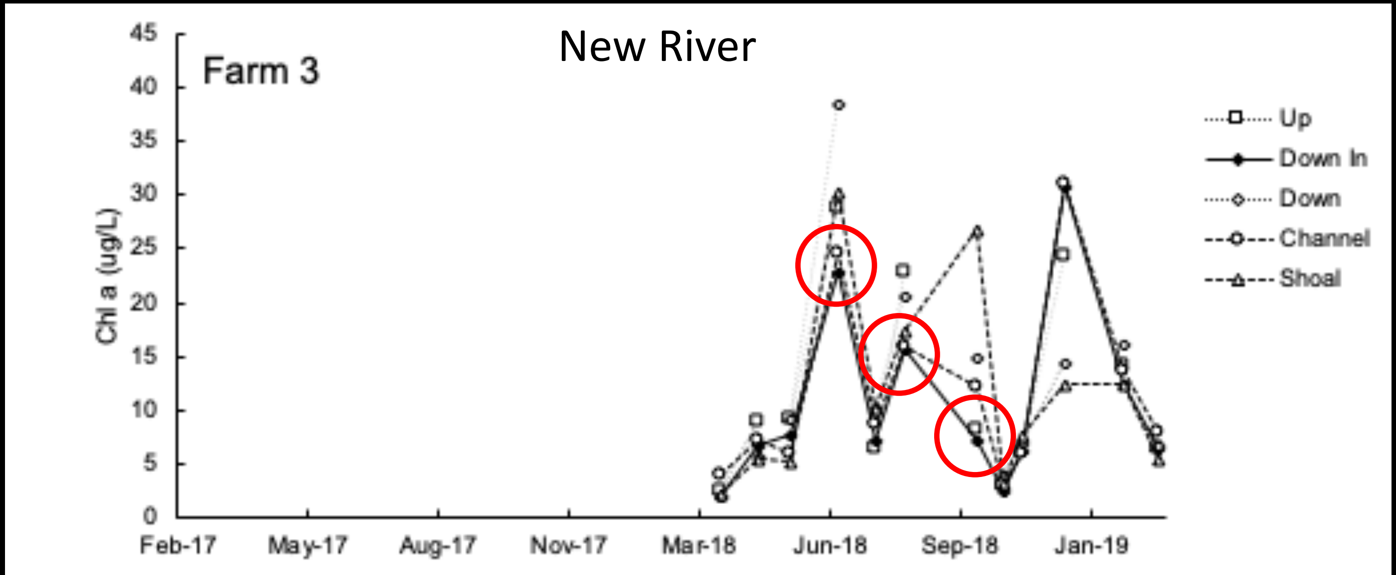
New River > Big Bay

Farms > other sites, only at New River in September

Water column

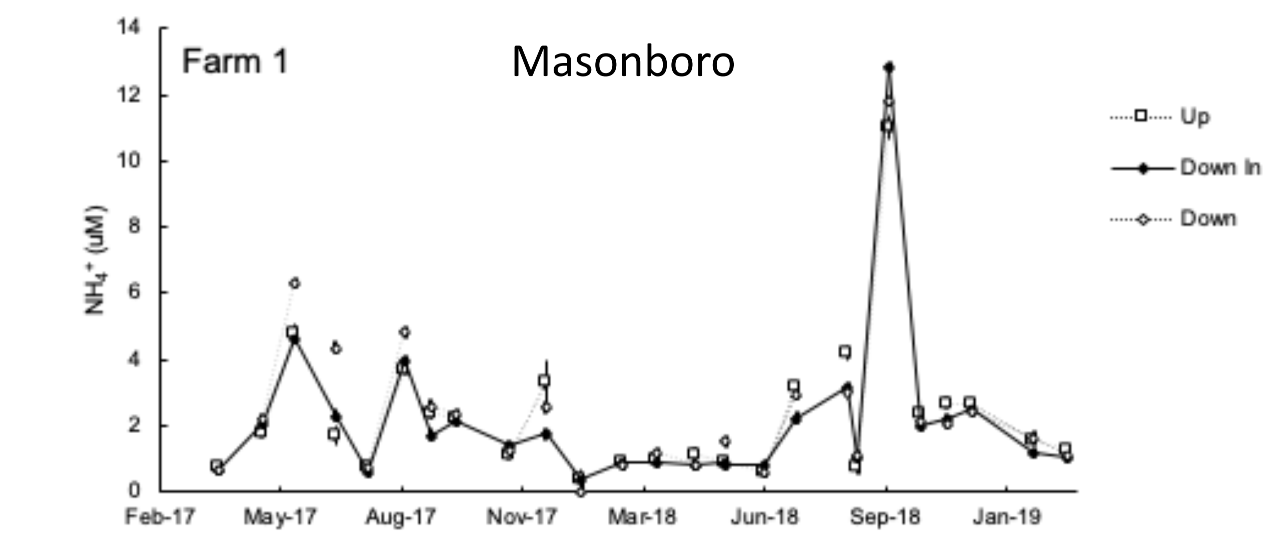
- Chlorophyll – food for oysters
- Higher concentrations at Farm 3 (New River)
- No consistent change across farms (drawdown by oysters)
    - New River: lower Chl in farms in summer
- No evidence of consistent seston depletion within farms
- Particulate organic matter data used to run FARM model

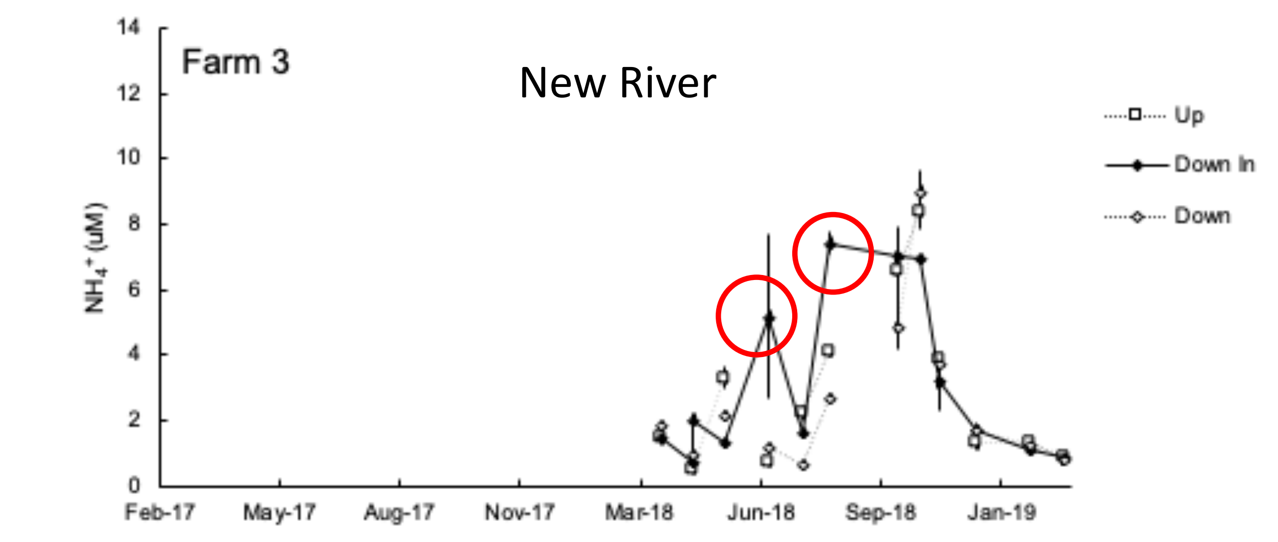




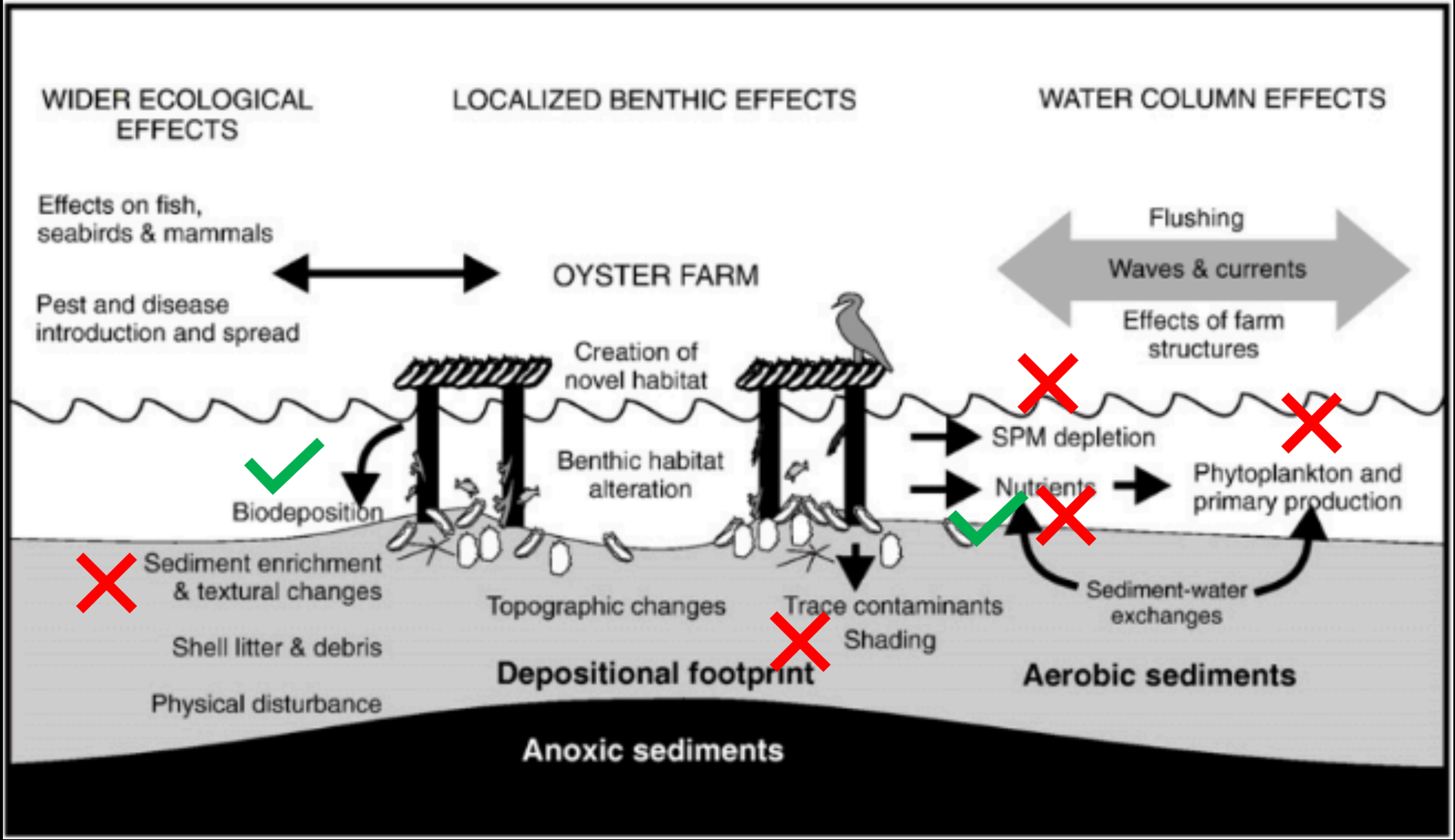
Water column

- Ammonium, nitrate, phosphate
- Could increase locally within farms with concentration of biodeposits
- Large seasonal variability
- No evidence of consistent change within farms
- Use modeling approach to calculate removal of N from embayment – incorporation into oyster biomass





Summary: Environmental Impacts



Forrest, B.M. et al., 2009. Aquaculture 298:1-15

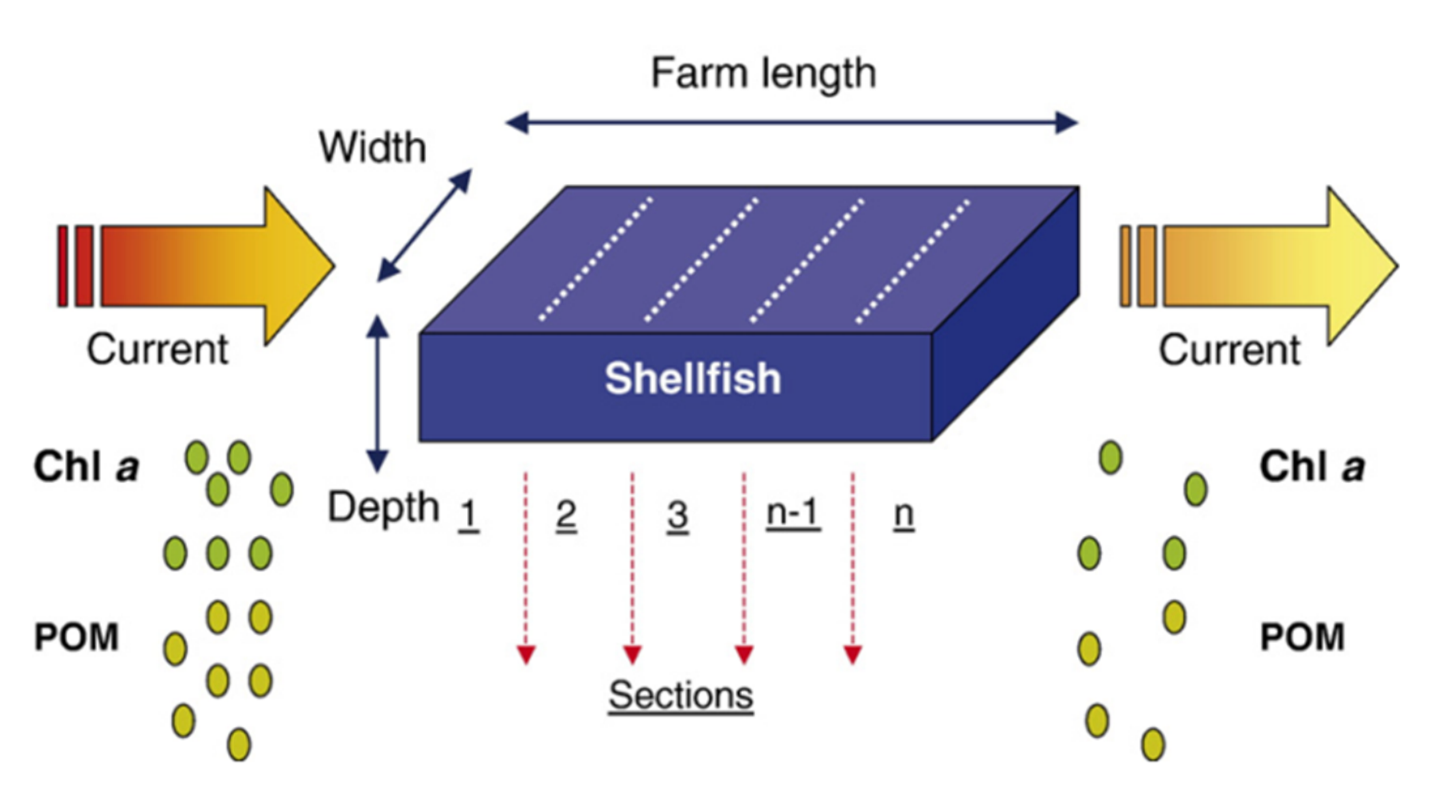
The FARM Model

Farm production

Filtration carrying capacity

Influence on nitrogen, oxygen

OYSTER GROWTH



PARTICULATE NITROGEN

LESS NITROGEN

Methods

Quantifying nitrogen removal by locally-farmed oysters

Environmental Drivers (monthly)

- Temperature
- Salinity
- Particulate organic matter
- Total suspended solids
- Current speed

Oyster Physiology (lab) *Kinsella*

Triploid oysters:

- Feeding
- Egestion
- Excretion
- Respiration

Oyster Growth (monthly) *Kinsella*

- All gear types
- All start dates
- Shell dimensions
- Wet weight, dry weight

Model Calibration

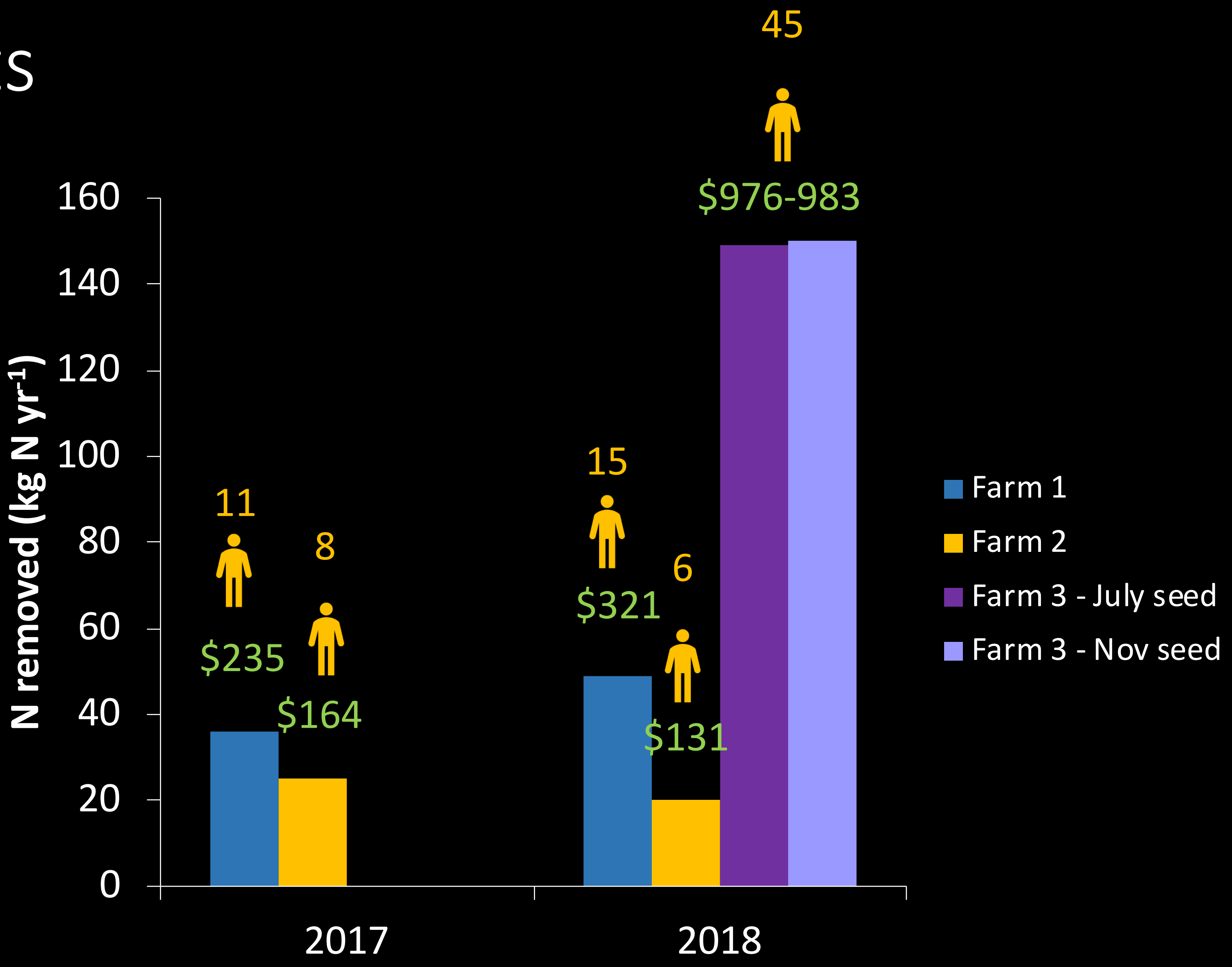
- Individual model – check growth
- Stocking densities
- Mortality rates
- Size of farm

FARM Model Results

Nitrogen removed by entire farm: highest at Farm 3

3.3 person equivalents/kg N

Nutrient offset credit value from the Neuse River watershed: $6.55/kg



Darrow, Cubillo, Ferreira, Kinsella, Bricker *unpublished*

Farms 1 & 2:

High tidal energy

High seeding density

High mortality

Higher N sequestration per area

Farm 3:

More food

More oysters

Larger leased area

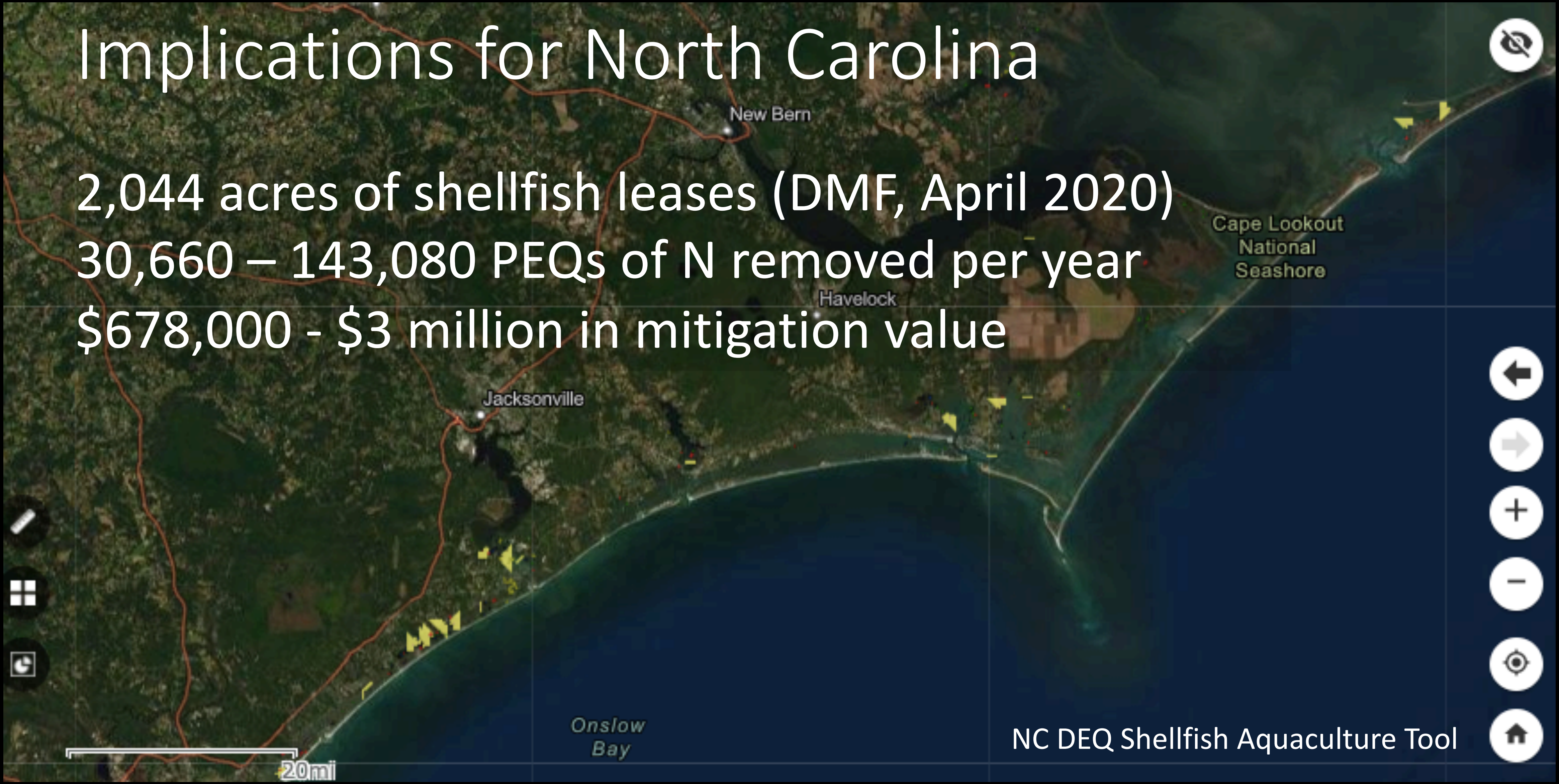
Higher N sequestration per farm

Literature Comparison

Location	N removed (kg $acre^{-1}$ yr^{-1})	Reference
Potomac River, MD	230	Bricker et al. 2014
Long Island Sound, CT	105	Bricker et al. 2018
Great Bay, NH	72	Bricker et al. 2020
Sanggou Bay, China	51	Ferreira et al. 2008
Masonboro Island, NC	104 - 230	This study
New River, NC	51	This study

Implications for North Carolina

2,044 acres of shellfish leases (DMF, April 2020)
30,660 – 143,080 PEQs of N removed per year
$678,000 - $3 million in mitigation value



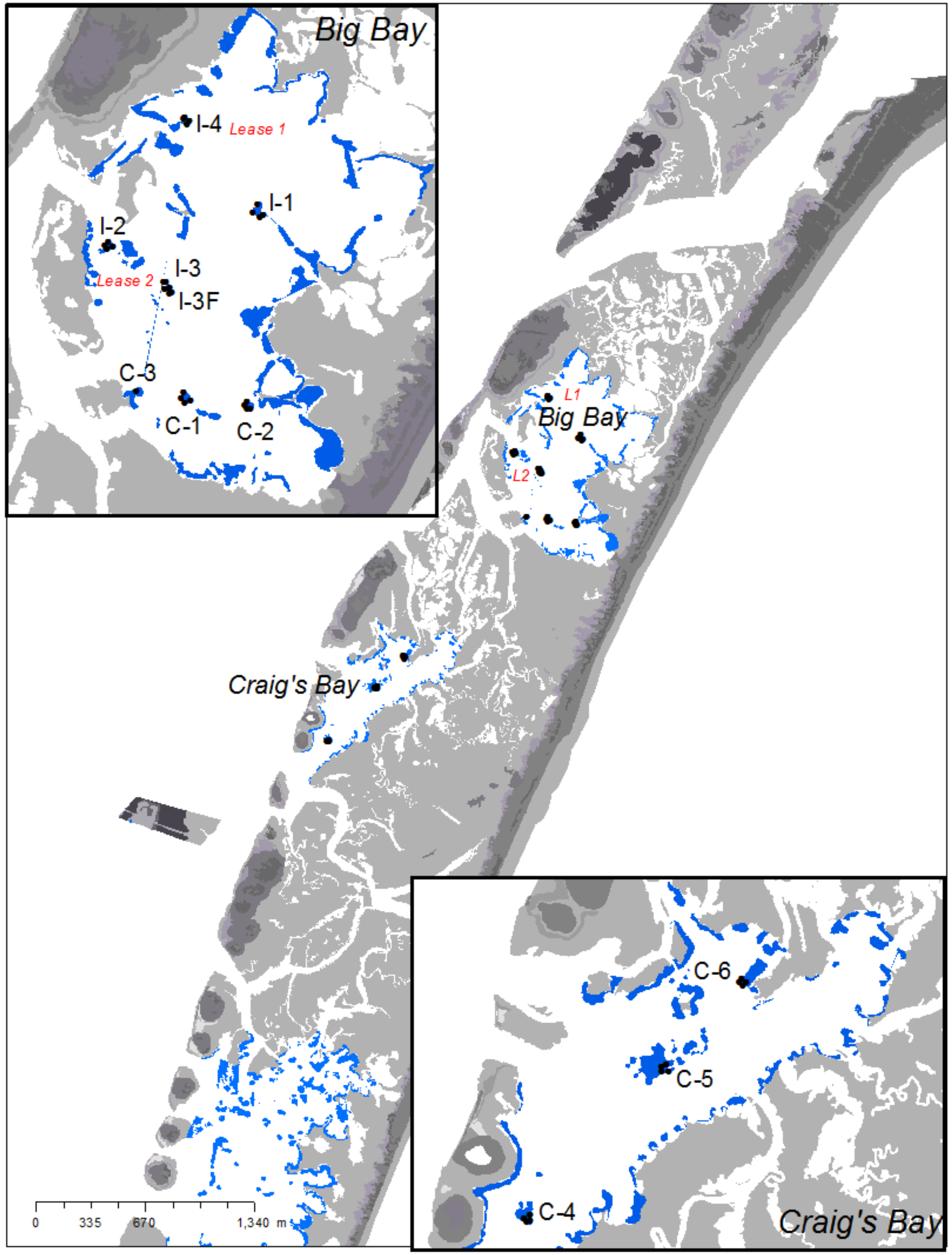
NC DEQ Shellfish Aquaculture Tool

Wild Oyster Sampling

<u>Targeted</u>
I-1, I-2, I-3, I-4

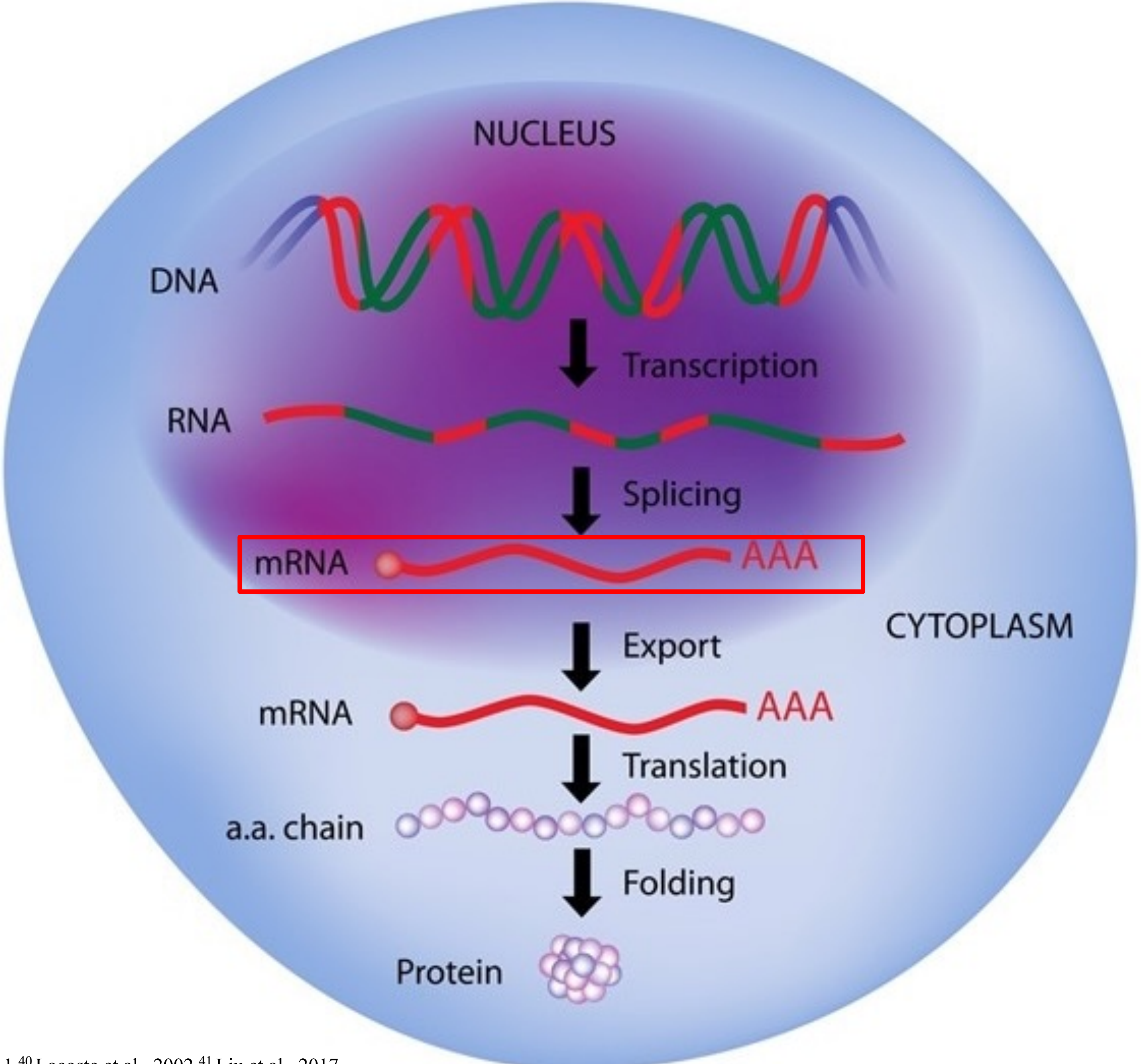
<u>Control</u>
Big Bay:
C-1, C-2, C-3

Craig's Bay:
C-4, C-5, C-6



BIOMARKERS

- The RNA resulting from changes in regulation of selected genes within the *C. virgnica* genus can be used as molecular biomarkers to indicate whether the oyster is being exposed to harmful biotic or abiotic factors such as environmental disturbances associated with aquaculture like increased incidence of disease and stress[36 37 38 39 40 41]



[36.]M.W. Beck et al., 2011 [37.]Genard et al., 2011 [38.]Genard et al., 2012 [39.]Piontkivska et al., 2011 [40.]Lacoste et al., 2002 [41.]Liu et al., 2017

https://www.news-medical.net/life-sciences/Regulation-of-Gene-Expression.aspx

Biomarkers

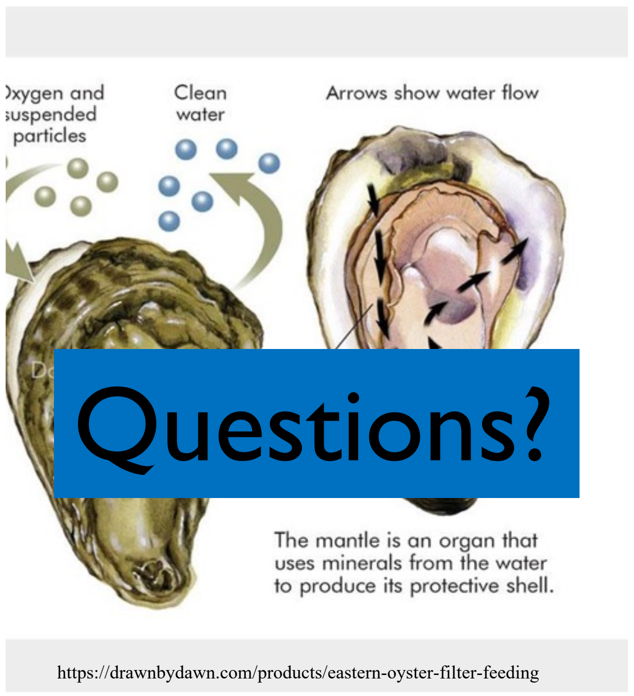
- Stress Response[40 41 42 43]
  - Elevated temperature, bacterial infection, pH, mechanical disturbances
  - Up regulation of genes
- Immune Response[37 38 44 45 46]
  - Increase in bacterial and viral disease, parasitic infection
  - Up regulation of genes
- Metabolism[37 38 39 47 48]
  - Elevated temperature, CO_2 level, salinity
  - Down regulaton of genes
- Reference Genes[37 49 50]

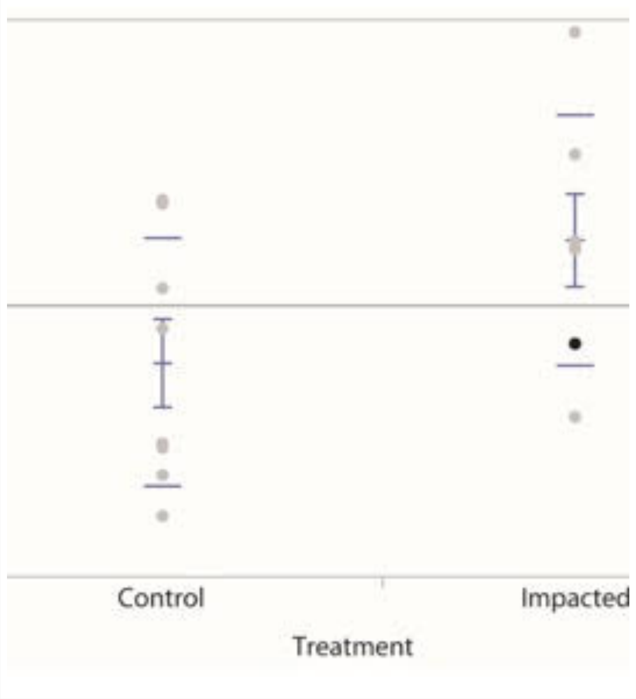
Gene	Symbol	Function
Killer cell lectin-like receptor	KCrec	Non-self recognition (lectin receptor family)
ATP synthase f0 subunit 6	AS6	Energy metabolism (complex V of electron transport chain)
Endothelial lipase precursor	EDL	Lipid metabolism (phospholipase)
Heat shock protein 70	HSP70	Chaperone protein (cytoprotection)
Peroxiredoxin 6	PRDX6	Oxidative stress (antioxidant enzyme)
Glutamine synthetase	GS	Protein metabolism (amino acid synthesis)
RAS supressor	SUP	Cell division inhibitor
Ribosomal protein 18s	R18s	Reference
Beta-actin	BActin	Reference

[42.] Clark et al., 2013 [43.] Wang et al., 2012 [44.] Ackerman et al., 2001 [45.] McGreal et al., 2004 [46.] Ymaura et al., 2008 [47.] Ivanina et al., 2013 [48.] Zacchi et al., 2017 [49.] Etschmann et al., 2006 [50.] Radonic et al., 2004

SUMMARY

- Differences in gene expression between control and potentially impacted sites, in gill tissue, was found for the EDL, HSP70, PRDX6 and GS genes. Differences in gene expression between seasons, in gill tissue, was found for the AS6, and KCrec genes. Site specific differential expression in gill tissue was found for EDL, PRDX6, and KCrec genes.
- For body tissue: PRDX6 between control and potentially impacted as well as seasonally. SUP showed differential expression site specifically for the Spring. This research shows that there is a difference in gene expression between naturally occurring reefs that are closer to aquaculture sites and naturally occurring reefs that are farther from aquaculture sites, supporting their continued use as molecular biomarkers of stress in oysters.
- The majority of significant or nearly significant differences observed were gill tissue, which indicates that gills are more sensitive to biotic and abiotic stressors[55]





One way analysis of variance (ANOVA) of the EDL biomarker in gill tissue of wild *Crassostrea virginica* between all control and all impacted sites. This result indicates an overall increase in lipid metabolism, which may mean oysters had a shift in diet and / or in metabolic rate due to the presence of mariculture activity nearby.

[55] Meistertsheim et al., 2007

Wild Oysters and Associated Fauna

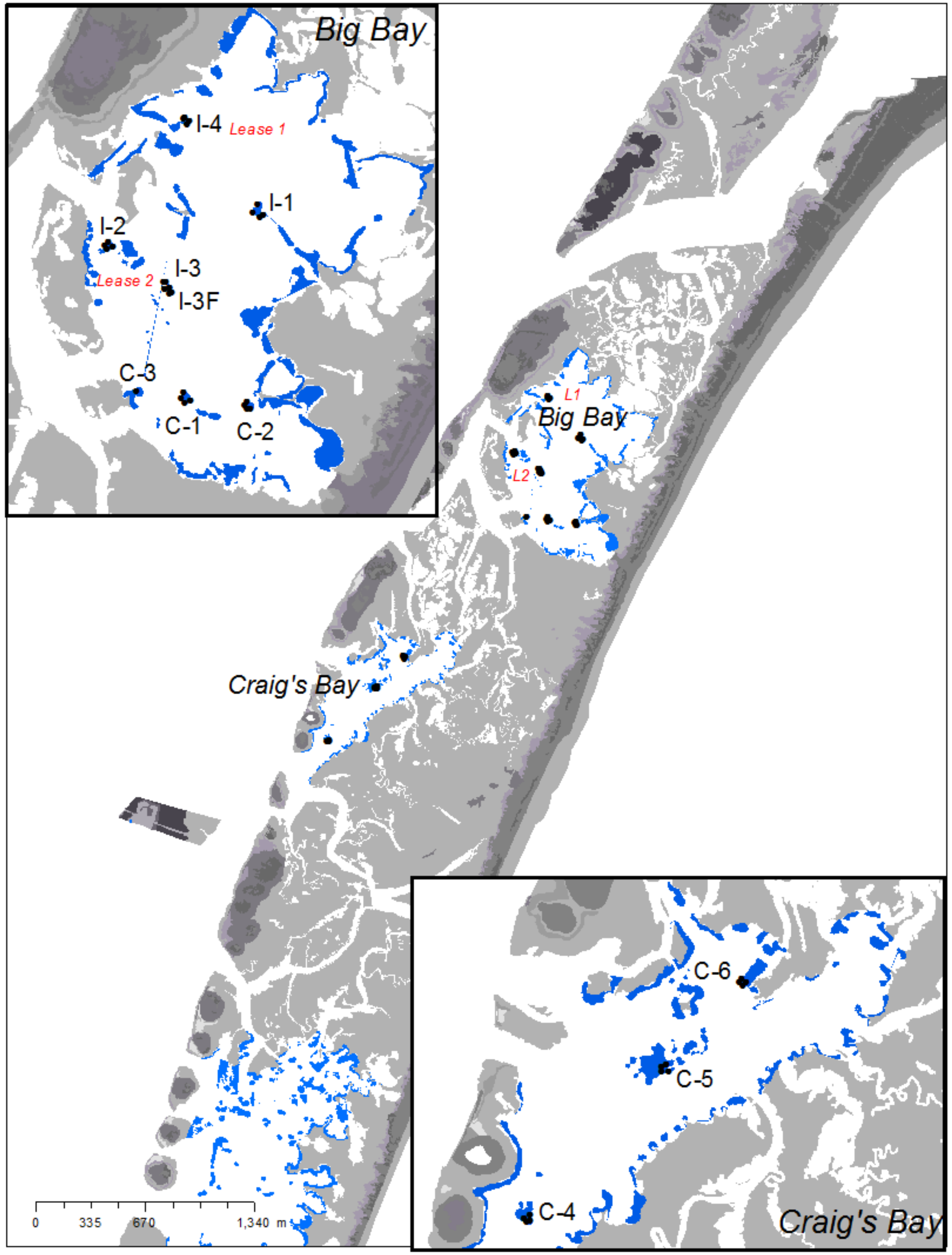
- Oysters
  - Sampled reefs near aquaculture operations (impacted) and reference (control) reefs more distant from aquaculture farms
  - Also sampled impacted reefs open to harvest versus impacted reefs not open to harvest
  - Quadrat sampling seasonally, excavations of oysters
    - Abundances, sizes (length), condition
  - Settlement of oysters using spat settlement racks
- Associated fauna
  - Same reefs as oyster sampling
  - Quadrat sampling with excavations; all organisms retained on a 1 mm screen (bivalves, polychaetes, crabs, other ..).
    - Abundances, sizes for selected taxa
- Nekton
  - Nekton under and adjacent to aquaculture operations (including varying distances from operations), impacted reefs, control reefs
  - Seines, Breder traps, lift nets, baited minnow traps
    - Abundances, sizes for selected taxa

Wild Oyster Sampling

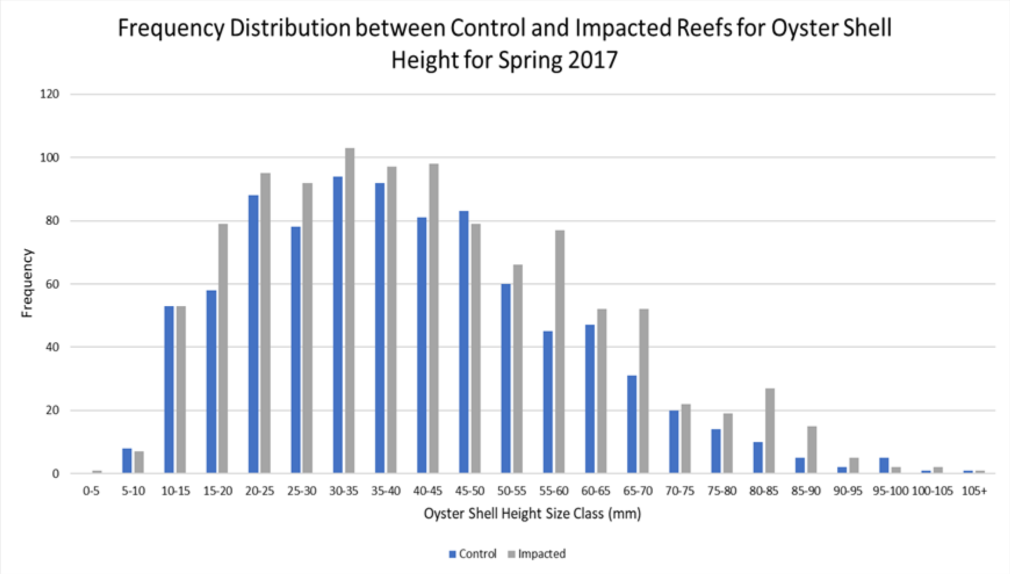
<u>Targeted</u>
I-1, I-2, I-3, I-4

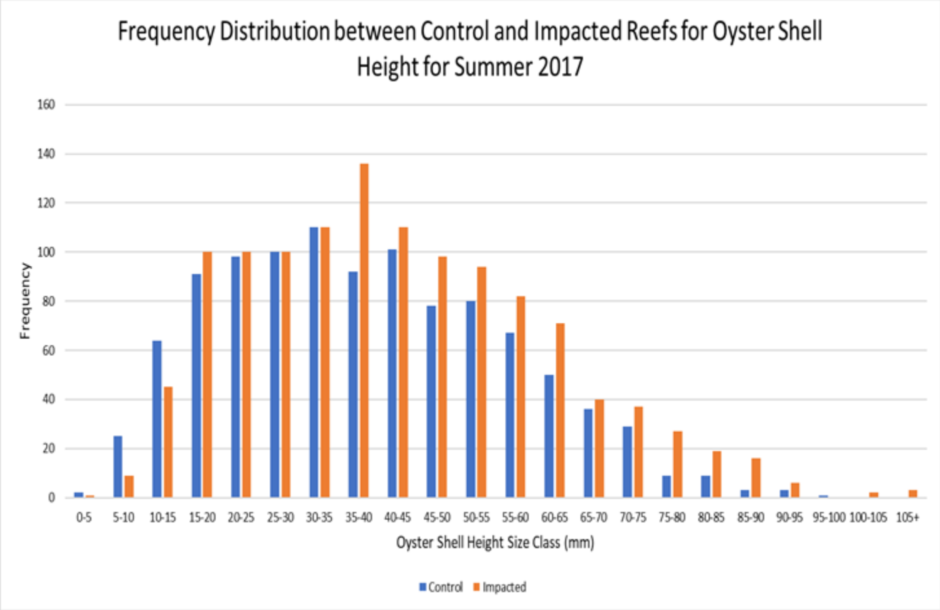
<u>Control</u>
Big Bay:
C-1, C-2, C-3

Craig's Bay:
C-4, C-5, C-6

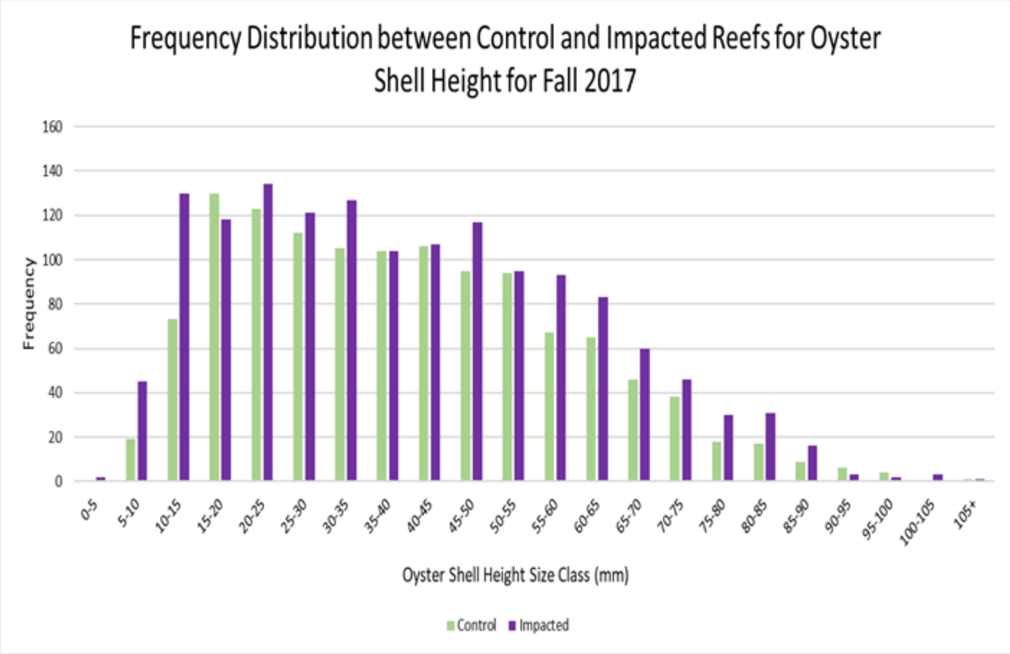


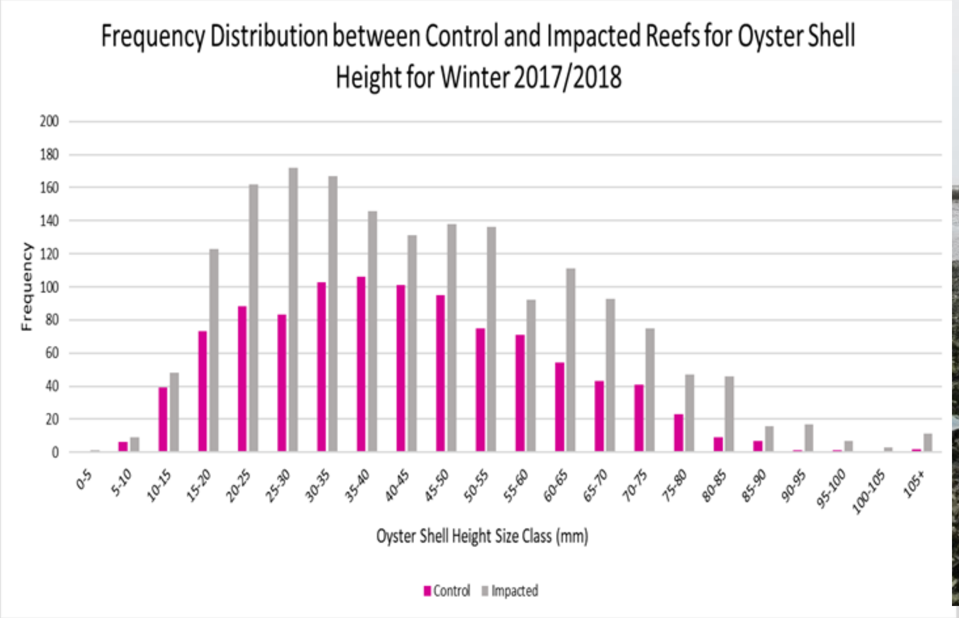
- Abundances and size distribution of oysters on impacted and reference reefs:

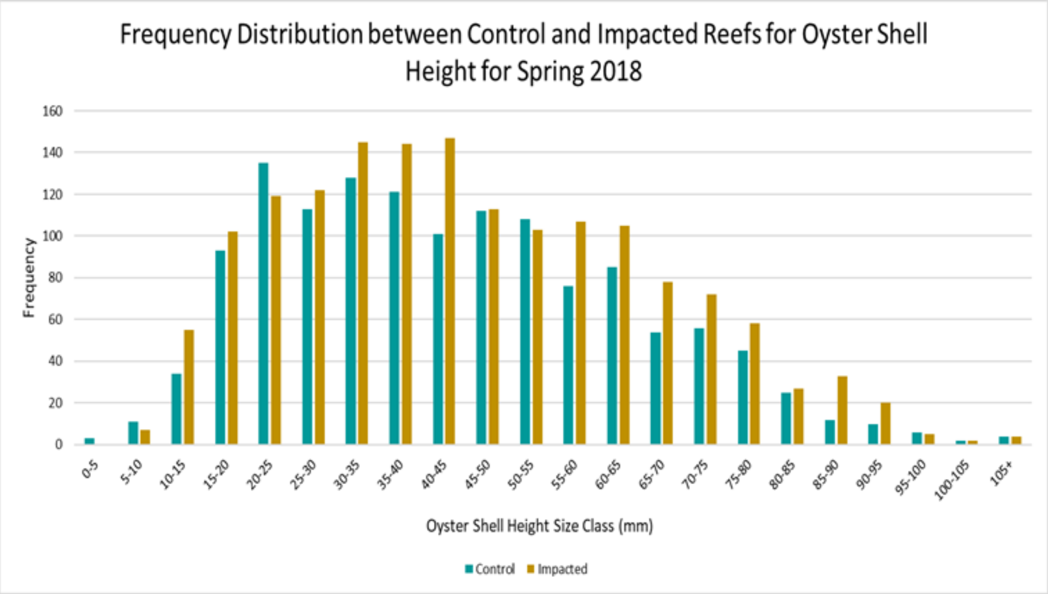


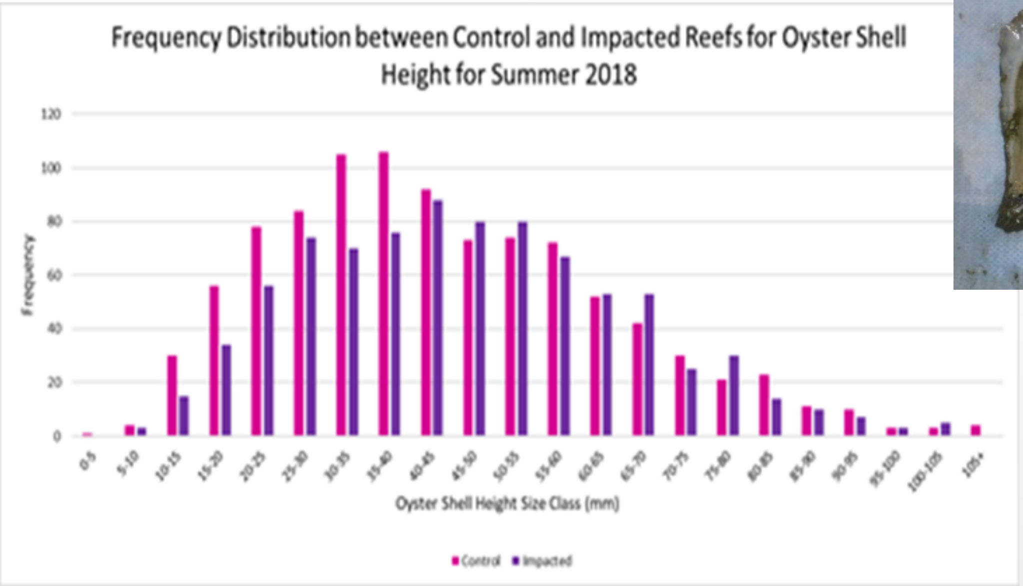


2017 size frequency distributions

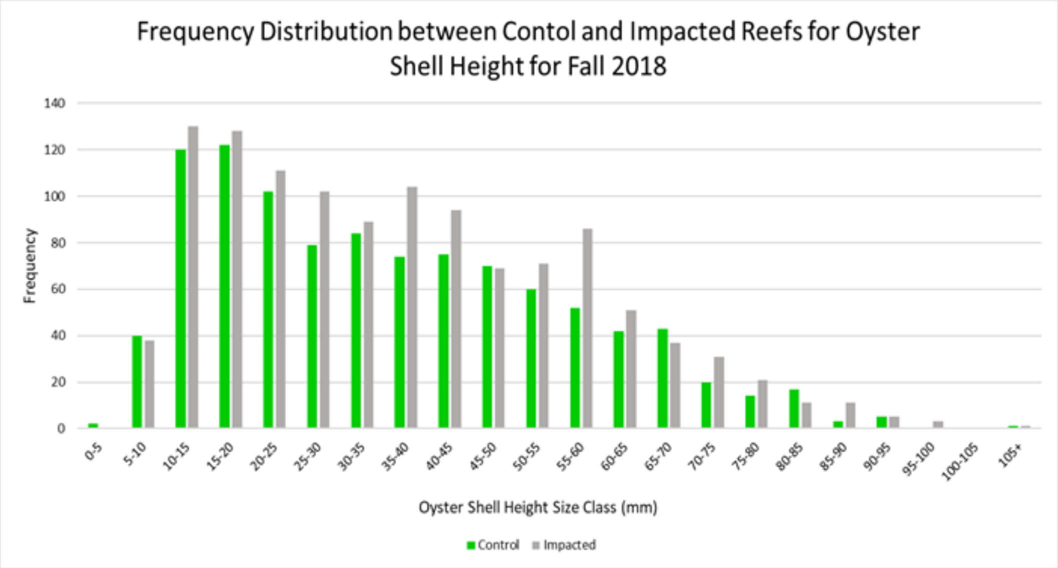


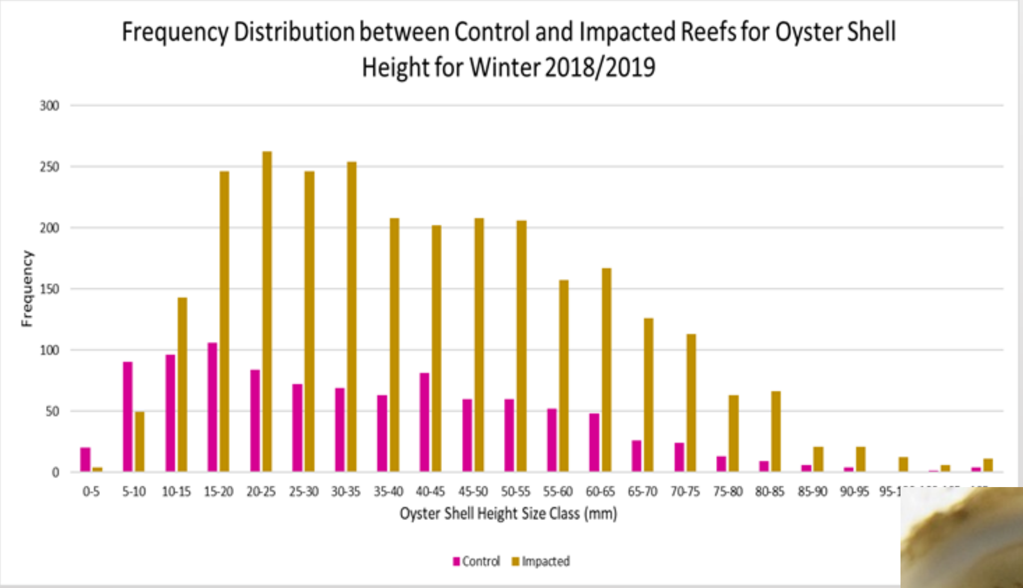




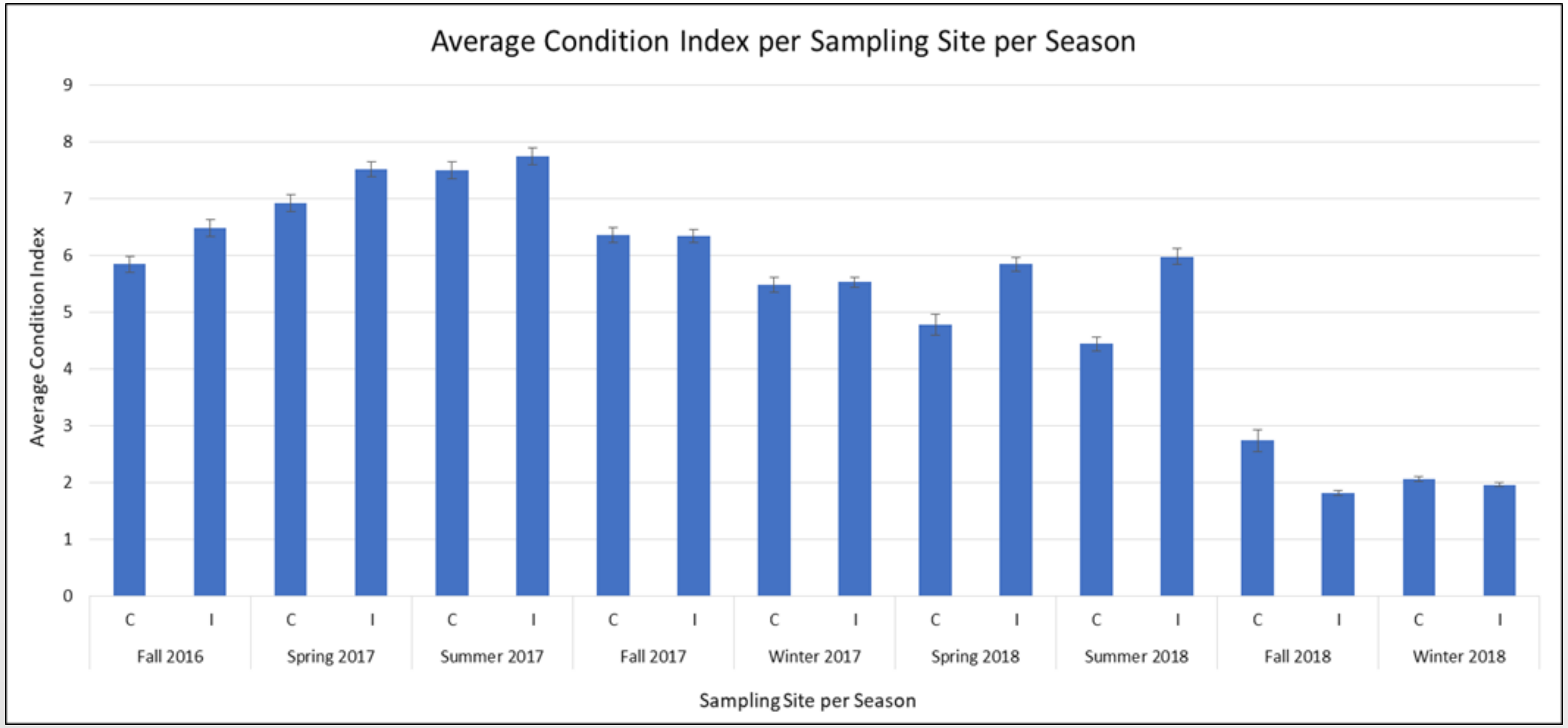


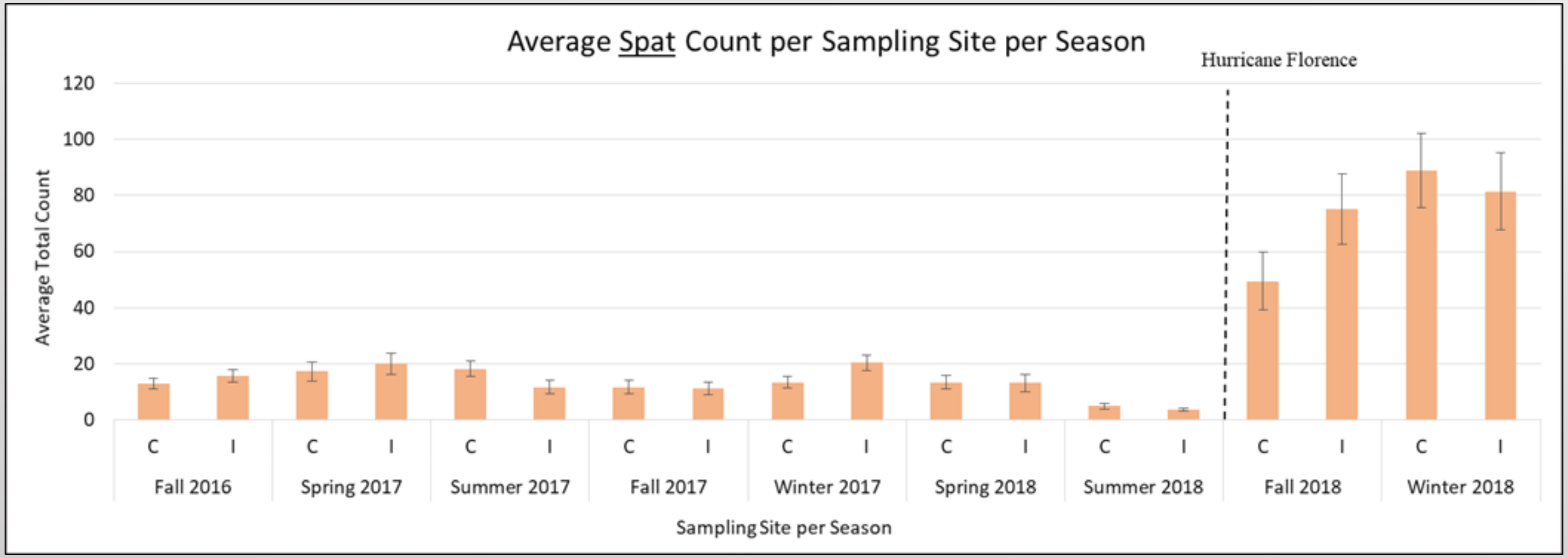
2018 size frequency distribution



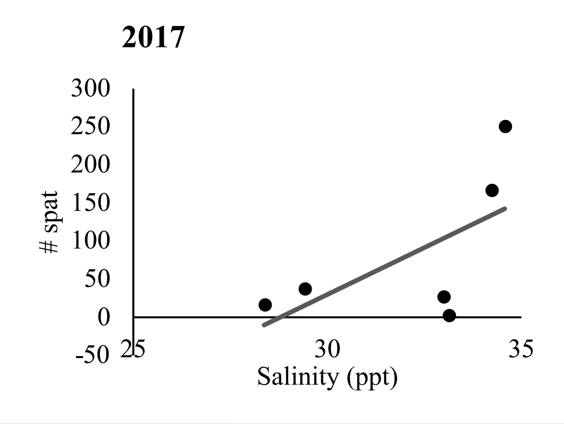


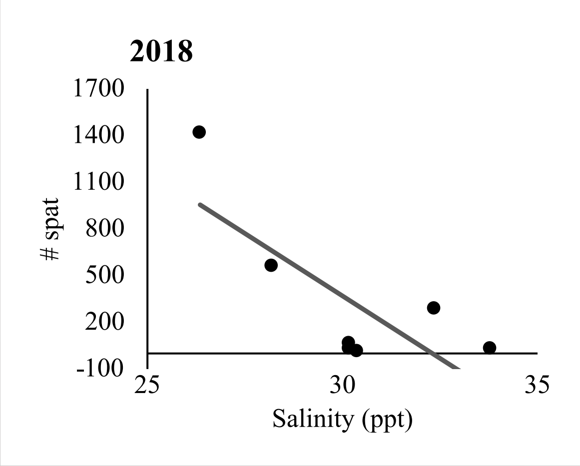
- Condition Index and spat counts within quadrats on impacted and reference reefs

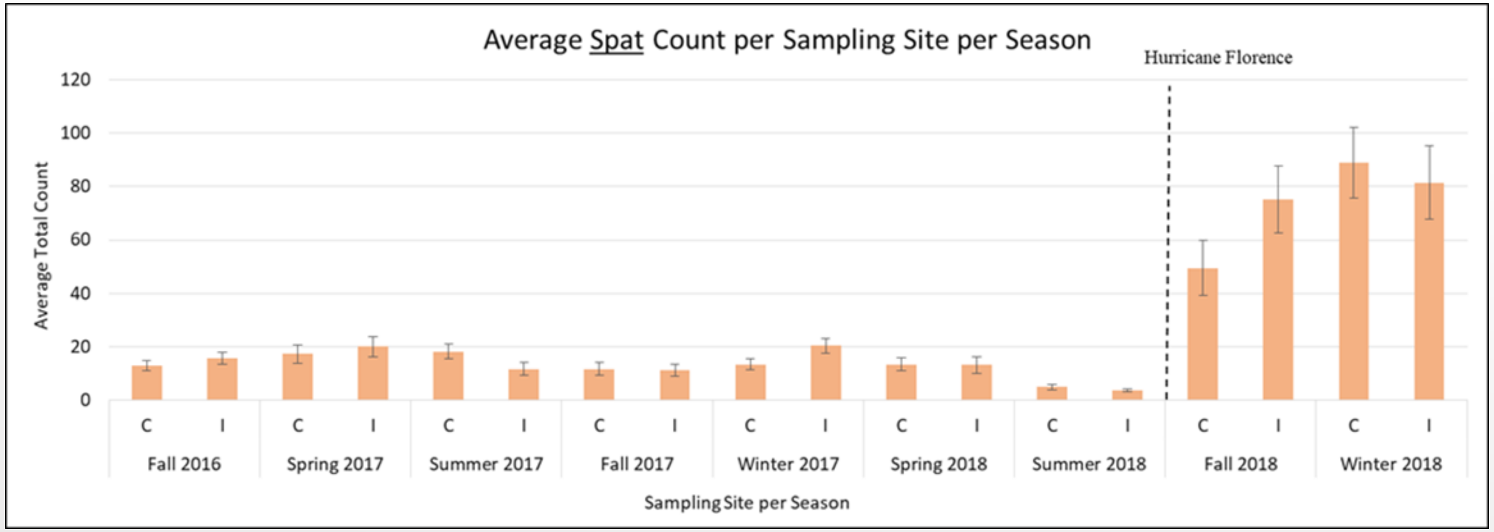




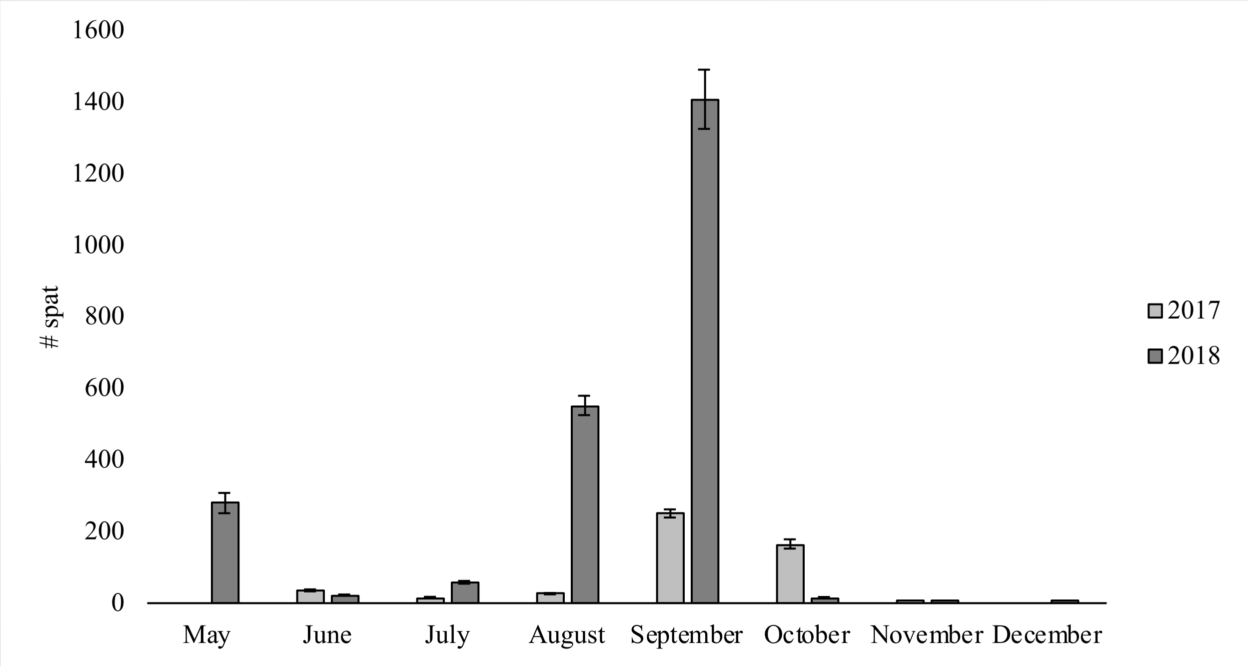
- Evidence for Hurricane Florence impacts on oyster recruitment





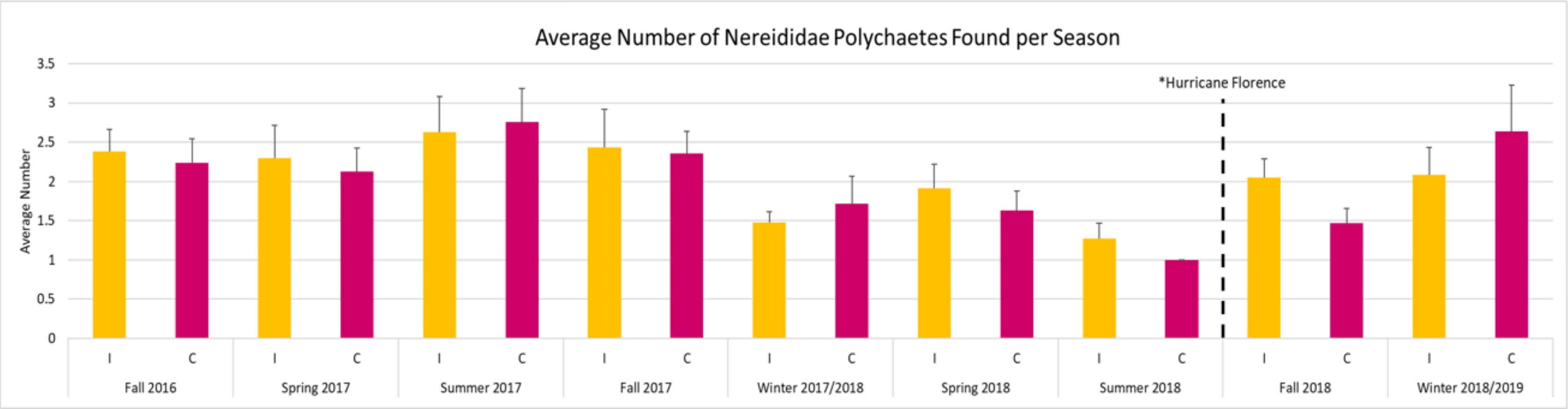


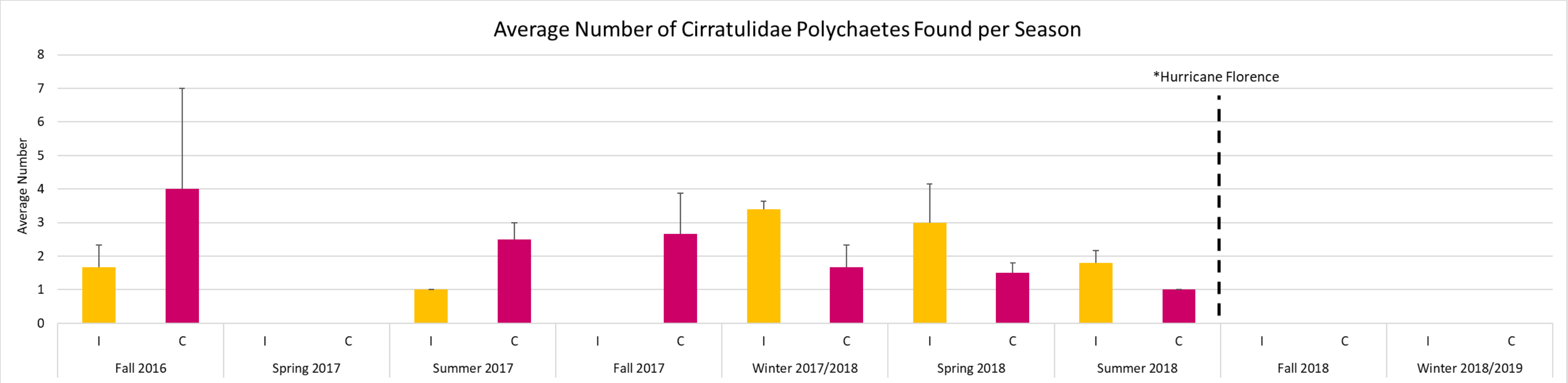
Spat count in quadrats

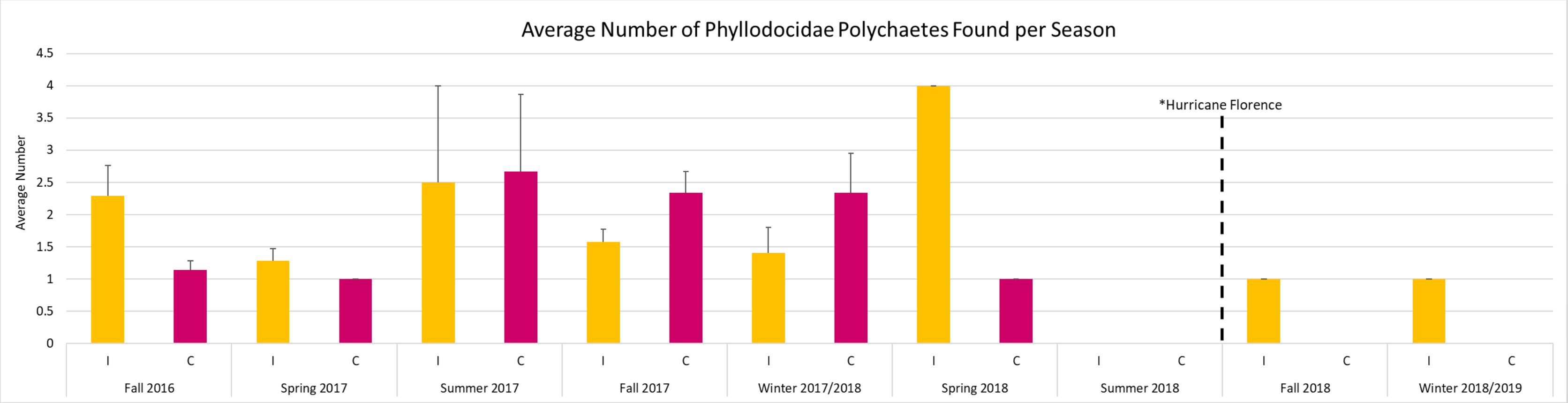


Spat settlement on tiles

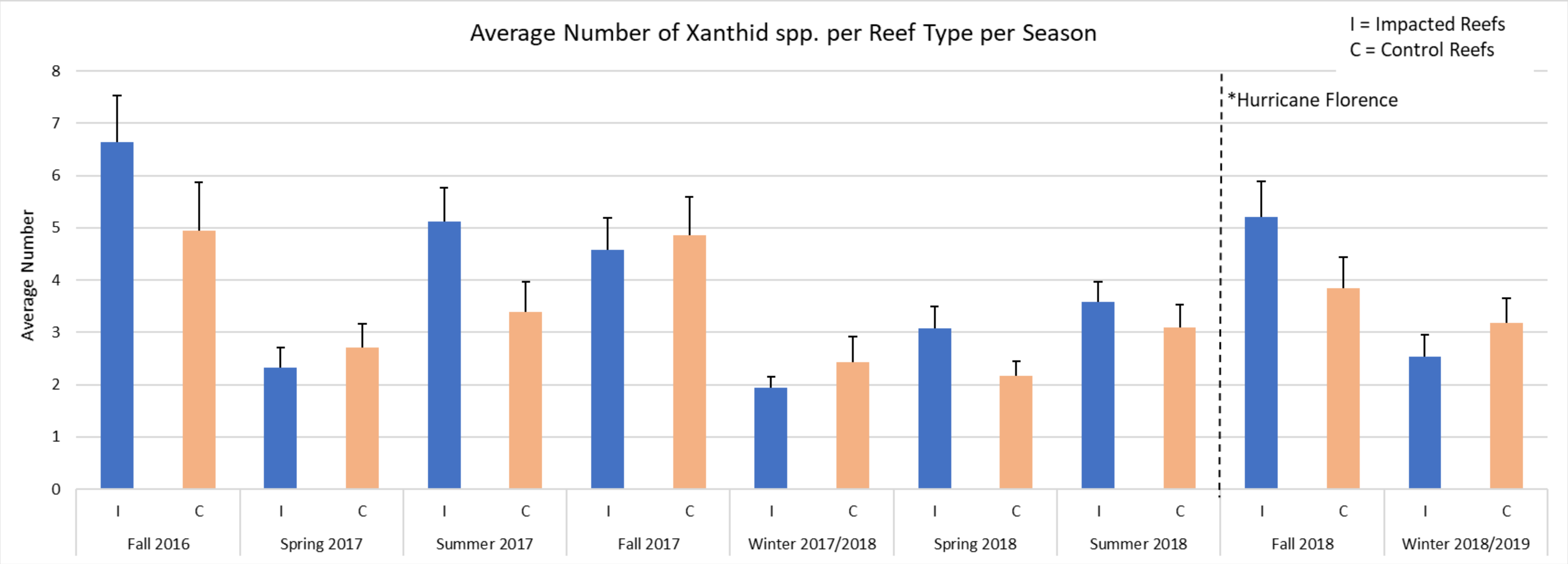
- Associated fauna in impacted and reference reefs – polychaetes
- Suggestion of Hurricane Florence effects



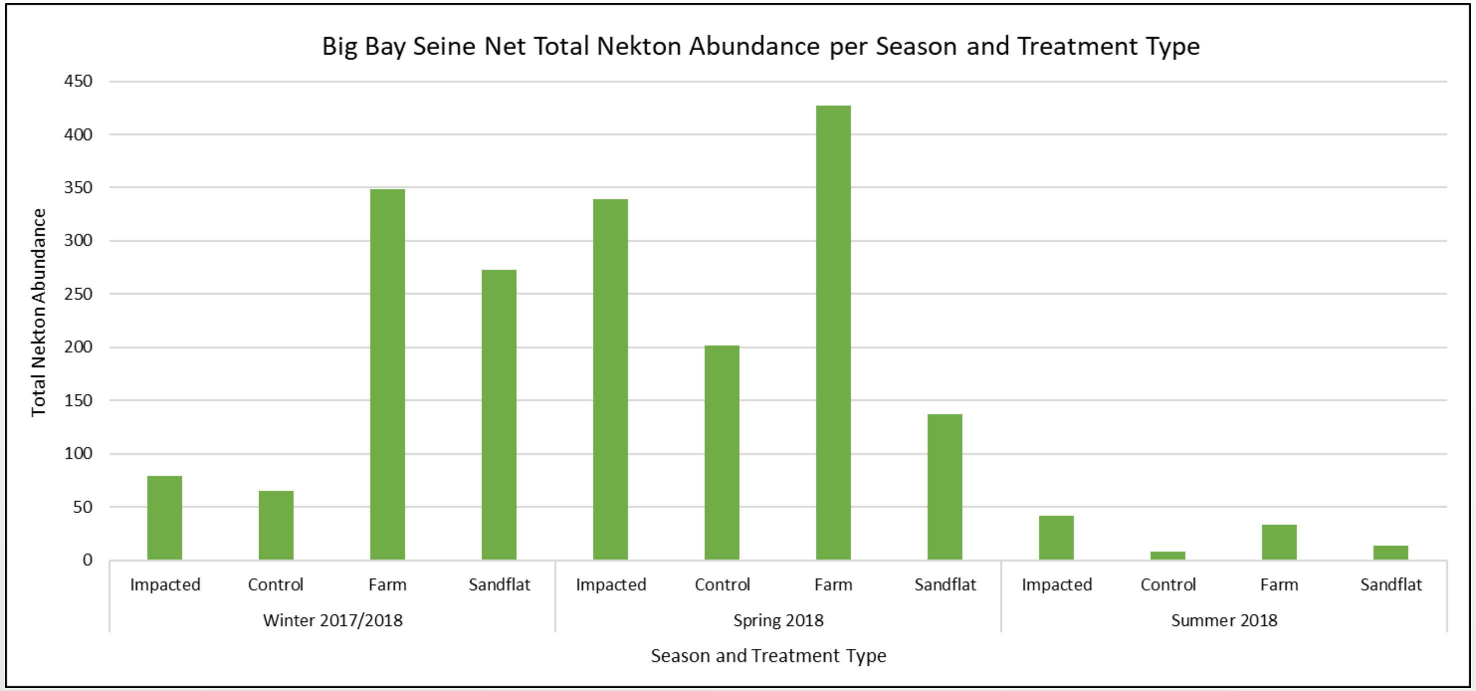


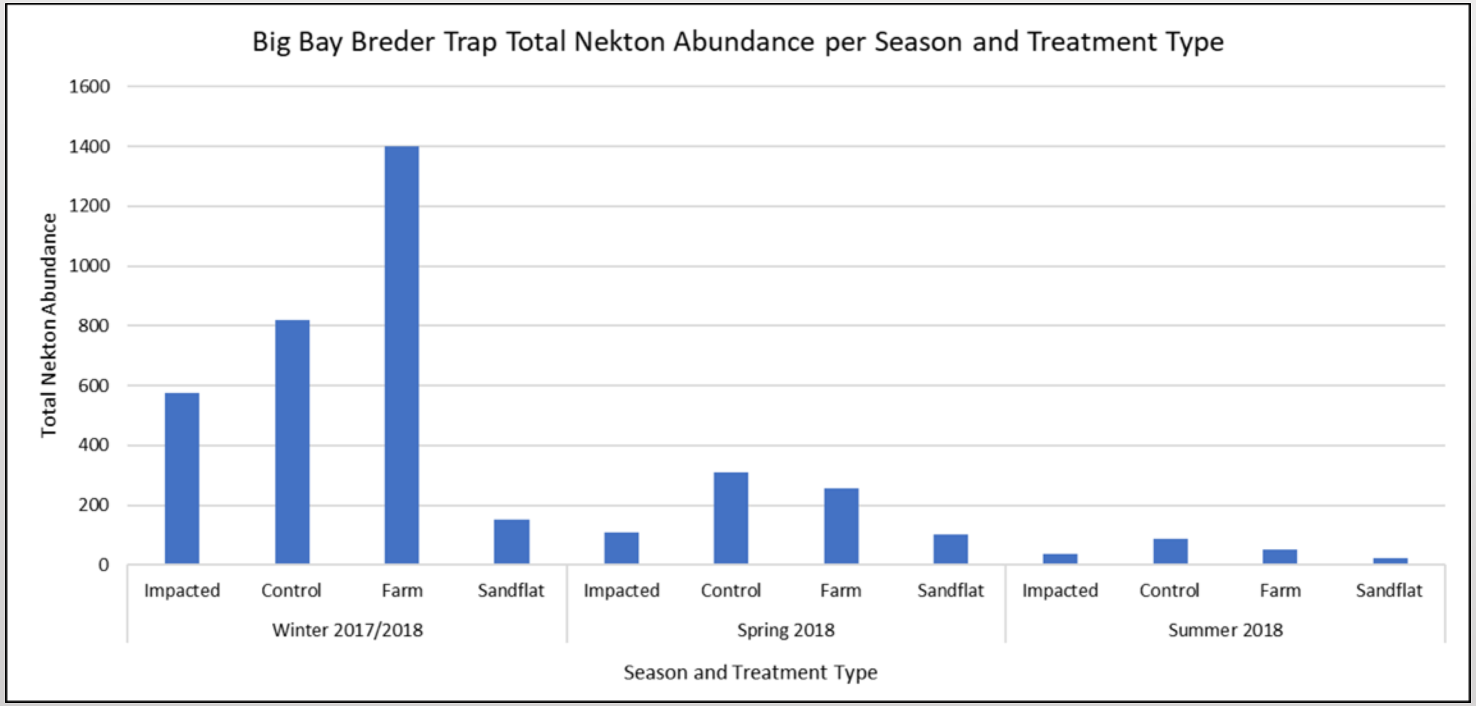


Associated fauna in impacted and reference reefs – xanthid crabs



- Total nekton abundance among 4 habitat conditions for seine and Breder trap catches.





- Summary points (noting that this is preliminary data which will be analyzed further)
  - Size distribution and condition varied between impacted and reference reefs
  - Trend towards abundance differences among reef types
  - Evidence for recruitment impact from Hurricane Florence
  - Little evidence for intra-matrix associated fauna differing between impacted and reference reefs
  - Suggestion of Hurricane Florence impacts on certain intra-matrix associated fauna
  - Nekton variable among years and among sampling gear. Variable abundance patterns among habitat types in the two years of higher abundances.

Stakeholder Breakout Group Summaries

Question 1:

Since the initiation of this project, there has been a growing body of information investigating the influence of shellfish aquaculture on coastal ecology. What do you think is the developing consensus, if any, and what needs to be further studied?

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Stakeholder Response - Developing Consensus

- Relative to other aquaculture and watershed pollution sources, shellfish aquaculture is less negatively impactful, with proper siting and management – no evidence for negative impact from this study.
- Ecosystem services of shellfish aquaculture might be overstated, especially in a Reserve where the system is already functioning well – not large changes to habitat function and the Reserve might not need much nutrient mitigation.

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Stakeholder Response – What Needs Further Study? Priorities:

- Socio-economic factors are very important for further study. For example:
  - Can shellfish aquaculture be seen as an “upgrade” if placed in areas of poorer water quality, as opposed to a “downgrade” if placed in Reserves?
  - Can presence of shellfish aquaculture in a watershed provide impetus for maintenance or improvement of water quality upstream?
- If ecological impacts were not observed in this study, what is the carrying capacity (density dependence) for scale of shellfish aquaculture where impacts or ecosystem services would be observed? This could be estimated using modeling.
- What are the environmental impacts of aquaculture debris and effects of density dependence? There is a need to develop regulatory BMPs for marine debris and microplastics.
- Interactions with submersed aquatic vegetation (SAV)
  - Potential for positive impacts by clearing water and allowing light penetration
  - Negative impacts of shading – has not been shown in North Carolina

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Stakeholder Response – What Needs Further Study? Other ideas:

- Valuation of shellfish aquaculture nitrogen mitigation in areas where wastewater point sources are not the major sources of nutrients. Mitigation of non-point or stormwater sources is much more expensive than wastewater.
- Valuation of <u>organic</u> nitrogen removal by oysters compared to wastewater treatment: this is a complex removal process in WTPs that oysters can handle.
- Effects on earlier life stages/larvae? Two Darrow lab undergraduate honors students studied zooplankton (including planktonic larvae) and phytoplankton and saw no effects in Masonboro, but not published yet.
- Concerns for environmental effects of a mass shellfish die-off, density dependence, need for regulatory BMPs for density of oysters per unit area.

Stakeholder Breakout Group Summaries

Question 2:

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Stakeholder Response:

- Siting of any activities within a Reserve deserves more scrutiny than external areas due to the low number of Reserve sites and their importance.
- Consider siting aquaculture in areas where the environmental benefit would be maximized.
- Place shellfish aquaculture in areas where it is socially supported, which may also be areas where it is viewed as an improvement due to ecosystem services.
- Stakeholders may not have a complete understanding of ecosystem services (from an Oyster Steering Committee poll there seems to be a difference in opinion on importance of oyster filtration vs. nitrogen removal).
- Geographically overlay survey data of shellfish aquaculture attitude with where it could be most useful for water quality.

Questions?

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