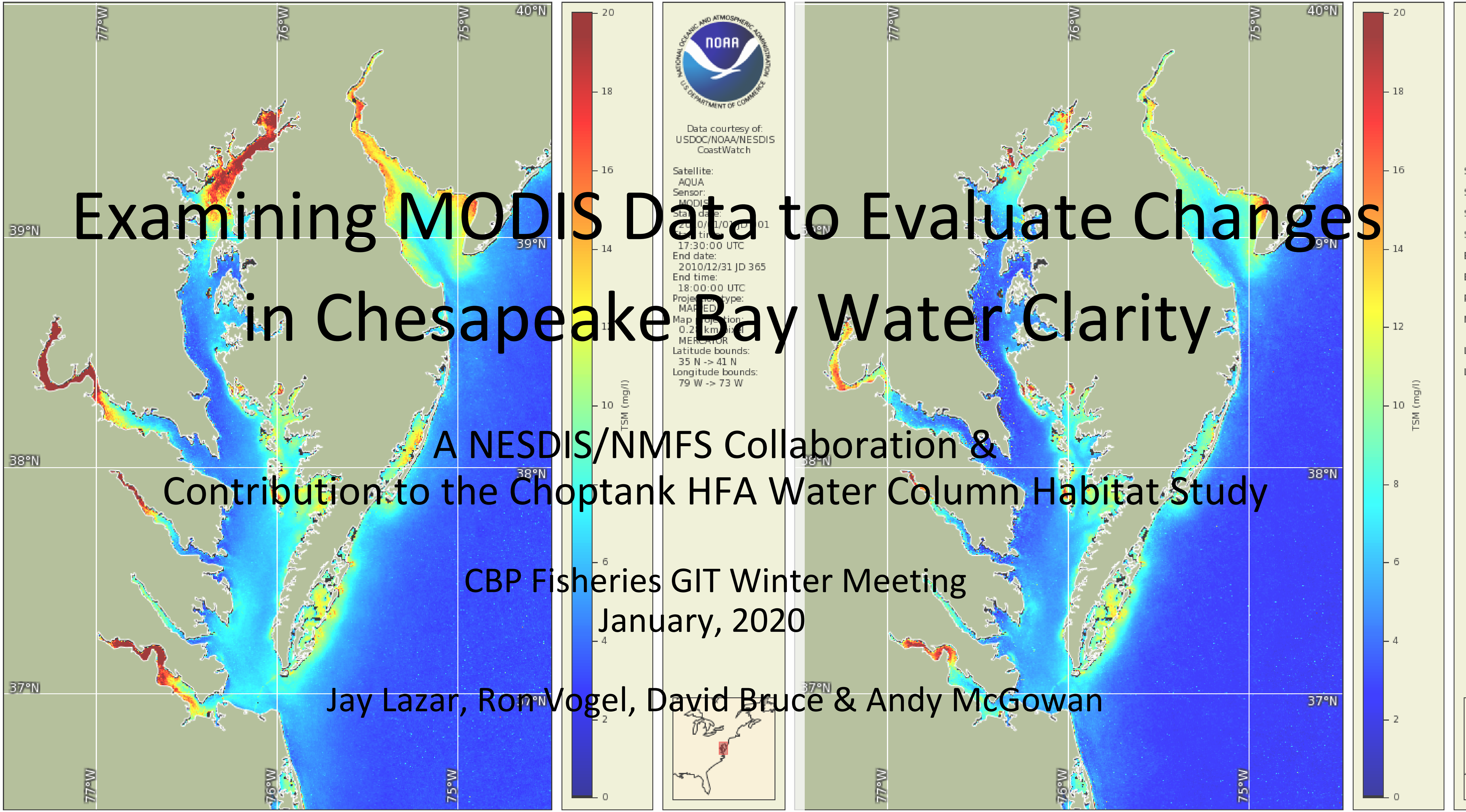


Examining MODIS Data to Evaluate Changes in Chesapeake Bay Water Clarity

A NESDIS/NMFS Collaboration & Contribution to the Choptank HFA Water Column Habitat Study

CBP Fisheries GIT Winter Meeting
January, 2020

Jay Lazar, Ron Vogel, David Bruce & Andy McGowan

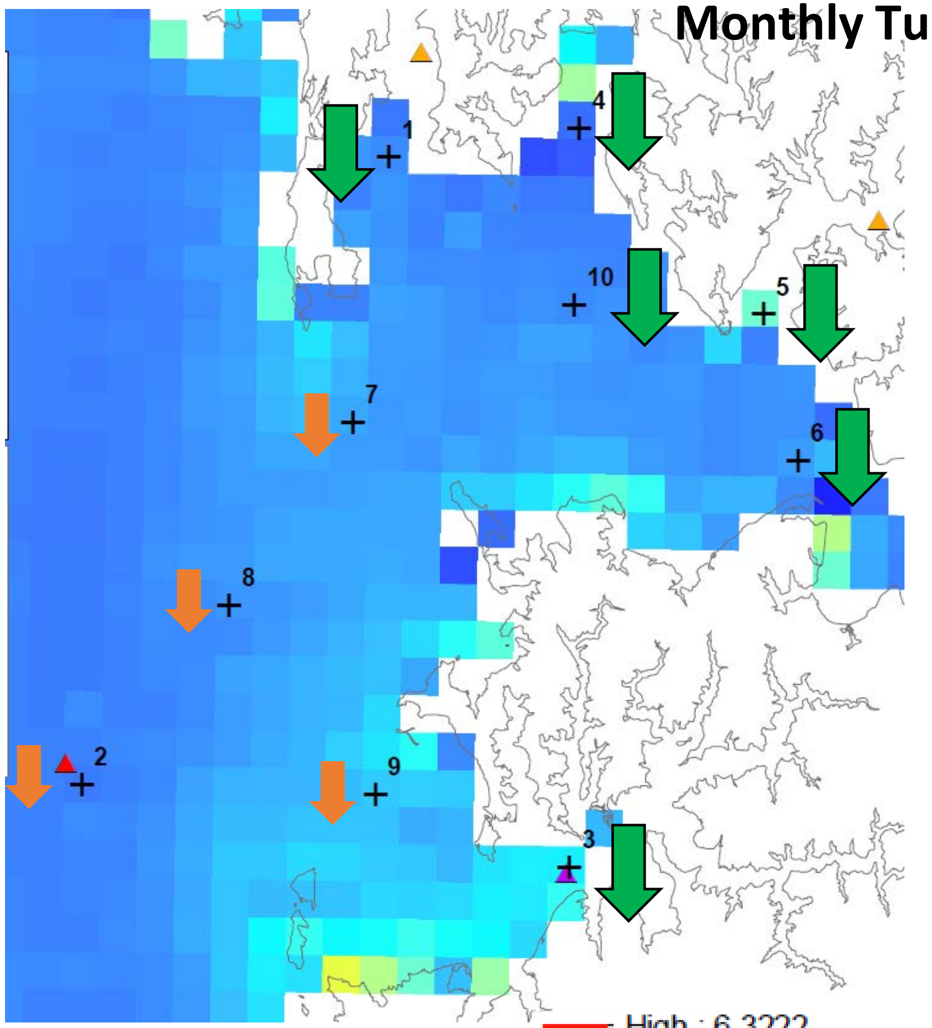
Background (Winter 2016)

- The first round of 3YR Metrics population monitoring had been delivered and the results were positive- oyster biomass was increasing
  - Sparking an interest in what these results may portend ecologically

- Ron Vogel (NOAA/NESDIS) had just given a presentation at a NCBO monthly staff meeting on the use of satellite turbidity data suggesting an improving trend toward decreased turbidity
  - Sharing the consensus that bay-wide improvements were from TMDL decreases in nutrient loading

- We wondered aloud 1) whether we crossed a threshold in oyster restoration scale that could demonstrate water quality change and 2) whether we could statistically relate it to oyster restoration or other environmental change

Satellite (MODIS) KD490 Total Suspended Solids (TSS) Trends at Select Stations



Satellite turbidity (m^{-1})
Jan 2016 monthly avg
Top 1m water

High : 6.3222
Low : 0.0424
Bay_shoreline

Monthly Turbidity Averages Oct 2010 – Mar 2016

Creek influenced

2010 – 2013

Small increase in turbidity

2013 – 2016

Decrease in turbidity (few steep drops)

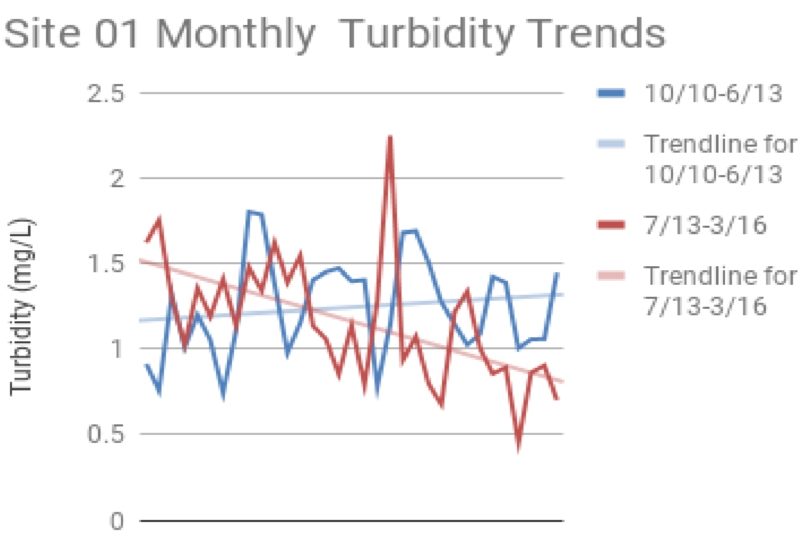
Main stem influenced

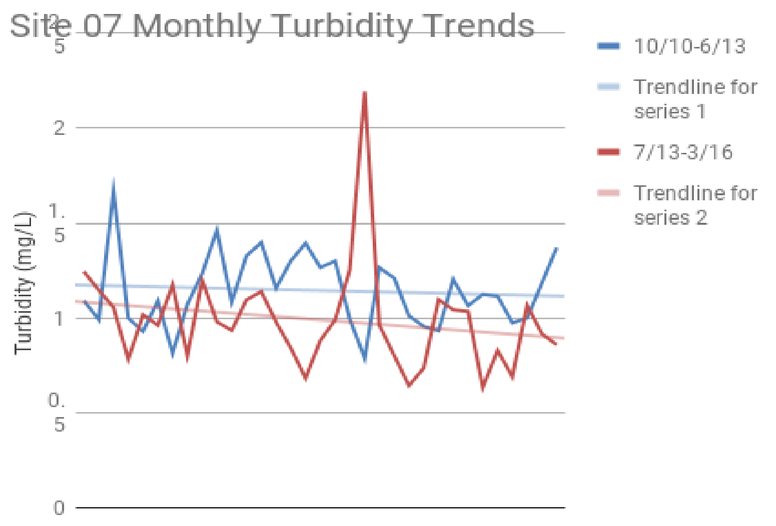
2010 - 2013

Decrease in turbidity

2013 – 2016

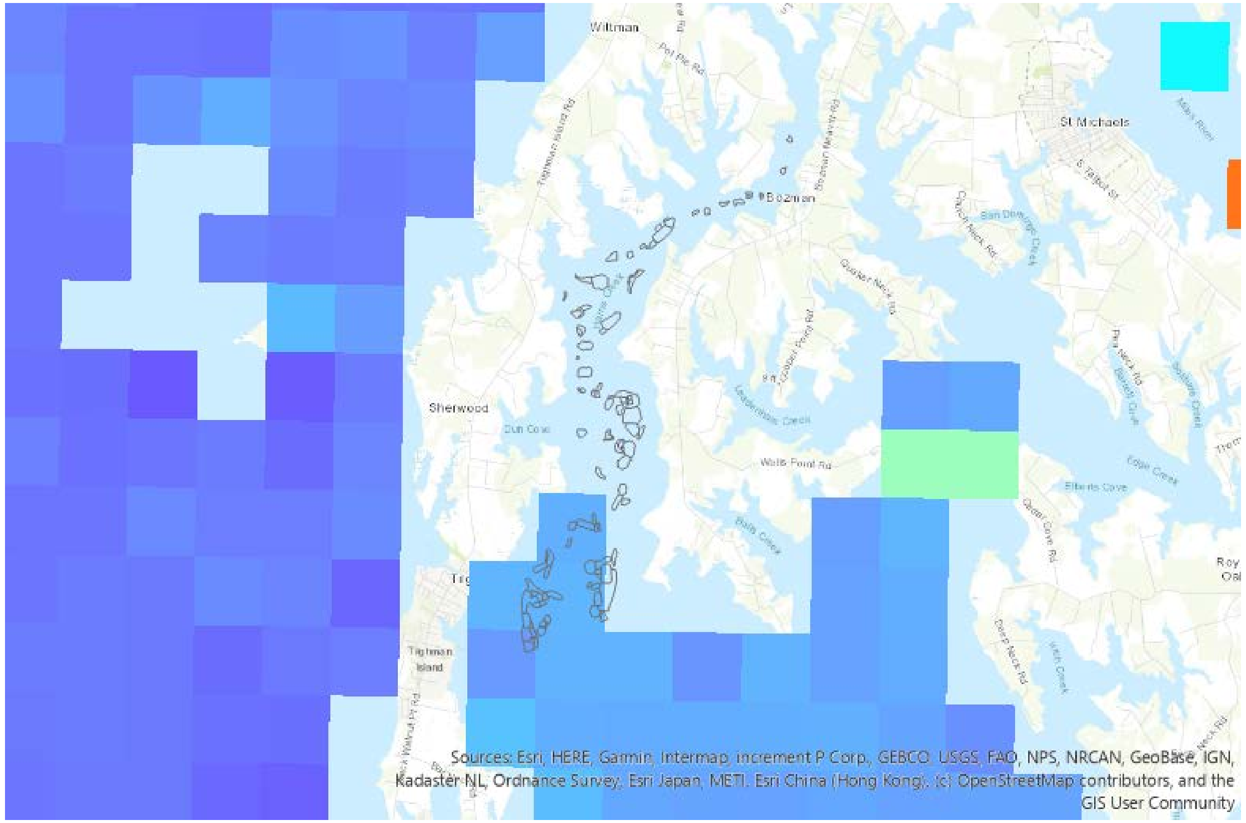
Small decrease or no change

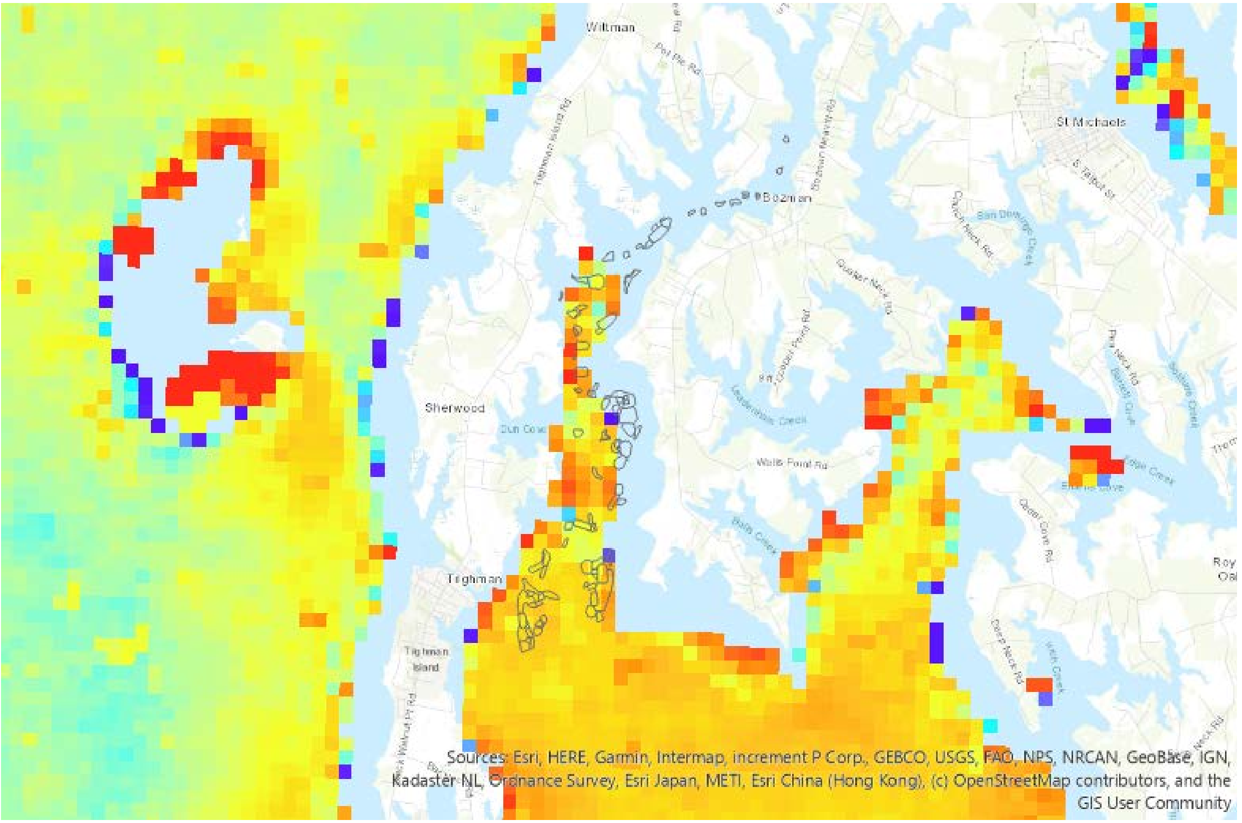




MODIS KD490 vs MODIS TSM Product Resolution

- And we were aware of other available products at better resolution, one that better represented the scale of oyster restoration





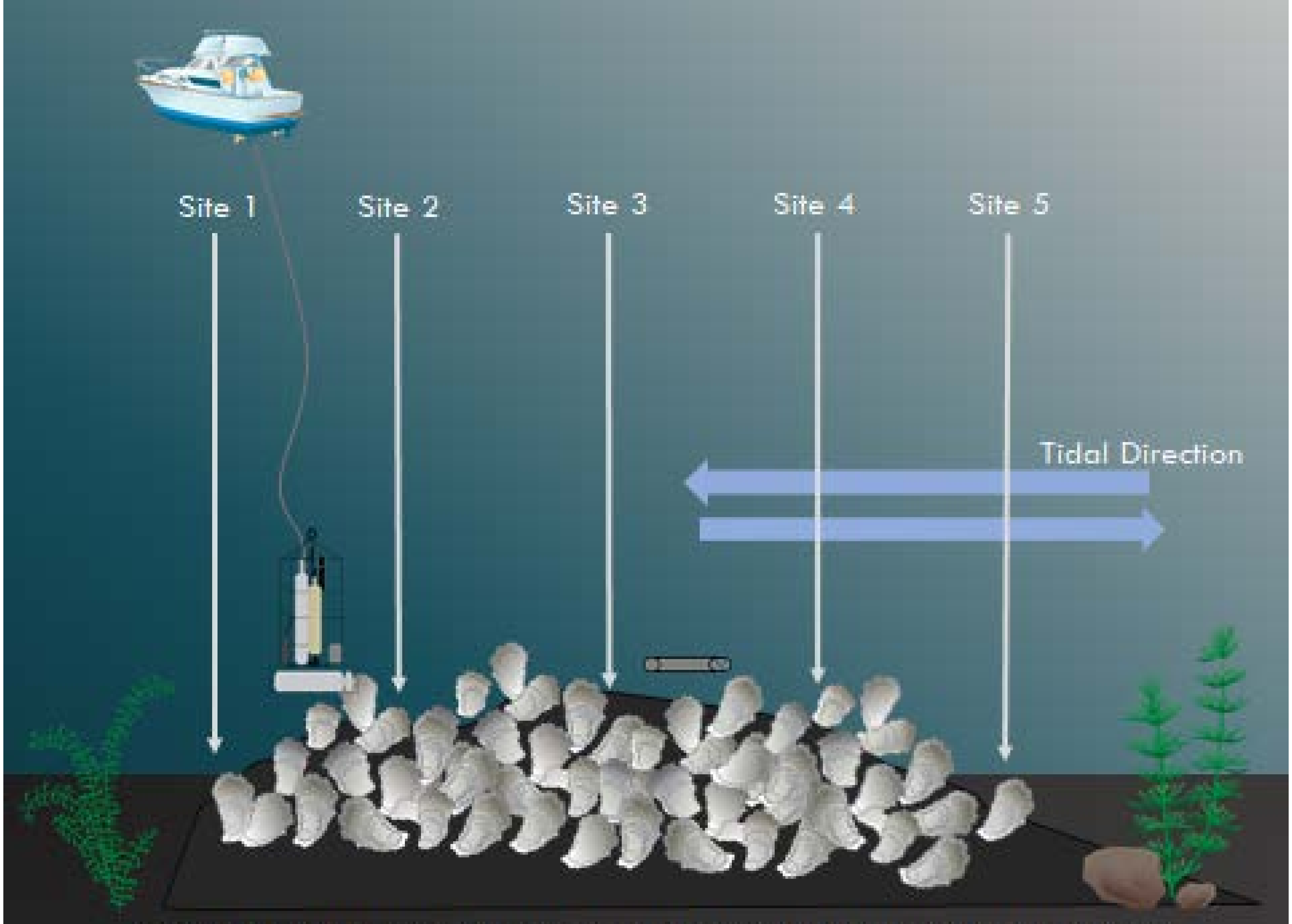
Background (Winter 2018)

- We knew in 2016 the restoration effort was relatively immature, so we waited to accumulate more data

- We found a tool, CurveFit, created by USGS that modeled trends in raster data

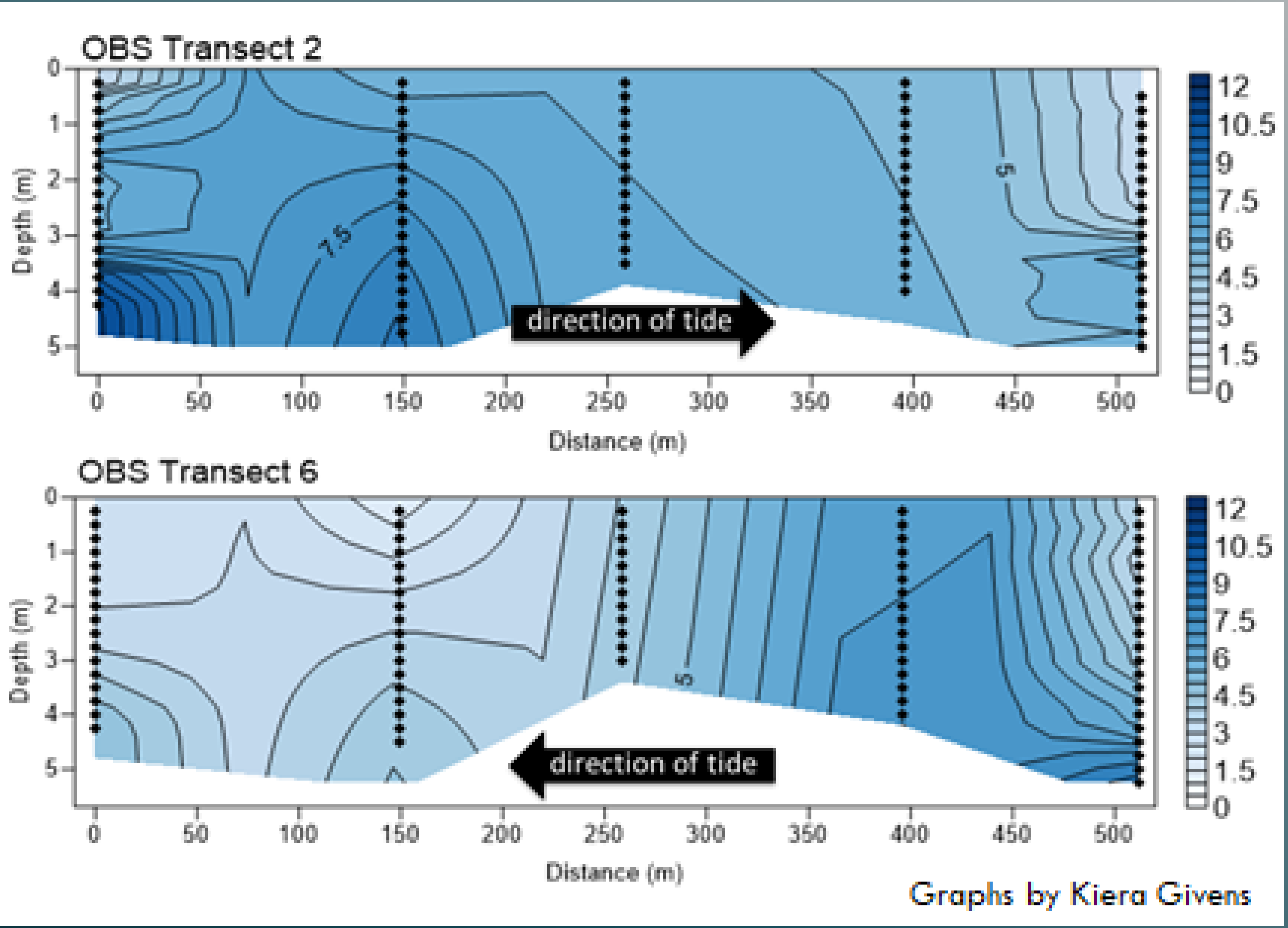
- And preliminary results from ORES project work on filtration, biodeposition and nutrient cycling collected in the summer of 2016 by Kevin Kahover in Lora Harris' lab had been shared

    - Modeling Recap: Conceptual Model > Numerical Model > Model Validation...



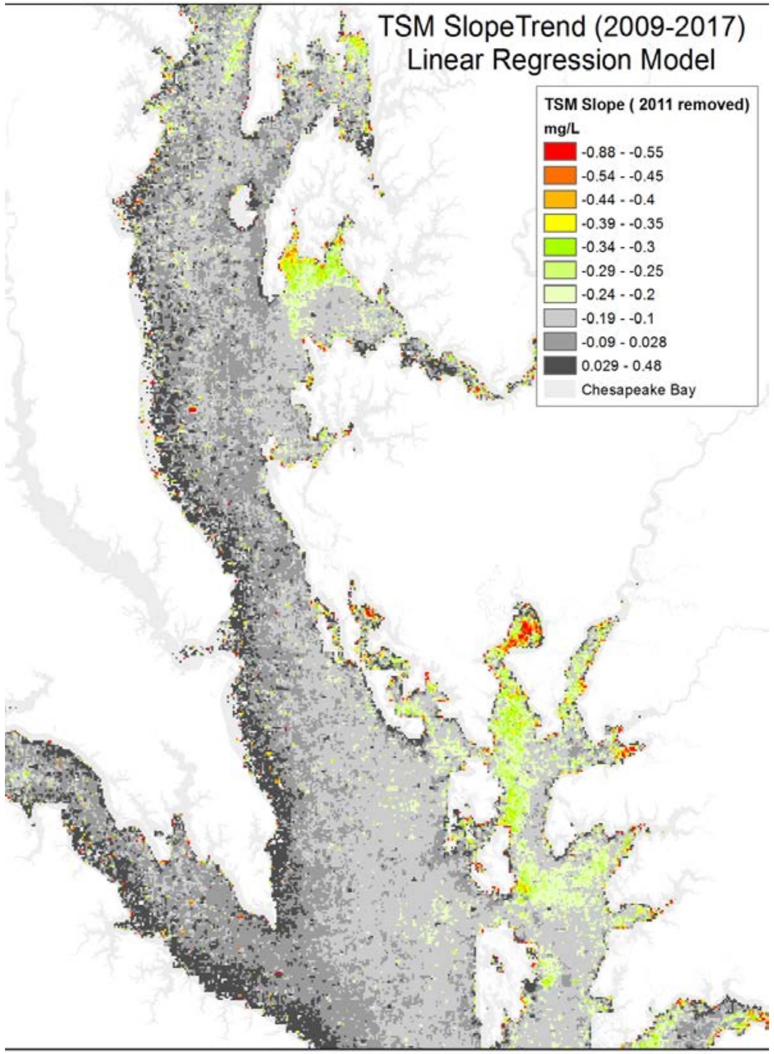
Schematic that depicts the planned sampling regime over the Harris Creek oyster reef (graphic by Givens and Kahover)

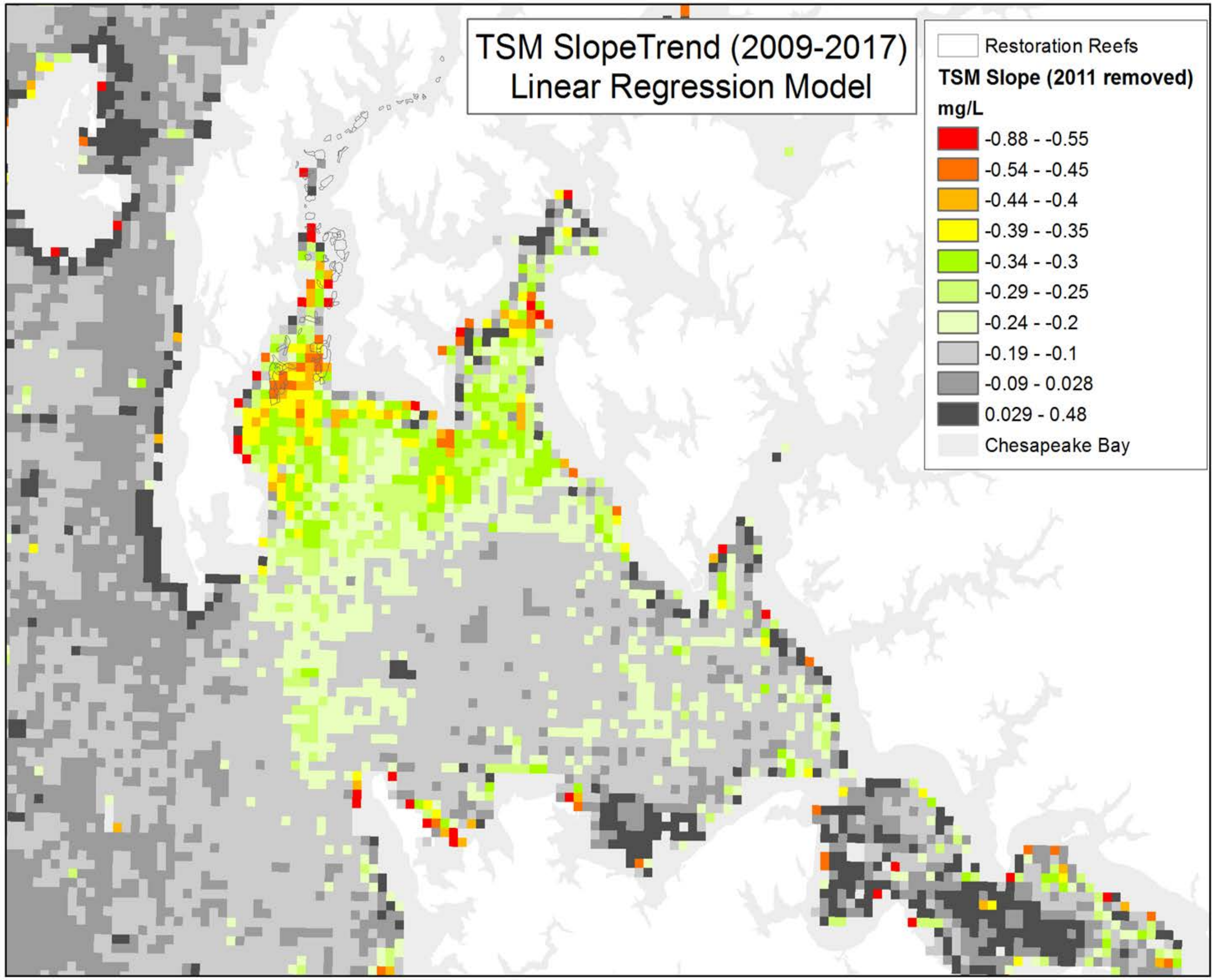
Preliminary Validation – Filtration Model



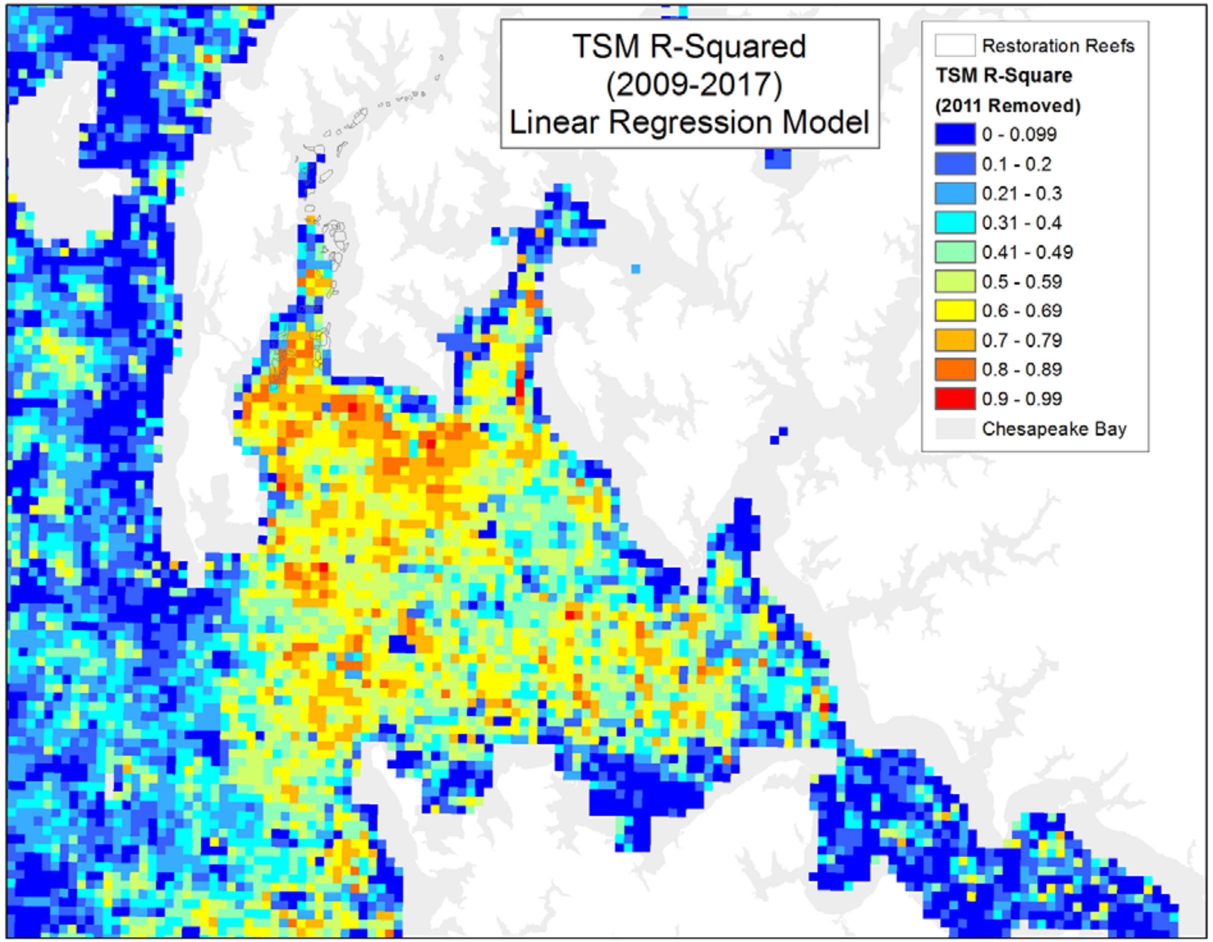
Model Confirmation?

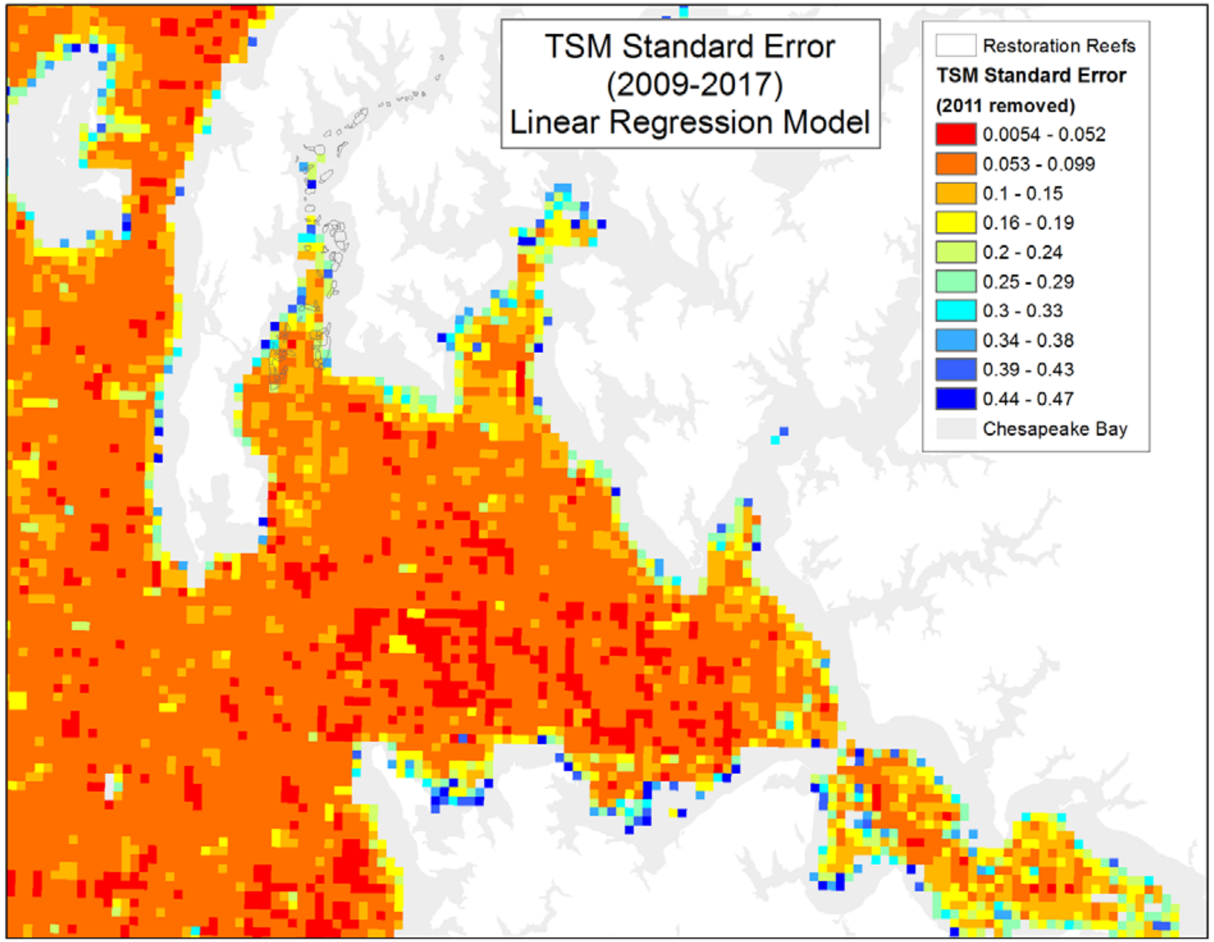
Slope Trend of Annual TSM (2009-2017)





Total Suspended Matter (TSM) Trend- Slope Supporting Statistics



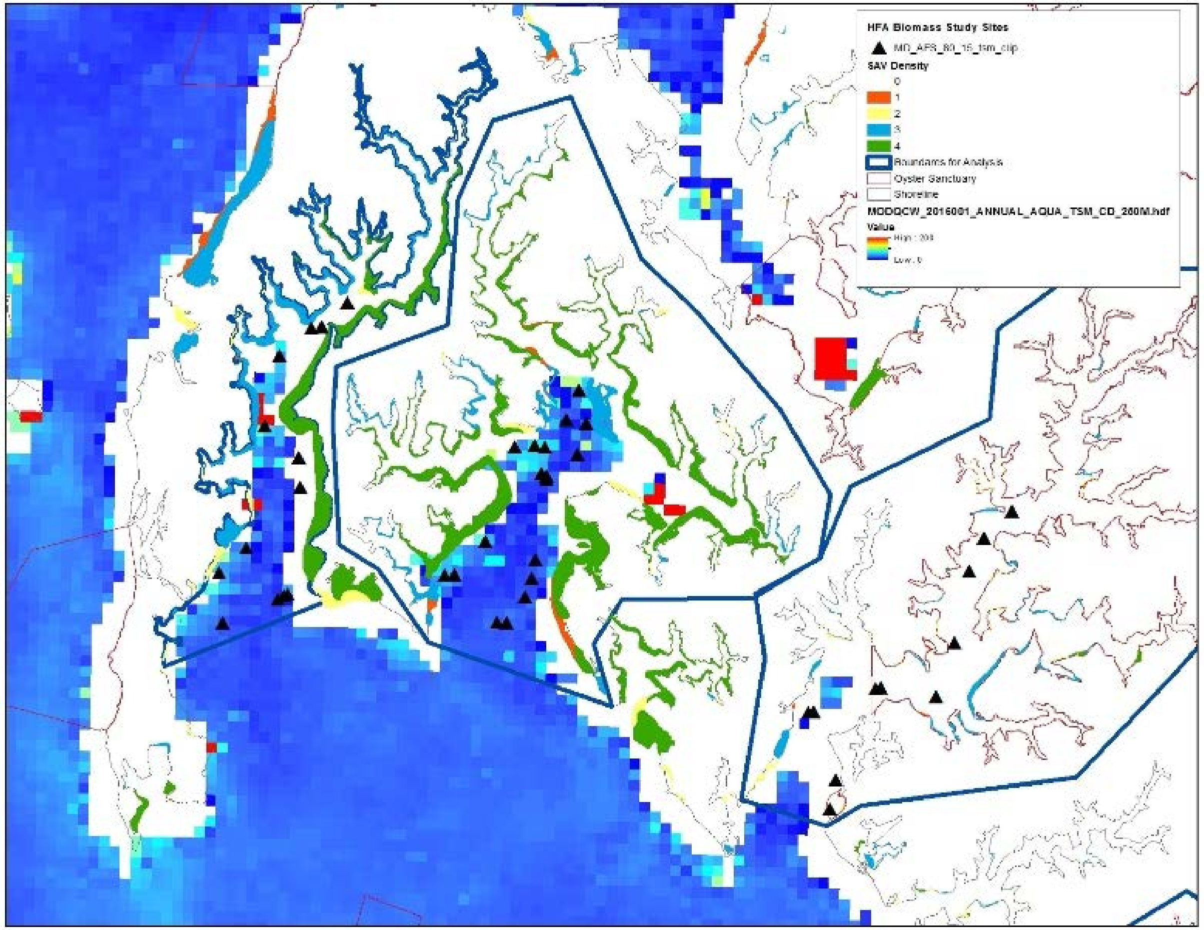


Does oyster restoration improve water clarity?

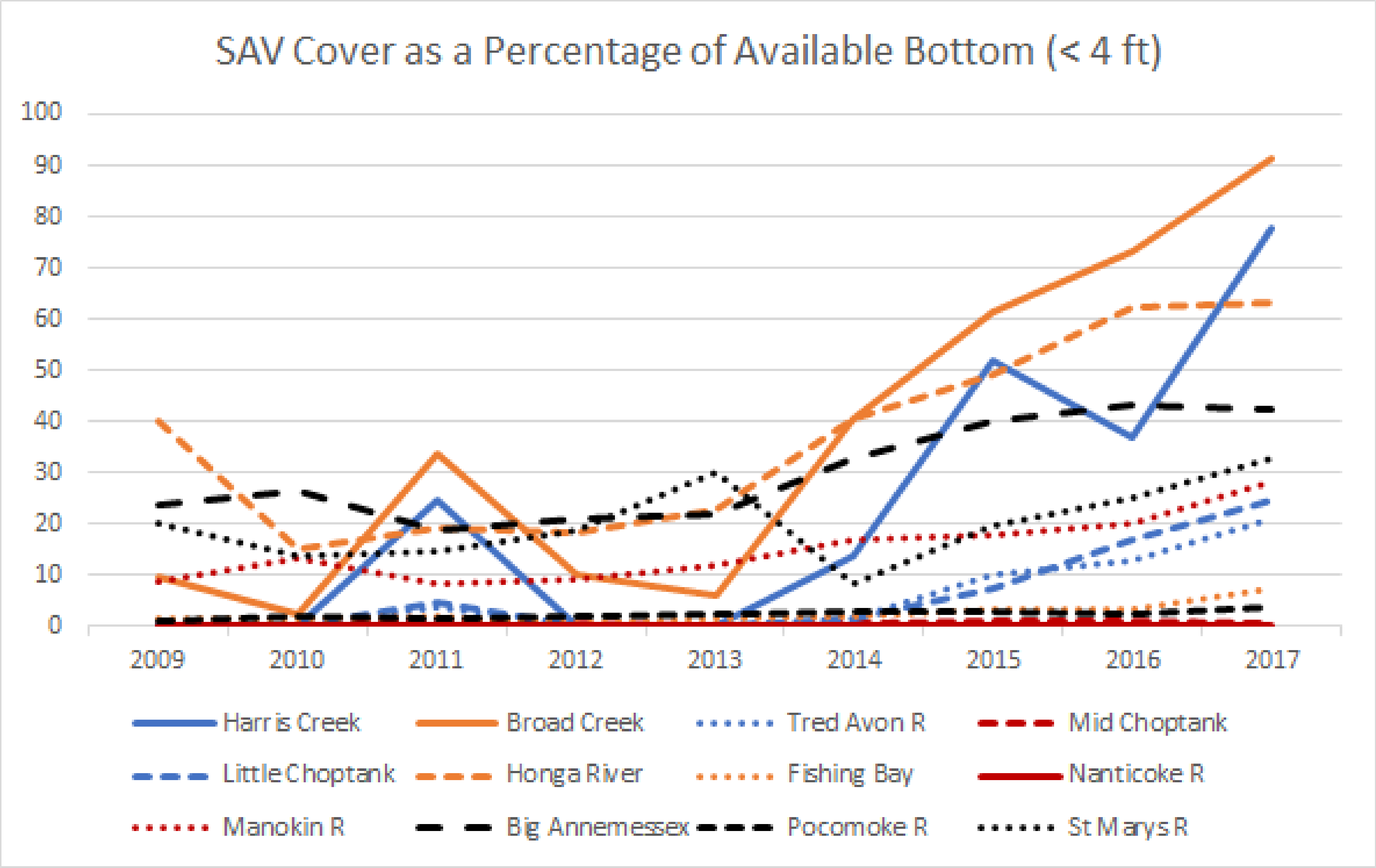
Choptank HFA: public interest in socioeconomic value of oyster restoration

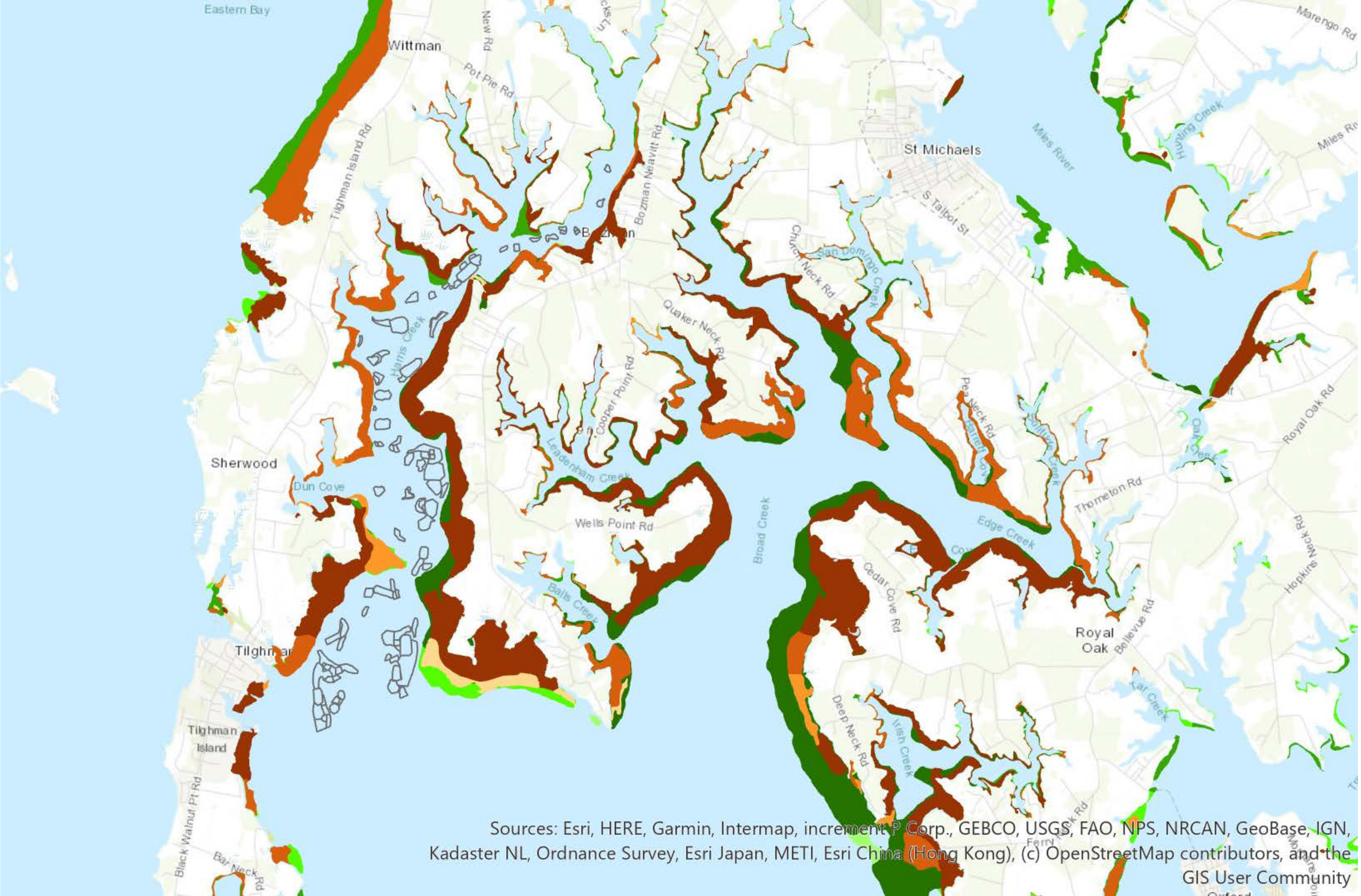
- Use satellite total suspended matter concentration (TSM) as an indicator of water clarity (250m resolution)
- Compare oyster biomass (AFS) and satellite suspended matter over 8 years (2009-2016); eventually 9
- Assess influence of other factors on water clarity: Submerged aquatic vegetation (SAV), Precipitation (land runoff)
    - Conversely is improved water clarity responsible for substantial SAV increases in the Choptank HFA

Map of TSM, SAV density and Oyster sample locations



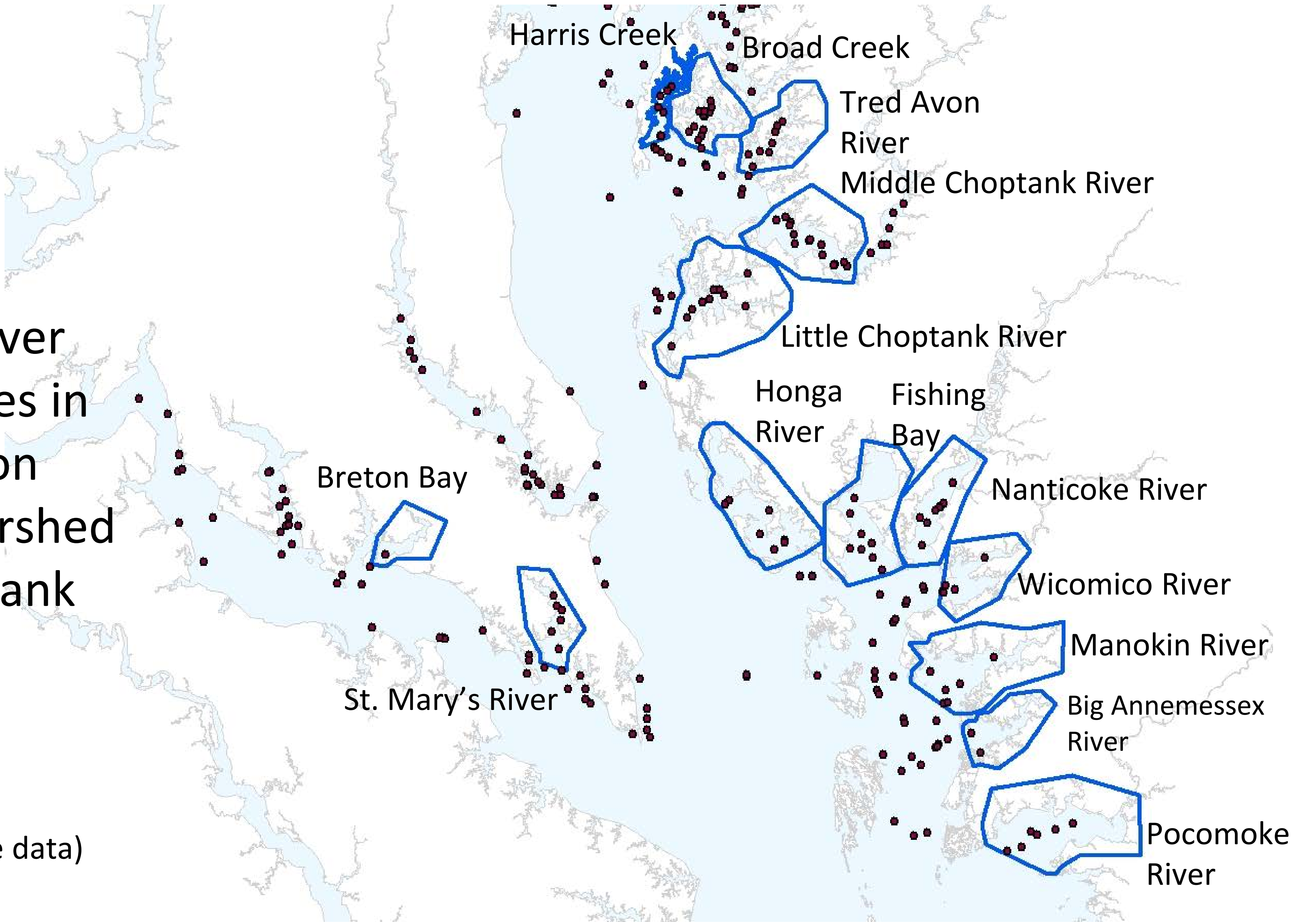
SAV Cover as a Percentage of Available Bottom (<4ft)




Eastern Bay
Wittman
New Rd
Pot Pie Rd
Tilghman Island Rd
Bozman Neavitt Rd
St Michaels
Miles River
S Talbot St
Church Neck Rd
San Domingo Creek
Quaker Neck Rd
Cooper Point Rd
Harris Creek
Leadenham Creek
Wells Point Rd
Balls Creek
Broad Creek
Sherwood
Dun Cove
Tilghman Island
Black Walnut Pt Rd
Bar Neck Rd
Cedar Cove Rd
Deep Neck Rd
Irish Creek
Edge Creek
Thornton Rd
Royal Oak
Bellevue Rd
Royal Oak Rd
Hopkins Neck Rd
Oak Creek
Tar Creek
Hunting Creek
Marengo Rd
Miles River Rd
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

“13 Zone” Study Design

- Management Type
- High vs Low Oyster Biomass
- High vs Low SAV Cover
- Presumed similarities in regional precipitation
- Similarities in watershed sizes (Middle Choptank and Nanticoke exceptions)



14 Tributaries originally identified
(Breton Bay excluded for too little data)

What Variables might have the greatest influence on TSM?

Q: Does TSM vary relative oyster biomass,SAV percent, year, and location?
Model: Rastervalu = LOG_Sav_val_pct + log_biomass + year + location
Zone_13 Only
Remove oyster biomass < 1 values
Analyses since 03/07/2018 Meeting

The GLM Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	1744.765004	134.212693	44.45	<.0001
Error	556	1678.791999	3.019410		
Corrected Total	569	3423.557003			

R-Square	Coeff Var	Root MSE	RASTERVALU Mean
0.509635	22.37617	1.737645	7.765607

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOG_Sav_val_pct	1	168.055724	168.055724	55.66	<.0001
log_biomass	1	49.893136	49.893136	16.52	<.0001
Zones_13	10	1510.664876	151.066488	50.03	<.0001
Year	1	16.151268	16.151268	5.35	0.0211

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LOG_Sav_val_pct	1	0.876608	0.876608	0.29	0.5902
log_biomass	1	1.767920	1.767920	0.59	0.4445
Zones_13	10	1514.976069	151.497607	50.17	<.0001
Year	1	16.151268	16.151268	5.35	0.0211

Multiple Regression Analysis: Evaluate TSM against Time, Location, Oyster Biomass, SAV

Sum of Squares statistics(SS)

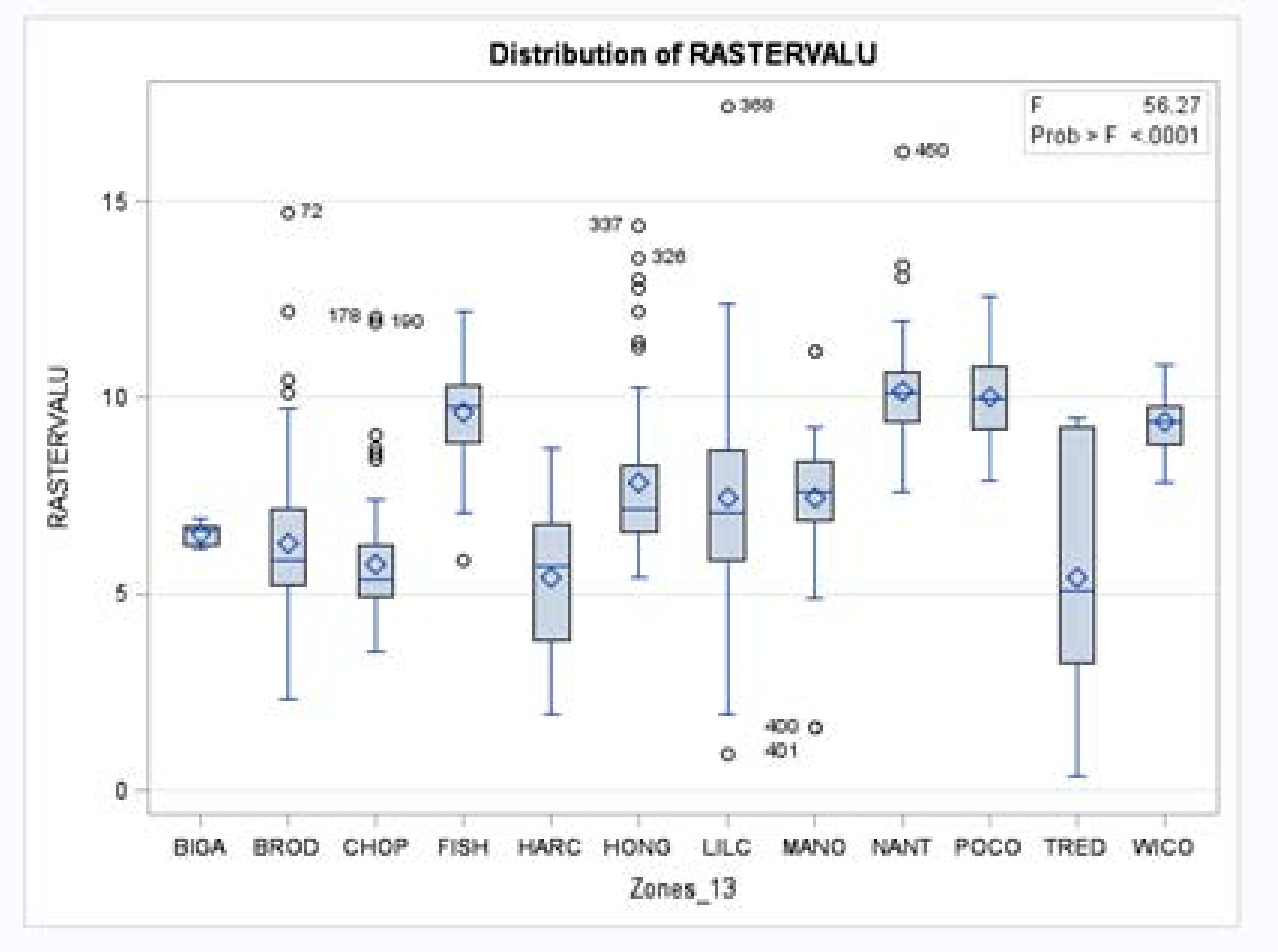
Type I SS: Considers each independent variable individually
- All p values < 0.05 indicating that TSM varies significantly with all variables

Type III SS: Considers all independent variables together
- When all variables are in the model TSM varies significantly only with Location (Zones_13) and Year (p values < 0.05)

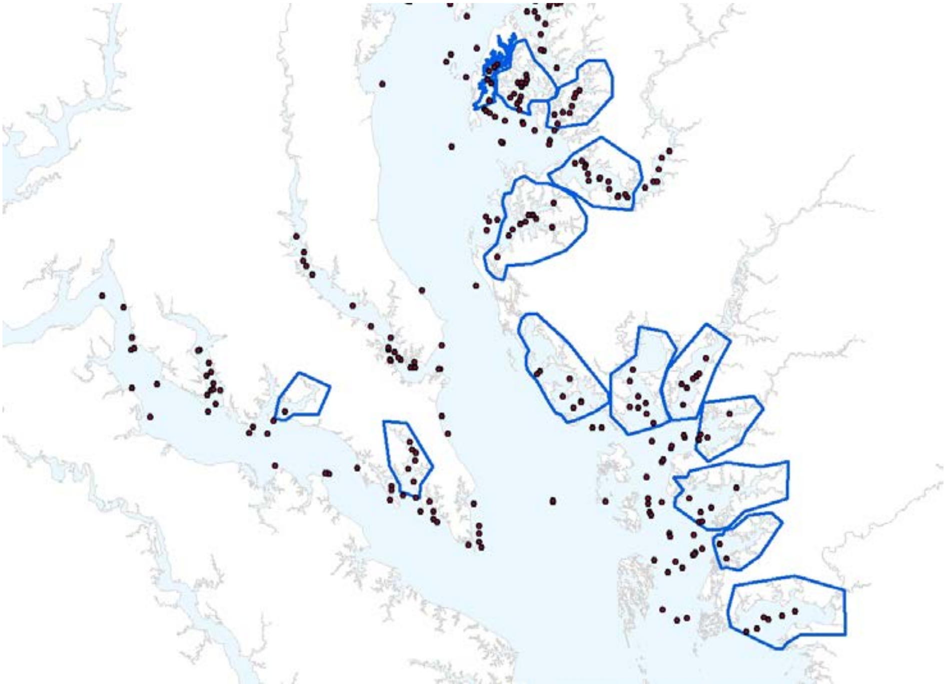
R2 – All 4 independent variables together explain **51%** of the variation in TSM

- Oyster Biomass- 4%, SAV- 5%, Location 51%

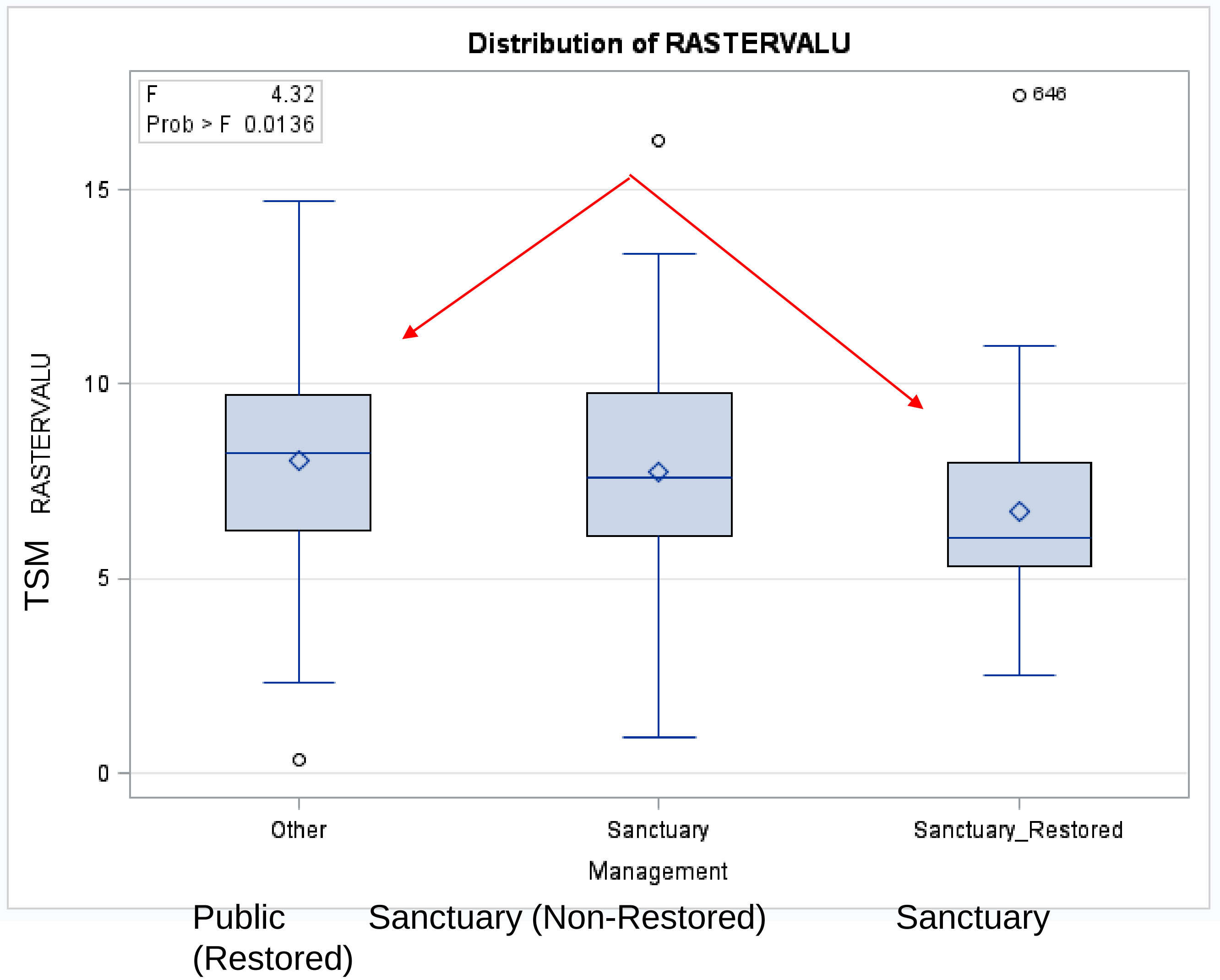
Data Distribution by Area- “13 Tribs”



Lowest TSM values come from Big Annemessex, Broad Cr., Choptank, Harris, and Tred Avon



Does Mean TSM vary by Management Regime (When Managing for Oysters)?

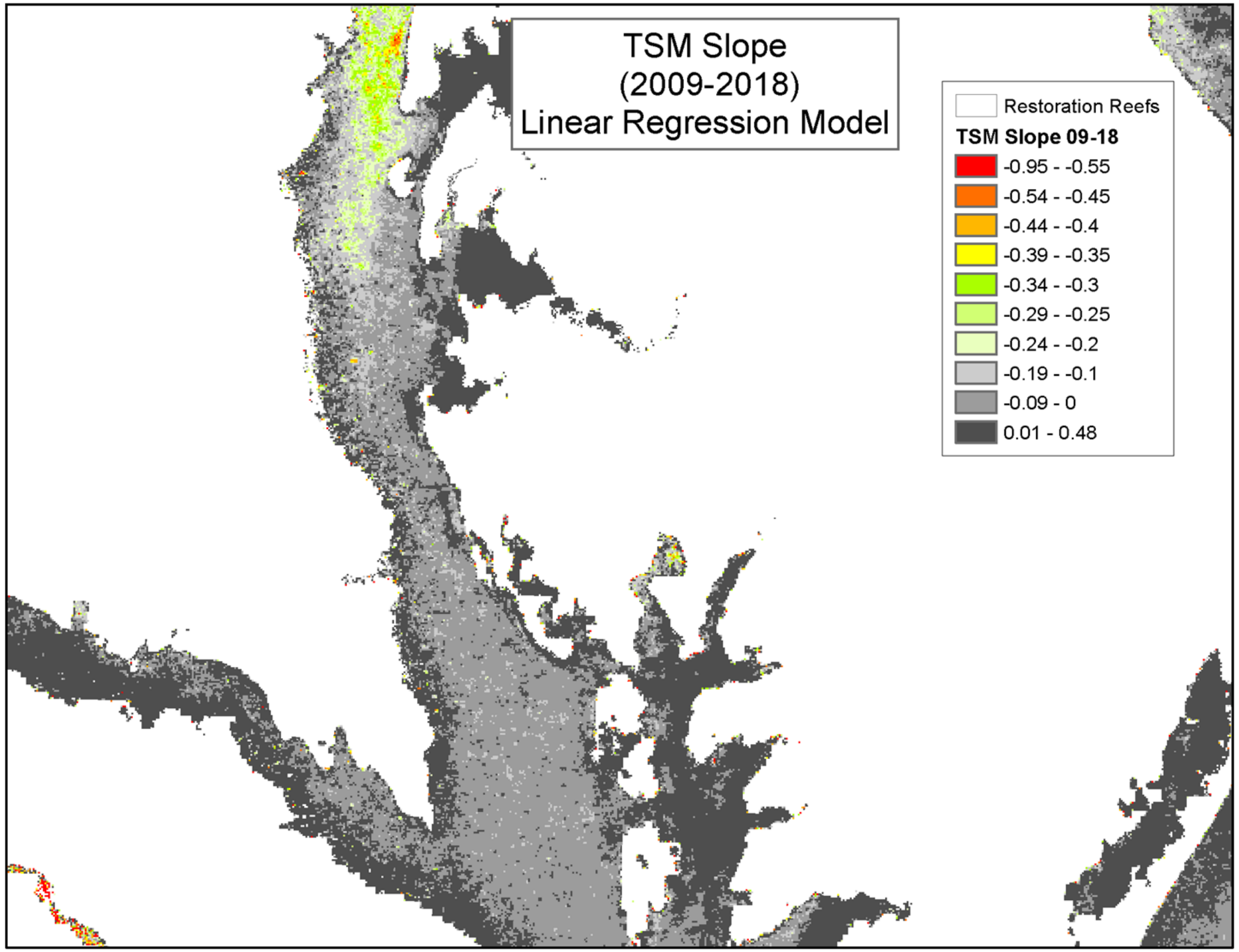


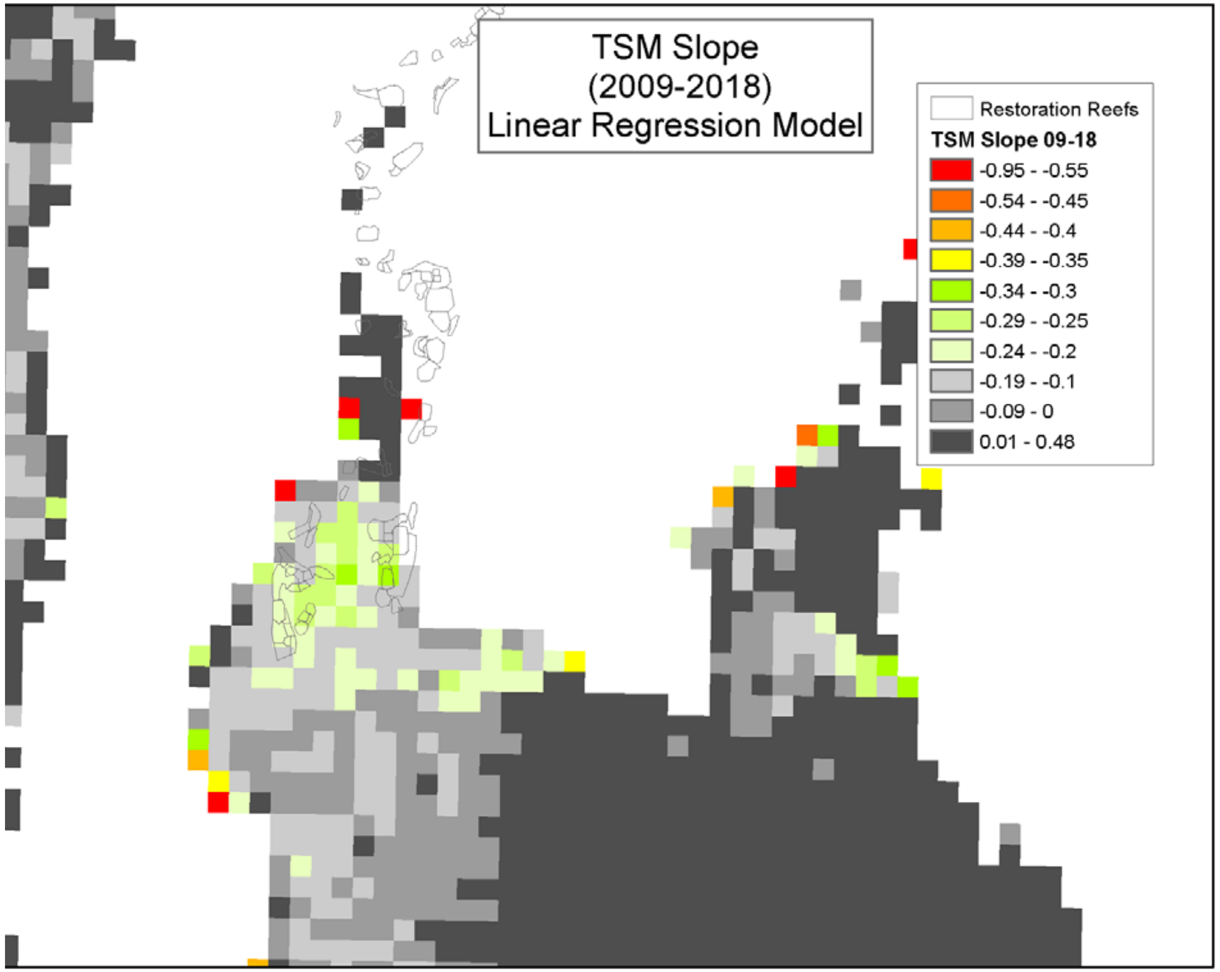
- TSM is significantly different between public and restored-sanctuary management types at the locations of oyster samples in the 13 tributaries, but non-restored sanctuary is not significantly different from the other 2 management types
- Pairwise comparisons indicate that mean TSM varies significantly (alpha = 0.05) among “Public” and “Sanctuary_Restored”
- Should have a “Mixed” class

Conclusions

- Temporal TSM trends suggest meaningful water quality improvement in the NW Choptank River
    - And SAV is approaching full capacity (as we understand it) in Harris & Broad Creeks
- Large scale remotely sensed environmental data should continue to be explored as we quantify the ecosystem services from oyster restoration
- TSM values vary significantly between Public and Restored Sanctuary Management Areas
- TSM decreases significantly with increased Oyster Biomass and increased SAV
- Oyster Biomass, SAV and Location explain 4, 5 and 51% of TSM variability respectively

Slope Trend of Annual Satellite Total Suspended Matter (TSM) 2009-2018





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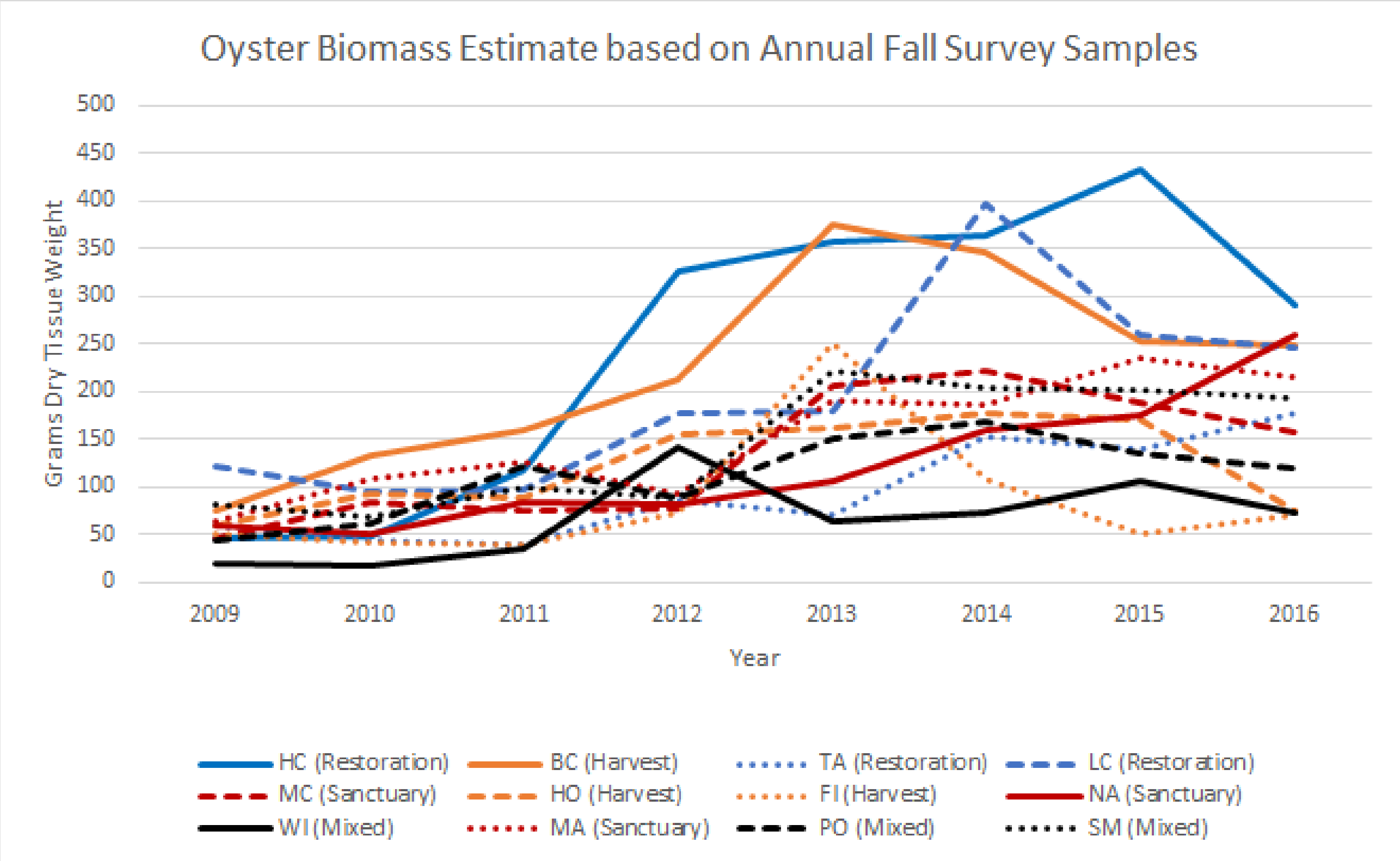
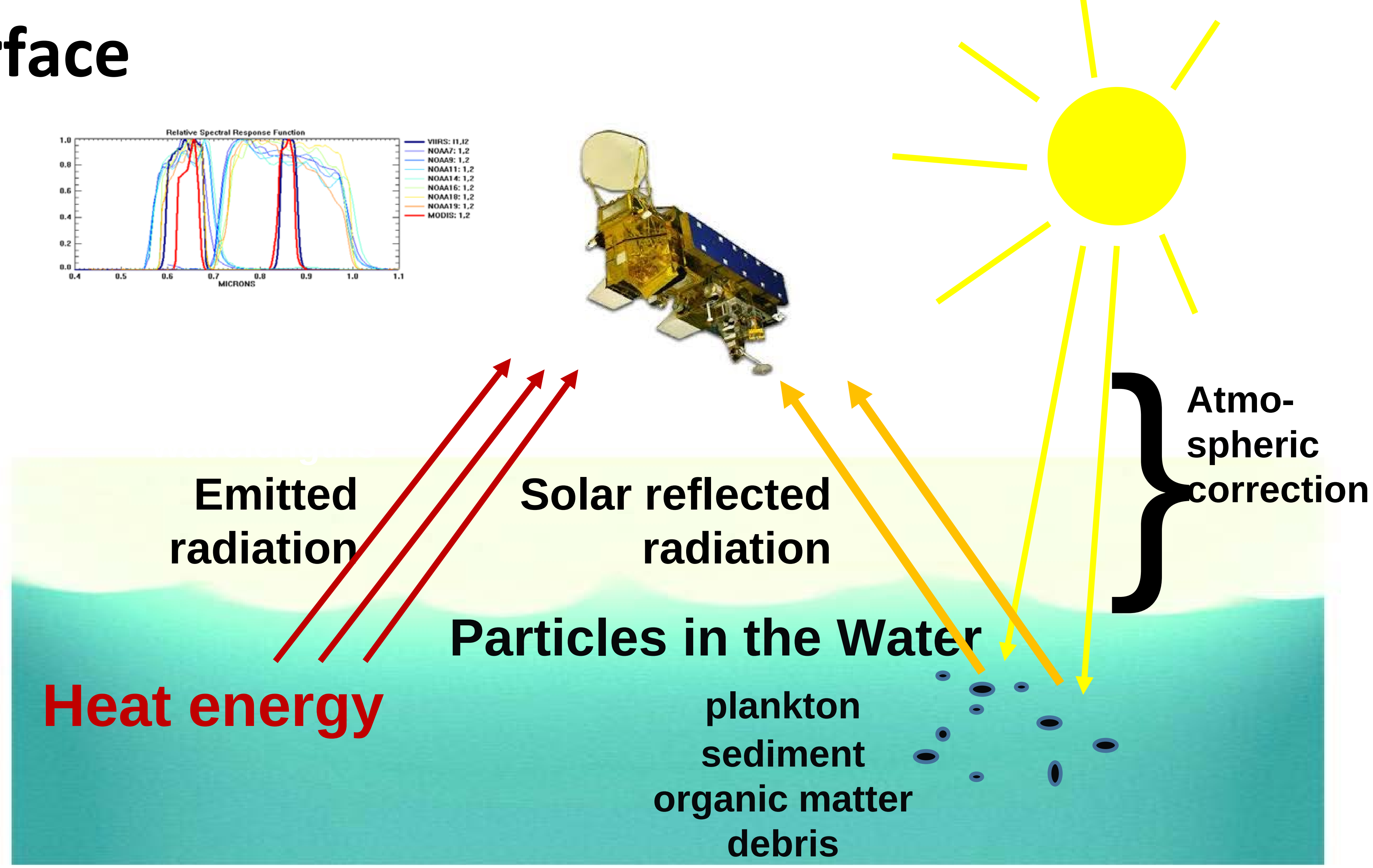
Mean Oyster Biomass* by Area from Oyster Annual Fall Survey (AFS) over Time

Biomass Estimates using a *modified formula by NOAA (Fall 2009 – Fall 2016)

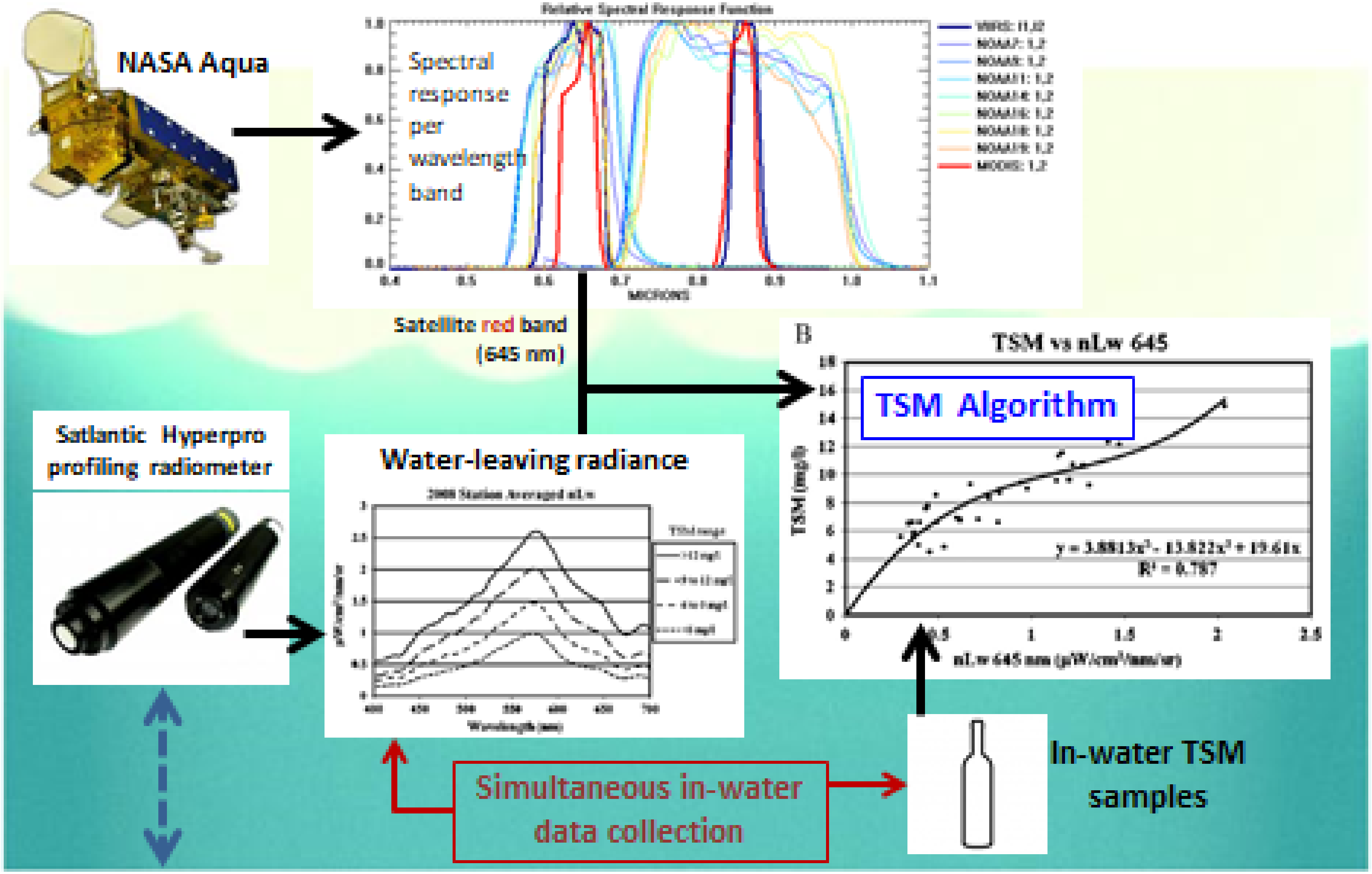


How a satellite instrument measures the earth surface



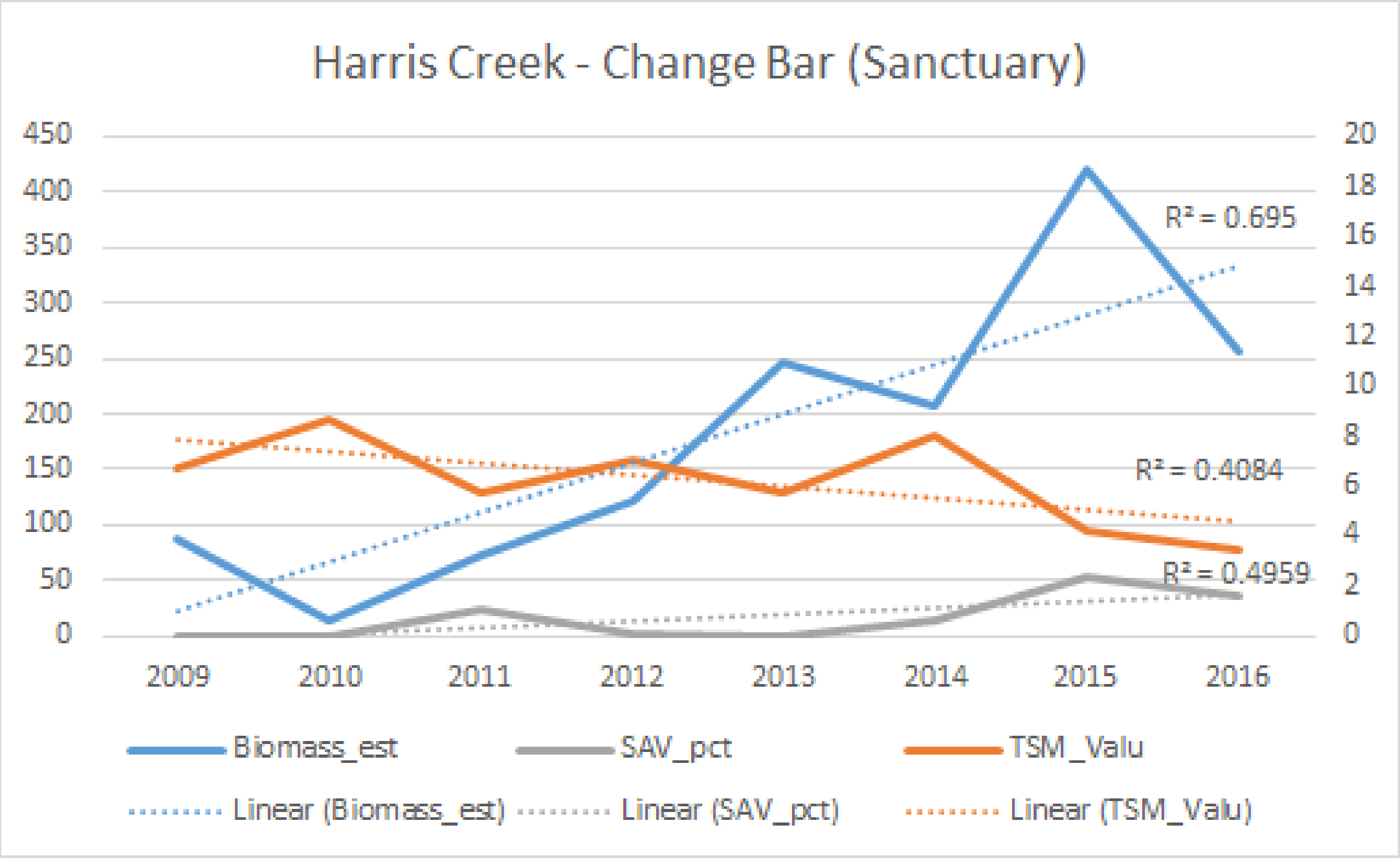
Algorithm Description

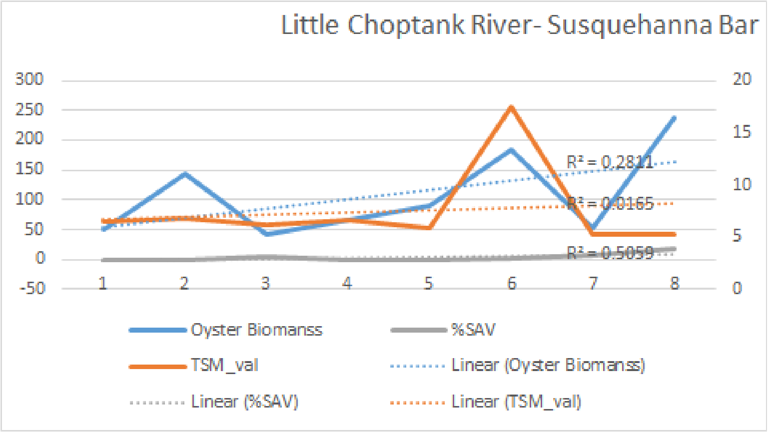
Ondrusek et al., 2012, Remote Sensing of Environment

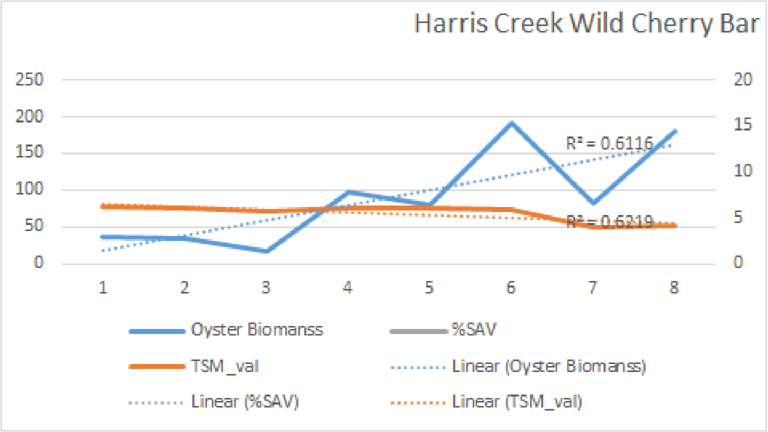


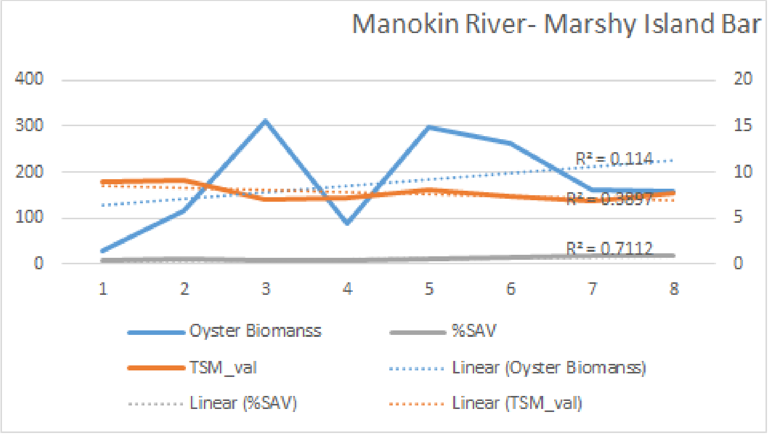
Individual Temporal Trend Plots

(2009-2016, stronger relationships)



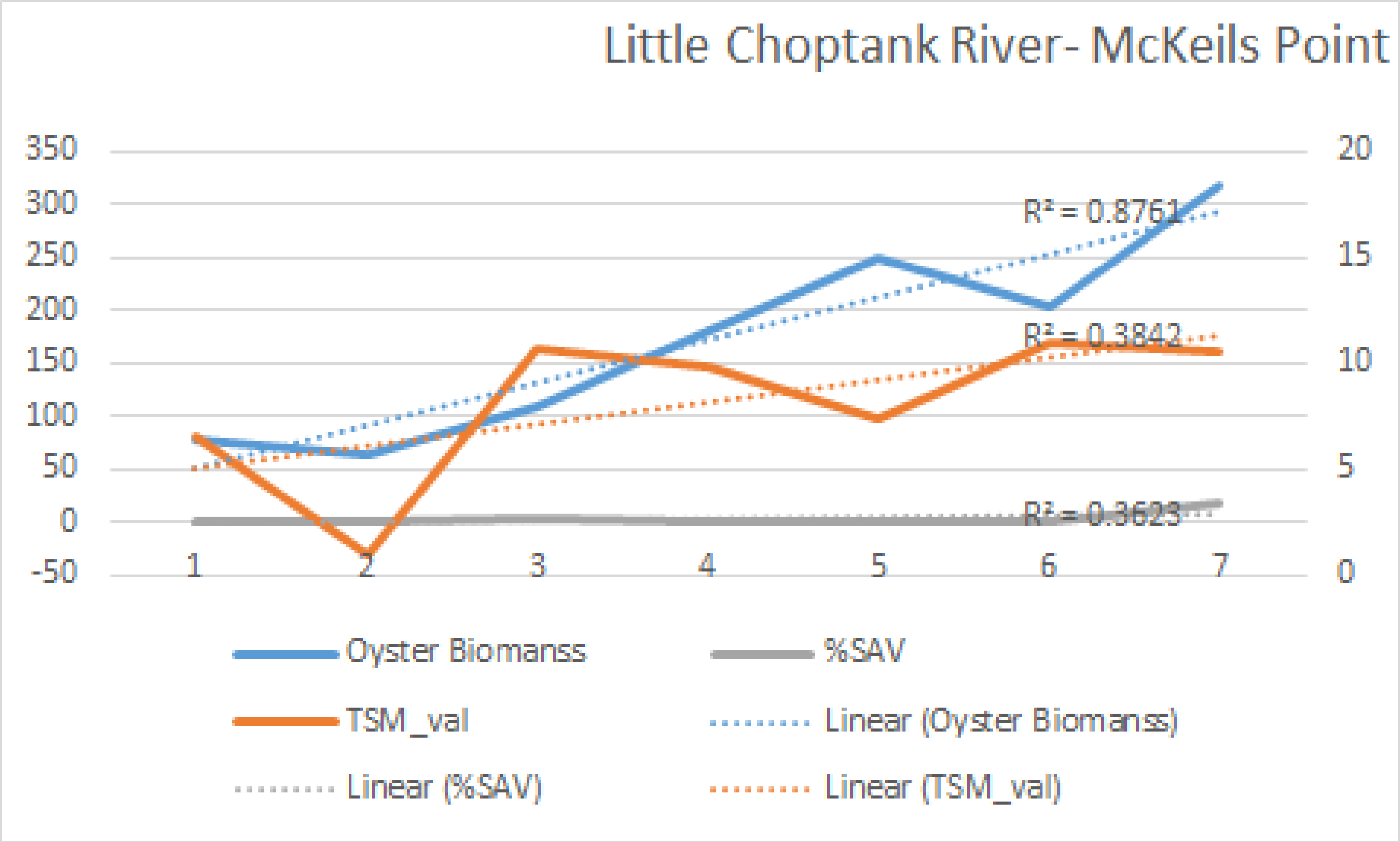


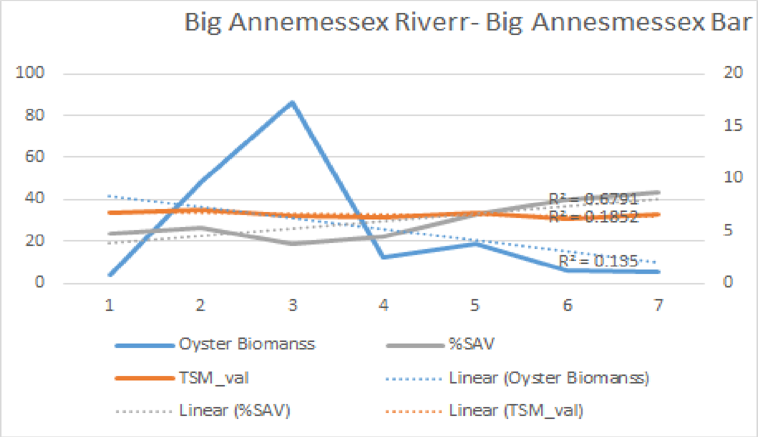


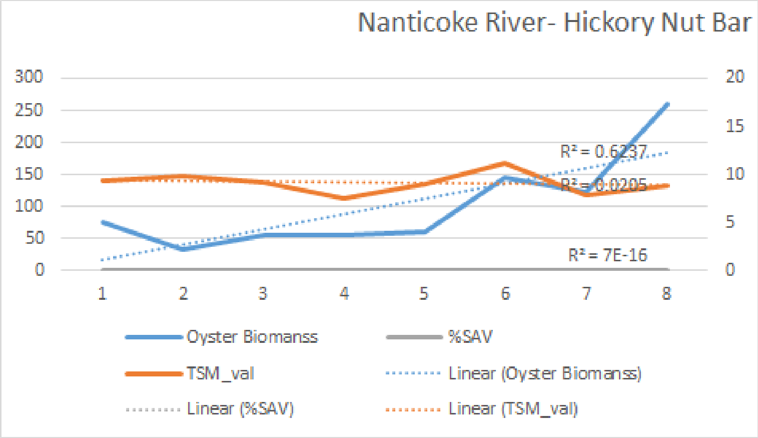


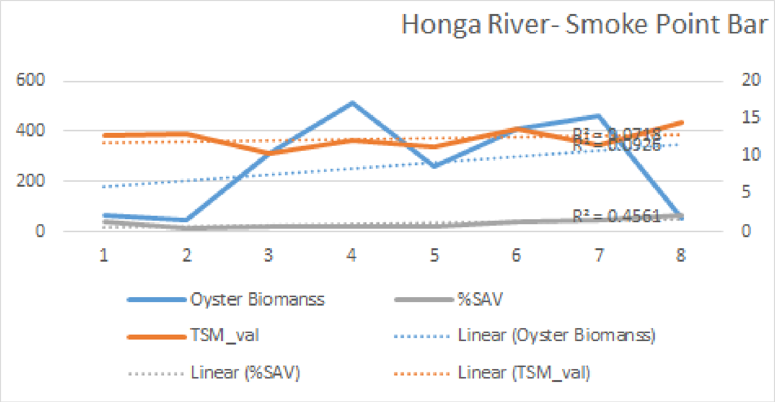
Individual Temporal Trend Plots

(2009-2016, relationships are unclear)









Question: If Management type is significant, and we're managing for oysters, does oyster biomass agree?

ANCOVA Q: Does the relationship between TSM and oyster vary relative to Management levels(Other/Sanctuary/Sanctuary_Resto
Model: Rastervalu = Log_Biomass + management + Log_Biomass*Management
Managment is the Co-variate
Remove oyster biomass < 1 values
Remove TSM = 1
03/07/2018 Analyses

The GLM Procedure

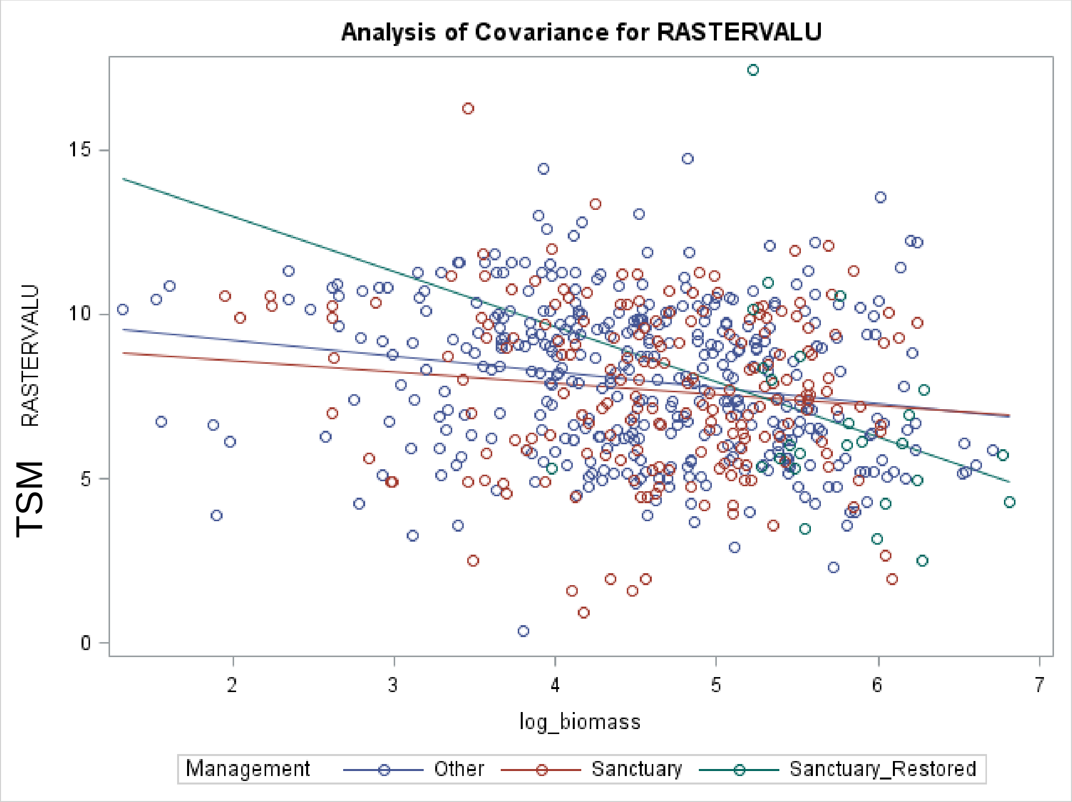
STERVALU

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	168.132802	33.626560	5.97	<.0001
Error	595	3349.565243	5.629521		
Corrected Total	600	3517.698045			

R-Square	Coeff Var	Root MSE	RASTERVALU Mean
0.047796	30.22933	2.372661	7.848871

Source	DF	Type I SS	Mean Square	F Value	Pr > F
log_biomass	1	136.3352676	136.3352676	24.22	<.0001
Management	2	17.3004118	8.6502059	1.54	0.2160
log_bioma*Management	2	14.4971224	7.2485612	1.29	0.2767

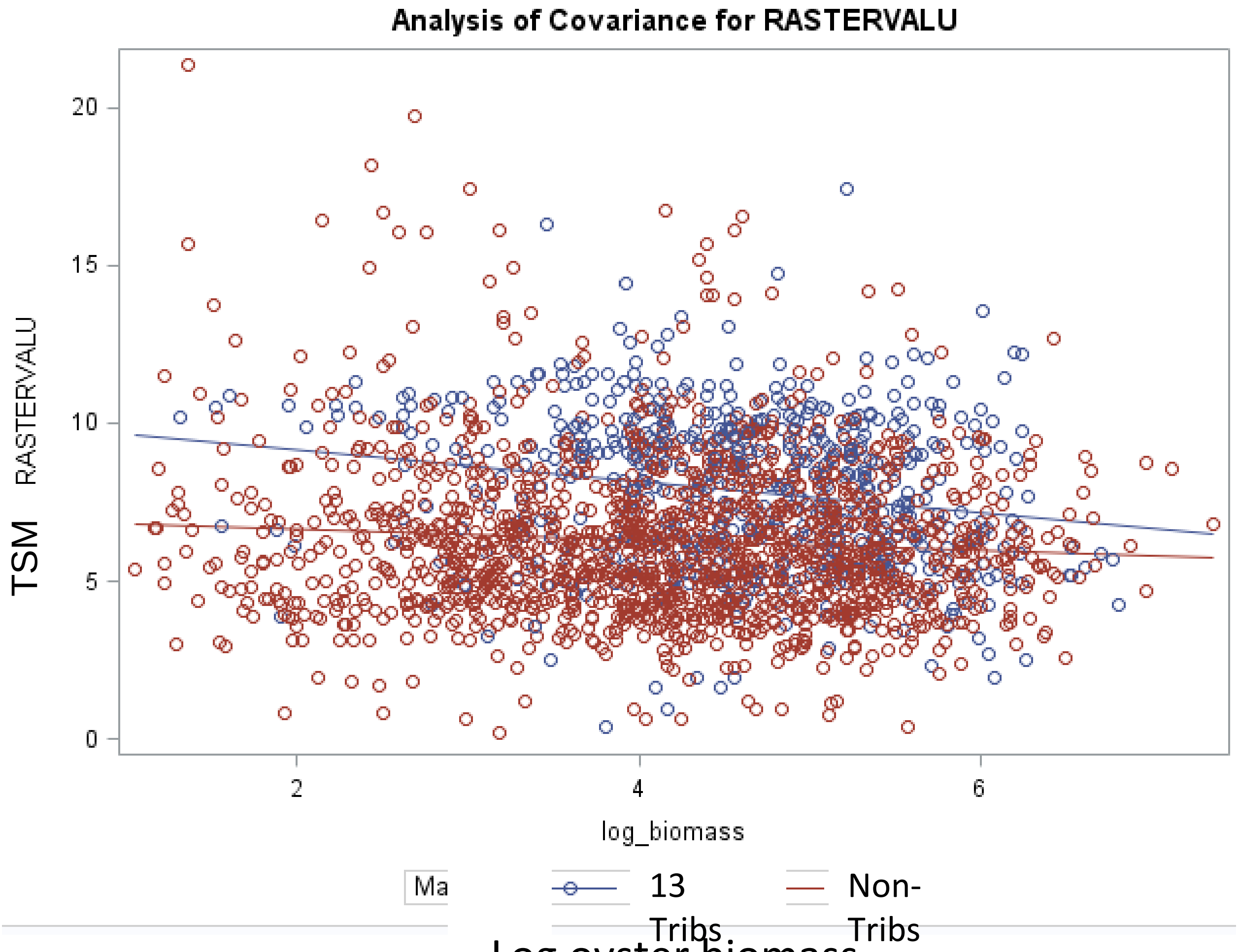
Source	DF	Type III SS	Mean Square	F Value	Pr > F
log_biomass	1	48.34692796	48.34692796	8.59	0.0035
Management	2	14.03701166	7.01850583	1.25	0.2882
log_bioma*Management	2	14.49712245	7.24856122	1.29	0.2767



Public (Restored)   Sanctuary (Non-Restored)   Sanctuary

- ANCOVA Results: A significant relationship exists between TSM and biomass but it is not affected by management regimen.

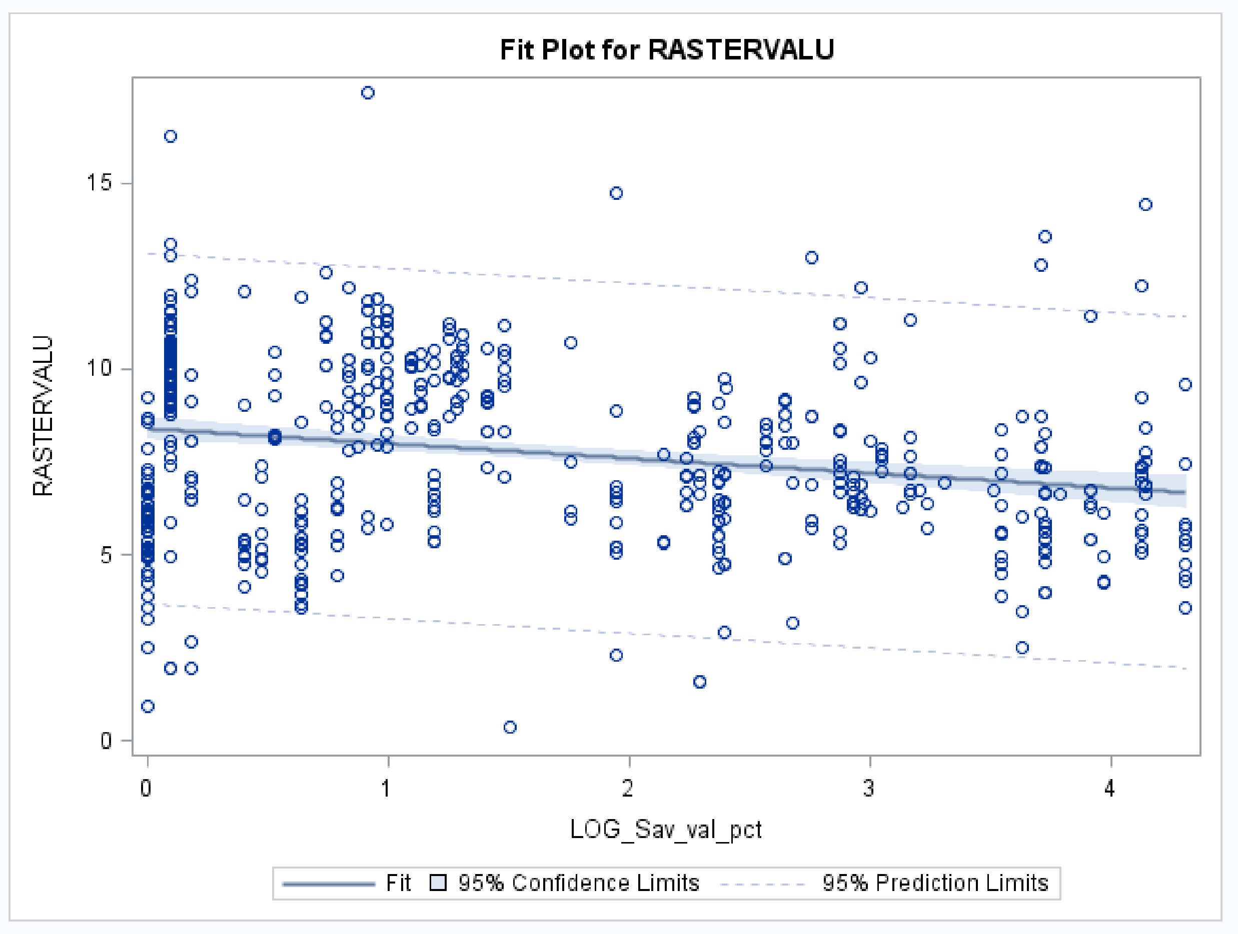
Question: What is the relationship between Oyster Biomass and TSM for all AFS sites?



Log oyster biomass

- ANCOVA Results: Relationship between TSM and biomass varies relative to 13 selected trib sites (blue) or non-13 sites (red), p=0.0052. Slope for the 13 trib sites is greater than non-13 sites.
- Simple regression: TSM = log_biomass
  - 13 Trib sites have significant negative slope (-0.499, p <0.0001) with r2 = 0.039. n=601 observations. This indicates that **3.9%** of TSM variation is explained by biomass in the 13 trib sites.
  - Non-trib sites have significant negative slope (-0.167, p <0.0024) with r2 = 0.0006. n=1468 observations. 0.06% of TSM variation explained.

TSM and SAV relationship



- parameter estimate (slope) is negative indicating that TSM decreases with increased log-transformed SAV coverage percent (slope of -0.4)
- p values < 0.0001 indicate that TSM varies significantly with log-transformed SAV coverage percent
- R_Square is small indicating that SAV explains only 5% of the variability in TSM

Question: What is the relationship between Oyster Biomass and TSM for Study Sites?

Q: Does TSM vary relative oyster biomass?
Model: Rastervalu = log_biomass
Zone_13 Only
Remove oyster biomass < 1 values
Analyses since 03/07/2018 Meeting

The GLM Procedure

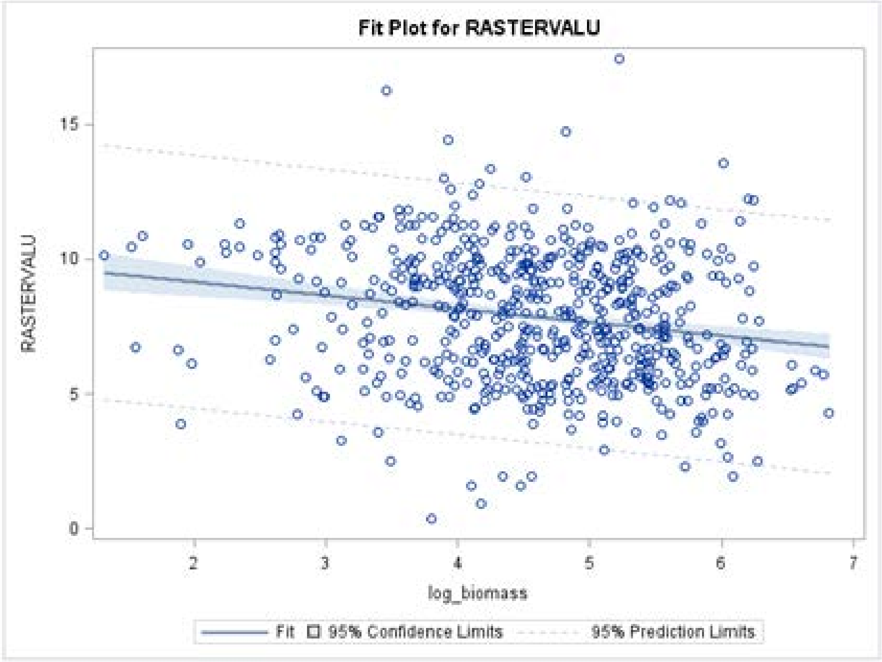
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	136.335268	136.335268	24.15	<.0001
Error	599	3381.362777	5.645013		
Corrected Total	600	3517.698045			

R-Square	Coeff Var	Root MSE	RASTERVALU Mean
0.038757	30.27090	2.375924	7.848871

Source	DF	Type I SS	Mean Square	F Value	Pr > F
log_biomass	1	136.3352676	136.3352676	24.15	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
log_biomass	1	136.3352676	136.3352676	24.15	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	10.15550521	0.47926256	21.19	<.0001
log_biomass	-0.49946549	0.10163279	-4.91	<.0001



- Removed oyster biomass values that = 0
- TSM declines significantly with Biomass (oyster)
- Slope = -0.499
- Biomass explains ~4% of the variability in TSM (r^2)
- Slope parameters (-0.413,-0.499) and r^2 (0.054, 0.039) are similar for the SAV and Biomass models respectively

<u>Question:</u> Is there a relationship between Oyster and SAV?

Q: Does SAV vary relative oyster biomass?
Model: LOG_Sav_val_pct = log_biomass
Zone_13 Only
Remove oyster biomass < 1 values
Analyses since 03/07/2018 Meeting

The GLM Procedure

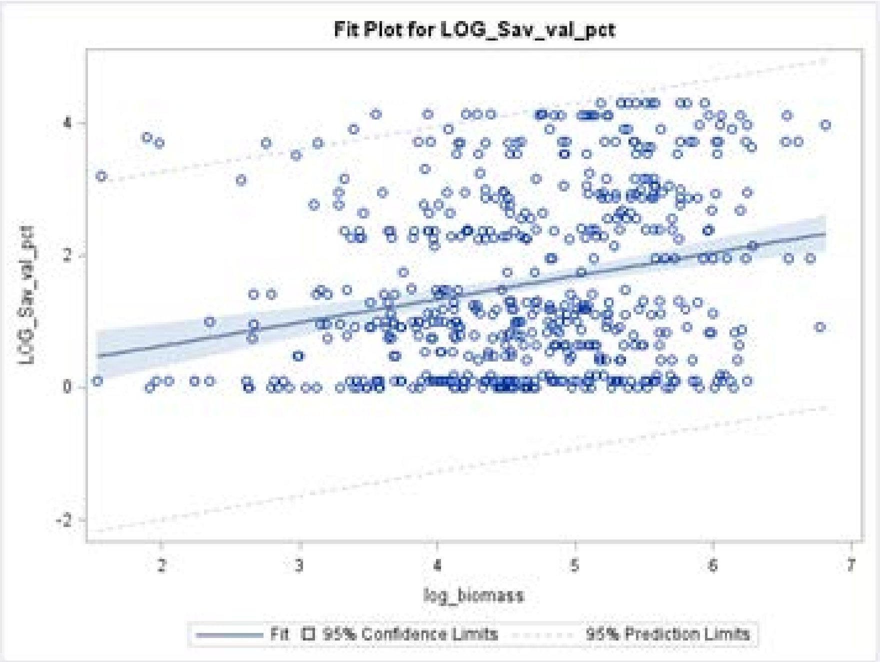
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	61.614405	61.614405	34.86	<.0001
Error	568	1004.059720	1.767711		
Corrected Total	569	1065.674125			

R-Square	Coeff Var	Root MSE	LOG_Sav_val_pct Mean
0.057817	84.61724	1.329553	1.571255

Source	DF	Type I SS	Mean Square	F Value	Pr > F
log_biomass	1	61.61440477	61.61440477	34.86	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
log_biomass	1	61.61440477	61.61440477	34.86	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-.0676279431	0.28312635	-0.24	0.8113
log_biomass	0.3519739105	0.05961766	5.90	<.0001



- Removed oyster biomass values that = 0
- SAV increases significantly with Biomass (oyster)
- Slope = +0.35
- Biomass explains 6% of the variability in SAV