Sustainable Oyster Aquaculture, Water Quality Improvement, and Ecosystem Service Value Potential in Maryland Chesapeake Bay

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Session #1 - Shellfish Aquaculture Business & Economics
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Cooperative Oxford Laboratory

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Sea Grant Maryland

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Aquaculture, Seafood, Eutrophication

- US imports >85% of seafood, half of that is farmed
- US seafood deficit is > $16 billion y^{-1}
- 2011 NOAA *National Aquaculture Policies* promote sustainable domestic aquaculture
- 2011 *National Shellfish Initiative* to increase shellfish aquaculture, water quality benefits also recognized*

*65% of US estuaries have moderate to high impacts of nutrients

Chesapeake Bay Program Approved Harvested Oyster Tissue for Nutrient BMP Credits

- Derived from oyster growth data from Chesapeake Bay locations.
- Determined five size class ranges based on shell height.

BMP Name	Lbs N Reduced/ million Oysters Harvested	Lbs P Reduced/ million Oysters Harvested
Diploid Oyster Aquaculture 2.25 Inch	110	22
Diploid Oyster Aquaculture 3.0 Inch	**198**	**22**
Diploid Oyster Aquaculture 4.0 Inch	331	44
Diploid Oyster Aquaculture 5.0 Inch	485	44
Diploid Oyster Aquaculture ≥ 5.5 Inch	683	66
Triploid Oyster Aquaculture 2.25 Inch	132	22
Triploid Oyster Aquaculture 3.0 Inch	**287**	**22**
Triploid Oyster Aquaculture 4.0 Inch	573	66
Triploid Oyster Aquaculture 5.0 Inch	970	110
Triploid Oyster Aquaculture ≥ 5.5 Inch	1,477	154

- Chesapeake Region - Harvested tissue now approved to fulfil required nutrient reductions.
- Mashpee MA oysters, clams (Mashpee CCMP, 2015), Danish mussel mitigation farms (Taylor et al., 2019)

What is the value of the nutrient removal service? How do we estimate that?

Estimated as an avoided or replacement cost - costs to remove nutrients via an alternative management measure used to assign value

VA Chesapeake Bay Alternative Management	$/kg N removed
Waste Water Treatment Plant[1]	$35 - $104
Agricultural BMP[1,2]	$7 - $1034
Urban BMP[1,2]	$66 - $4873
VA Nutrient Credit Exch. Assoc. 2018 Sales Price[2]	$8.33

[1]Stephenson et al. 2010. Evaluation of nutrient nonpoint offset trading in VA. Water Resources Research.
[2]Jones et al. 2010. How nutrient trading could help restore Chesapeake Bay. World Resource Institute.
[3]Virginia Department of Environmental Quality. 2017. Exchange Compliance Plan 2017 Annual Update.

Range of $ values possible

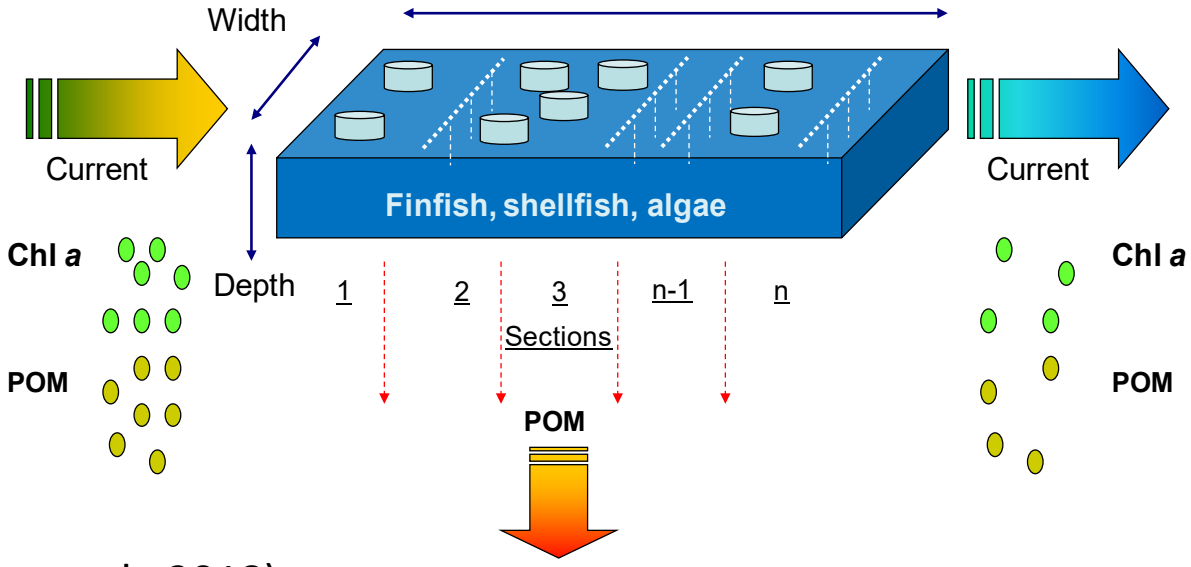
An example of potential value for legal harvest size of diploid and triploid oysters

BMP Name	Lbs N Reduced /million Oysters Harvested	Value Based on WWTP		Value Based on Ag BMP		Value Based on Urban BMP		VA Nutrient Credit Exchange Assoc. 2018 Sales Price
		Low	High	Low	High	Low	High	
		$1000s / million oysters harvested						
Diploid Oyster Aquaculture 3.0 Inch	198	$3	$9	<$1	$93	$6	$439	<$1
Triploid Oyster Aquaculture 3.0 Inch	287	$5	$14	$1	$135	$9	$636	$1

Represents potential payment to growers for water cleaning ecosystem service provided by cultivated oysters – low end of the range is the likeliest payment.

Farm Aquaculture Resource Management (FARM) Model

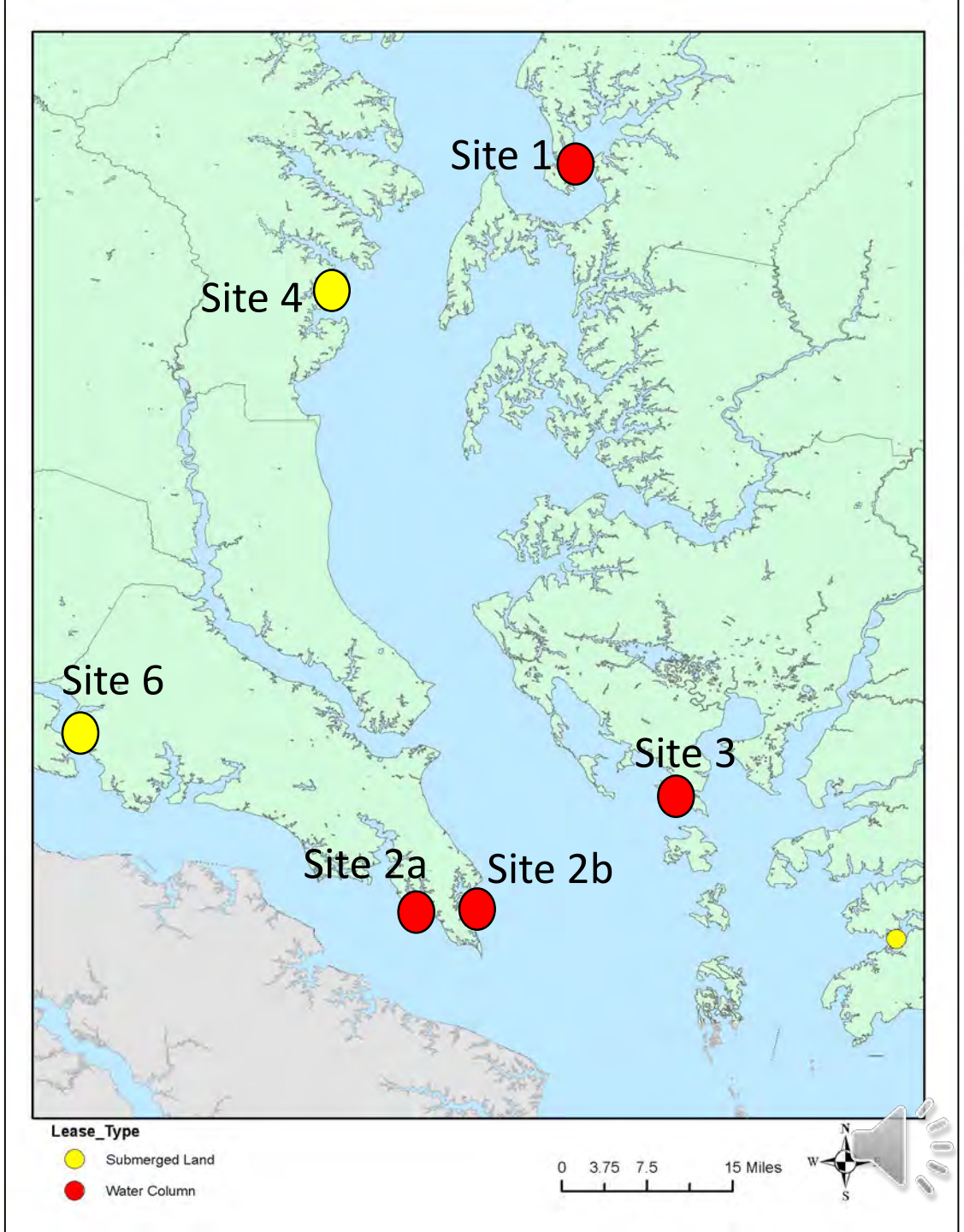
- A local-scale carrying capacity and environmental effects model
- Accounts for food conditions, shellfish eco-physiological characteristics, and farming practices
- Estimates production potential, farm optimization (configuration, stocking density), environmental effects (i.e. nitrogen removal)



(Ferreira et al., 2007; Bricker et al., 2018)

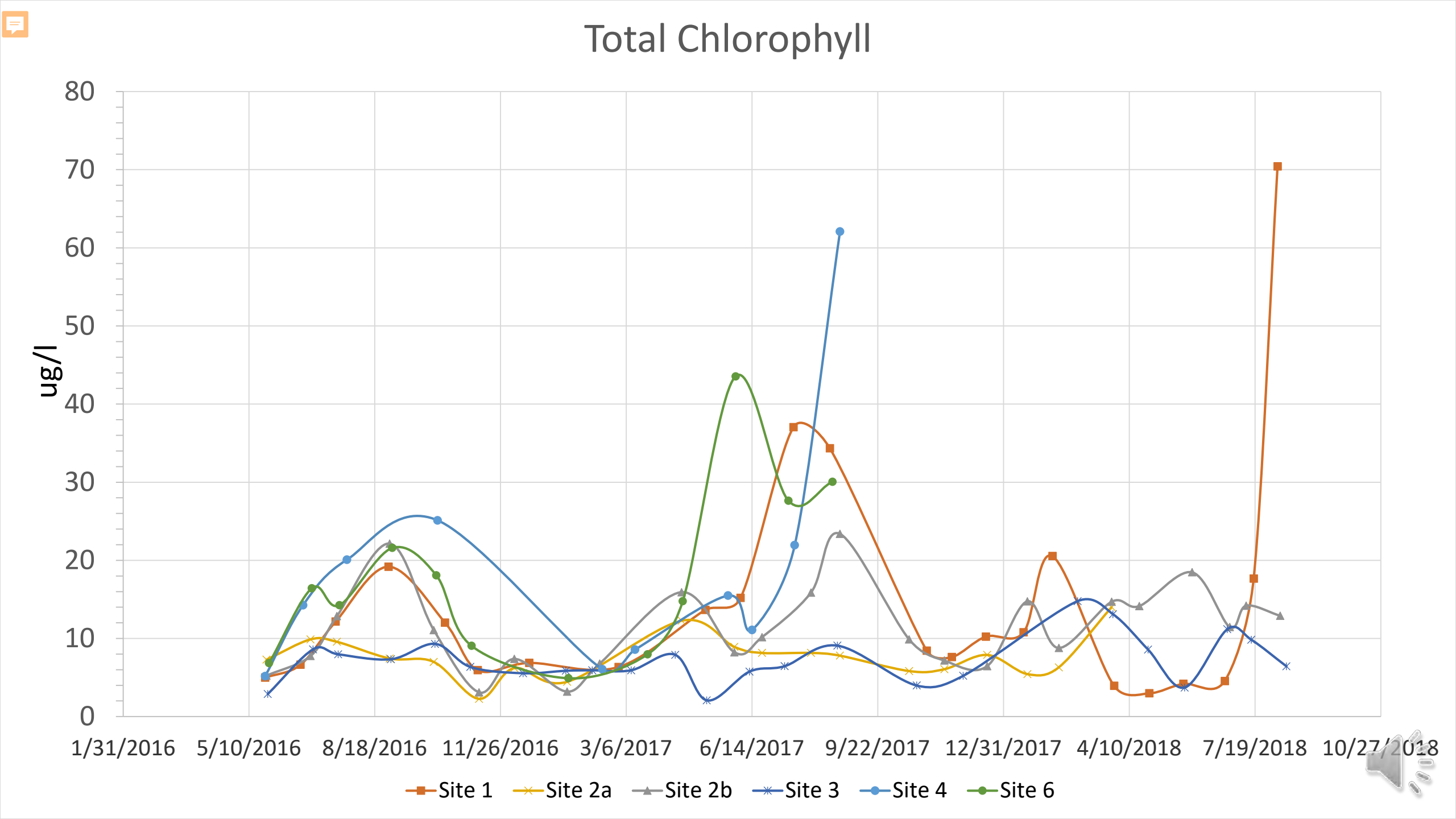
Field work and FARM Model Estimate of Nutrient Reduction

- Collected water and oyster samples May 2016 – Aug 2018
- Input data into FARM Model
- Estimate nutrient reduction due to oyster feeding
- Includes tissue and shell



Water Parameters Measured

- Lat/Long
- Dissolved Oxygen
- Salinity
- Chlorophyll
- Total Suspended Solids
- Total Volatile Solids
- Ammonia
- Nitrate/Nitrite


Total Chlorophyll
ug/l
80
70
60
50
40
30
20
10
0
1/31/2016
5/10/2016
8/18/2016
11/26/2016
3/6/2017
6/14/2017
9/22/2017
12/31/2017
4/10/2018
7/19/2018
10/27/2018
Site 1
Site 2a
Site 2b
Site 3
Site 4
Site 6

Nutrient Reduction Comparison: FARM Model and Expert BMP Panel (Tissue only)

Location	Culture Type	FARM Model Estimate of Nitrogen Removal (kg/yr) tissue only	BMP Estimate of Nitrogen Removal (kg/yr)
Site 1	bottom cage triploid	**182**	**50**
Site 2a	floating cage triploid	**710**	**299**
Site 2b	floating cage triploid	**1372**	**722**
Site 3	bottom cage triploid	**399**	**133**
Site 4	bottom culture diploid	**859**	**46**
Site 6	bottom culture diploid	**1200**	**93**

Comparison of Potential Revenue for Nutrient Reduction: Farm Model and Expert BMP Panel

Potential Revenue based on avoided costs for each farm for FARM Model production estimates $1000s / year (tissue only)							
		3 inch Triploid Oysters				3 inch Diploid Oysters	
	Alternative Management	Site 1	Site 2a	Site 2b	Site 3	Site 4	Site 6
Farm Model Estimate	WWTP Minimum	$6	$25	$48	$14	$30	$42
	WWTP Maximum	$19	$74	$143	$42	$89	$125
	Ag BMP Minimum	$1	$5	$9	$3	$6	$9
	Ag BMP Maximum	$189	$734	$1,419	$413	$888	$1,241
	Urban BMP Minimum	$12	$47	$91	$27	$57	$79
	Urban BMP Maximum	$888	$3,460	$6,687	$1,944	$4187	$5,850
	VNCEA 2018	$2	$6	$12	$3	$7	$10
BMP Estimate	WWTP Minimum	$2	$10	$25	$5	$2	$3
	WWTP Maximum	$5	$31	$75	$14	$4.8	$10
	Ag BMP Minimum	<$1	$2	$5	$1	<$1	$1
	Ag BMP Maximum	$52	$309	$747	$138	$48	$96
	Urban BMP Minimum	$3	$20	$48	$9	$3	$6
	Urban BMP Maximum	$244	$1,457	$3,518	$648	$224	$453
	VNCEA 2018	<$1	$3	$6	$1	<$1	$1

Concluding Comments

- Incorporation of aquaculture science into resource management
- Optimistic results for water quality improvement AND potential revenue for oyster farms nutrient reductions

  –> Payment already made to 2 MD oyster growers!! (Wheeler; May 2020)
- FARM Model is useful tool, needs refinement for Chesapeake Bay

  –> Project investigating FARM N removal in Greenwich Bay, CT
- Transferrable approach to other waterbodies that require nutrient removal and also support oyster aquaculture

Questions?

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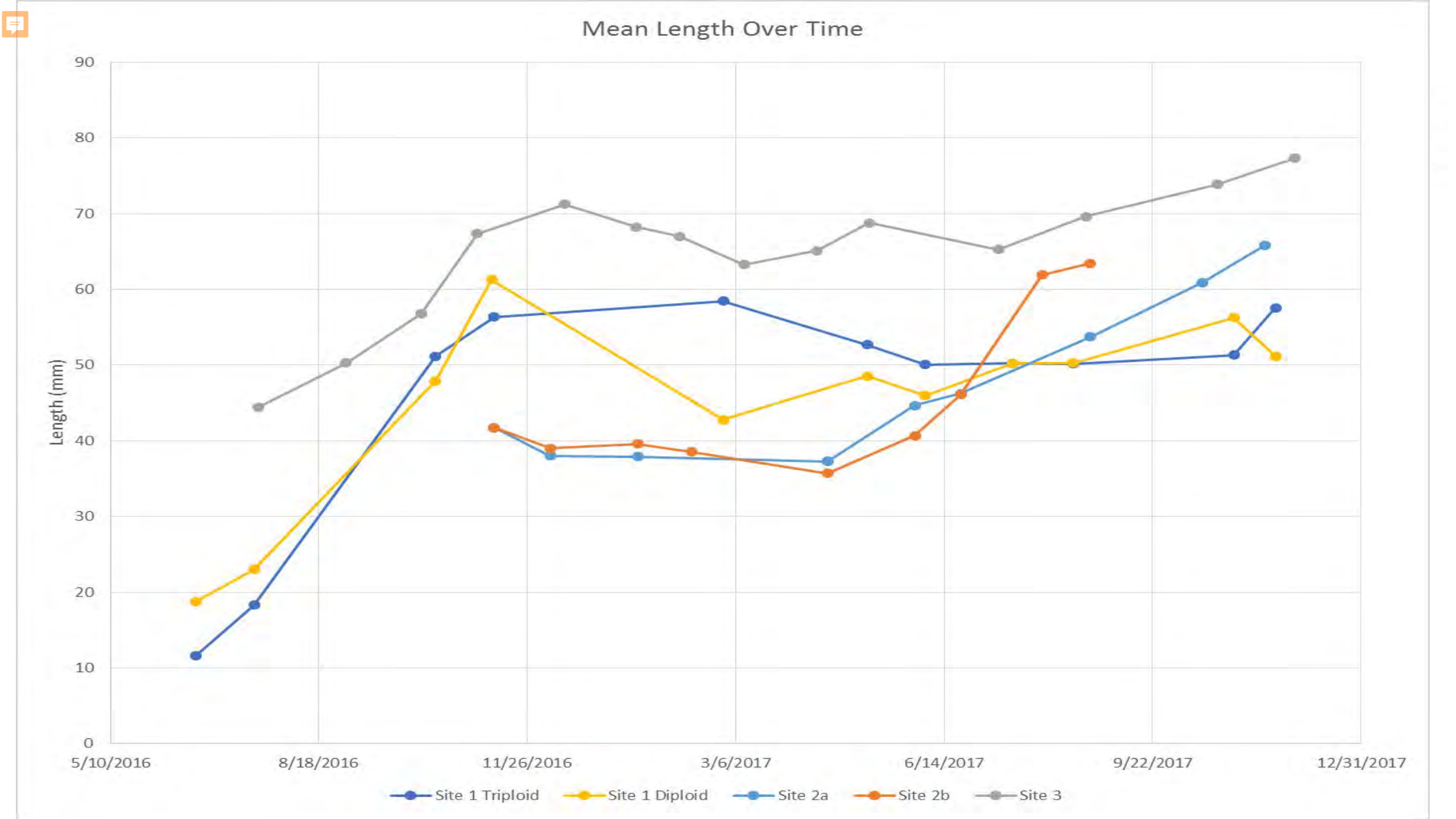
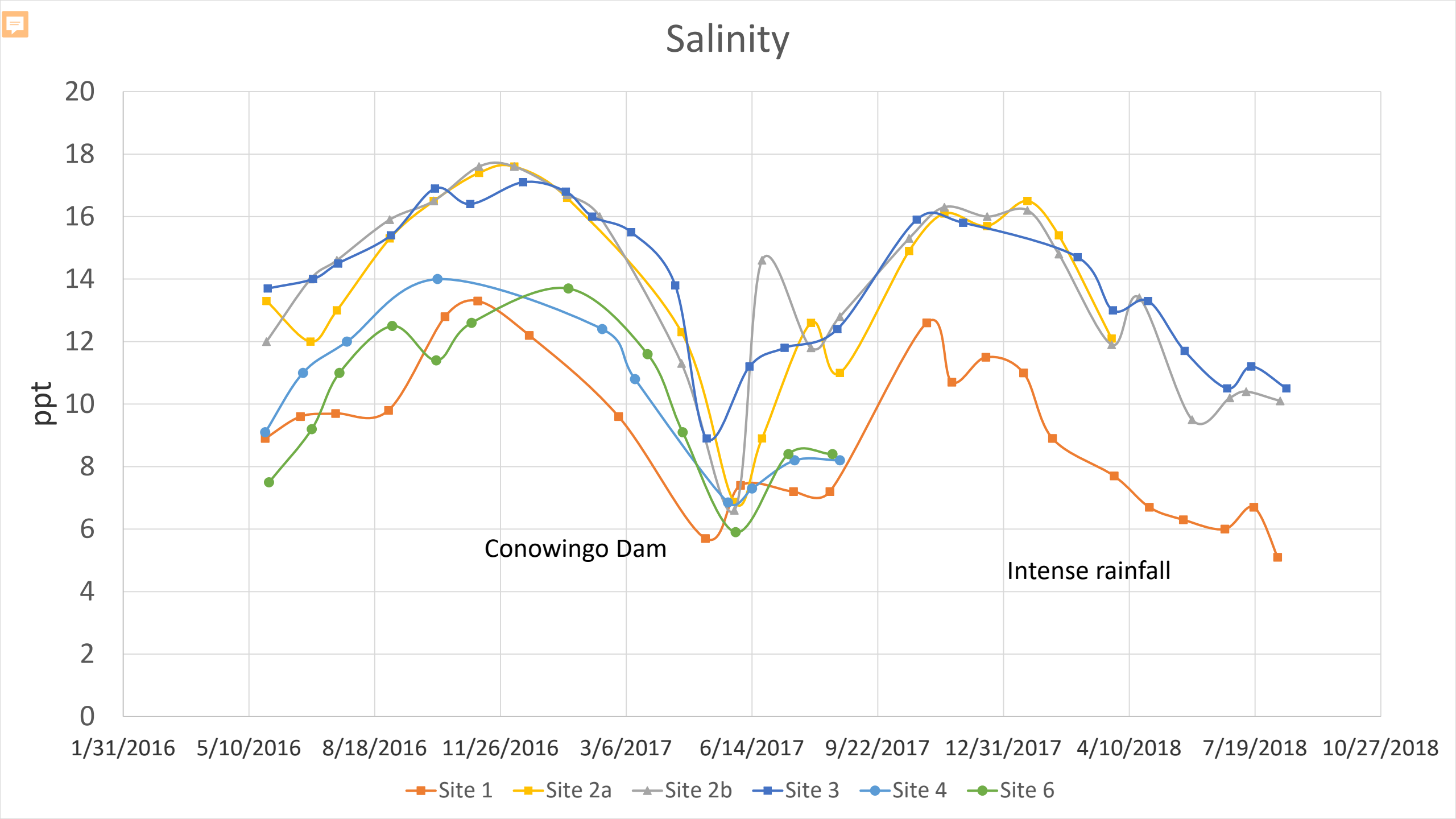
THANK YOU!!

Slides 15 – 23 can be used in a longer presentation – left here for completeness.


Mean Length Over Time
Length (mm)
90
80
70
60
50
40
30
20
10
0
5/10/2016
8/18/2016
11/26/2016
3/6/2017
6/14/2017
9/22/2017
12/31/2017
Site 1 Triploid
Site 1 Diploid
Site 2a
Site 2b
Site 3

Oyster Measurements

- Fresh weight
- Wet tissue weight
- Wet shell weight
- Volume of liquid in oyster
- Dry tissue weight
- Dry shell weight


Salinity
20
18
16
14
12
10
8
6
4
2
0
ppt
1/31/2016
5/10/2016
8/18/2016
11/26/2016
3/6/2017
6/14/2017
9/22/2017
12/31/2017
4/10/2018
7/19/2018
10/27/2018
Conowingo Dam
Intense rainfall
Site 1
Site 2a
Site 2b
Site 3
Site 4
Site 6

FARM model results for MD Chesapeake Bay farms
Nitrogen removal (as tissue and shell from 3 inch oyster) normalized to tissue only per Cornwell et al 2016:
N is 72% triploid cage oyster, 47% diploid bottom oyster

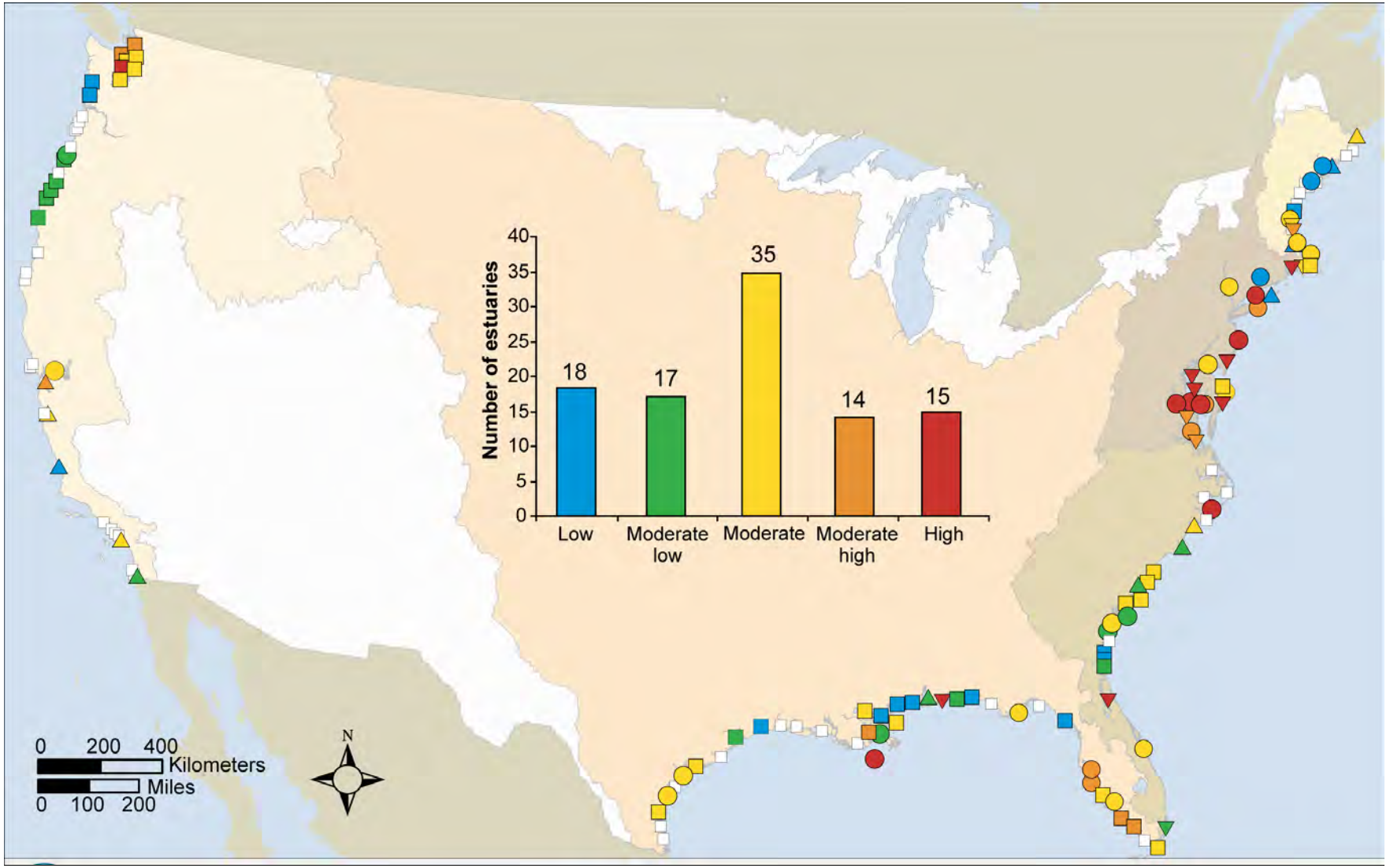
Location	Culture Type	N removed (kg/acre/yr)	Total N removed (kg/yr)
Site 1	bottom cage triploid	**37**	**182**
Site 2a	floating cage triploid	**222**	**710**
Site 2b	floating cage triploid	**63**	**1372**
Site 3	bottom cage triploid	**20**	**399**
Site 4	bottom culture diploid	**215**	**859**
Site 6	bottom culture diploid	**171**	**1200**

Expert BMP Panel results for MD Chesapeake Bay farms
Annual nitrogen removal (as tissue) for 3 inch oyster using FARM Model Production Estimates (number oysters)

Location	Culture Type	N removed (kg/acre/yr)	Total N removed (kg/yr)
Site 1	bottom cage triploid	**10**	**50**
Site 2a	floating cage triploid	**93**	**299**
Site 2b	floating cage triploid	**33**	**722**
Site 3	bottom cage triploid	**7**	**133**
Site 4	bottom culture diploid	**11**	**46**
Site 6	bottom culture diploid	**13**	**93**

Eutrophic Condition: US

65% of US estuaries have moderate to high nutrient related impacts



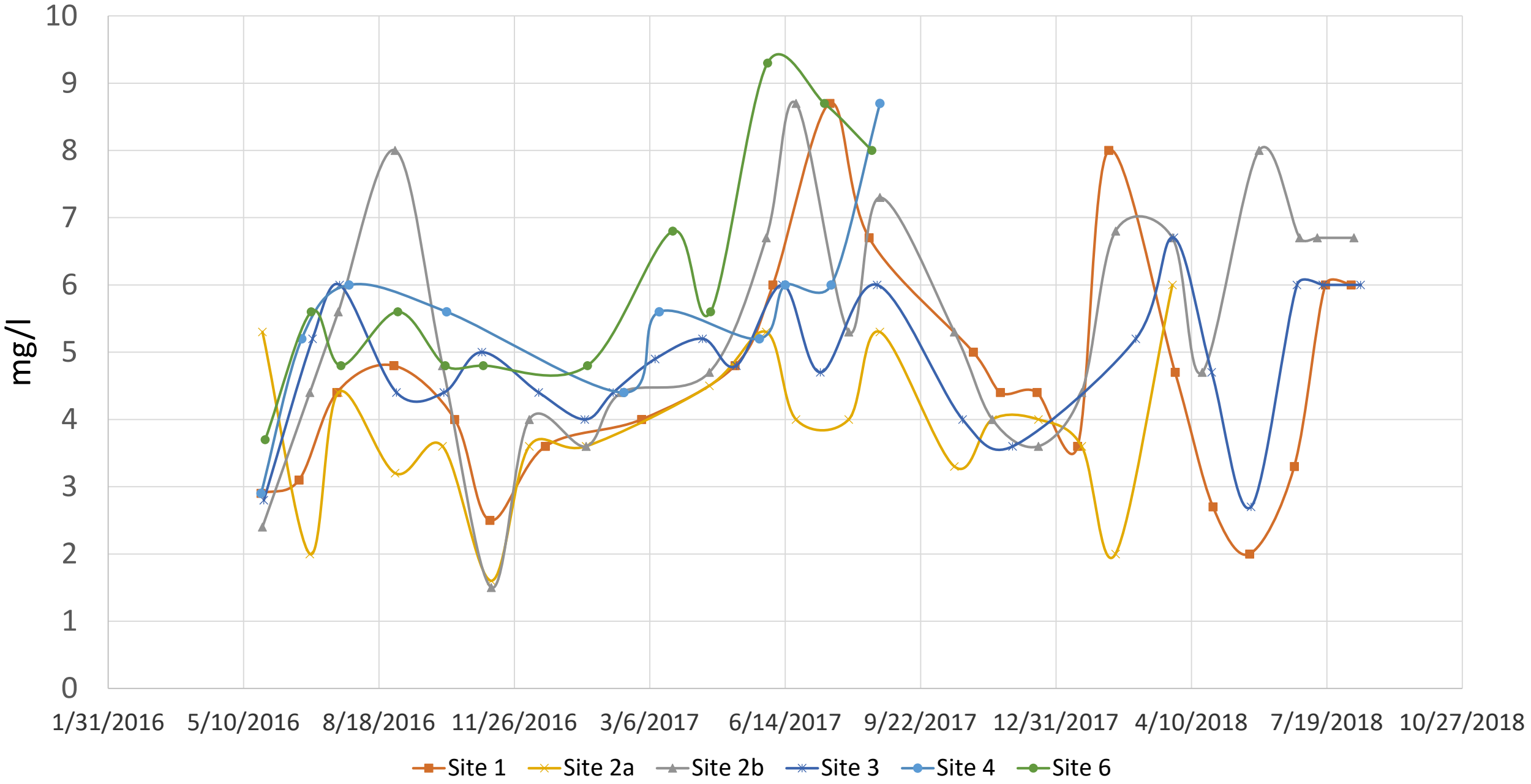
http://www.eutro.us http://www.eutro.org/register

Chesapeake Bay Oyster Expert Panel

- Nutrient reduction via harvested aquaculture oyster tissue approved as a BMP by Chesapeake Bay Program in Dec 2016.

- Panel continues to examine nutrient reduction effectiveness for aquaculture oyster shell, enhanced denitrification, and restoration practices

Total Volatile Solids



Next steps

- Continue to refine model for Chesapeake Bay
- Evaluate what it would take to compensate farms for nutrient reductions (complete in 2018)
- Economic Evaluation of MD Oyster Industry (complete in 2018)
- BMP Expert Panel to continue to review science for additional BMP's
  - Shell, denitrification, etc