Using A Satellite to Help Us Evaluate the Impacts of Oyster Restoration: A Perspective From Above

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

Sept 27, 2018

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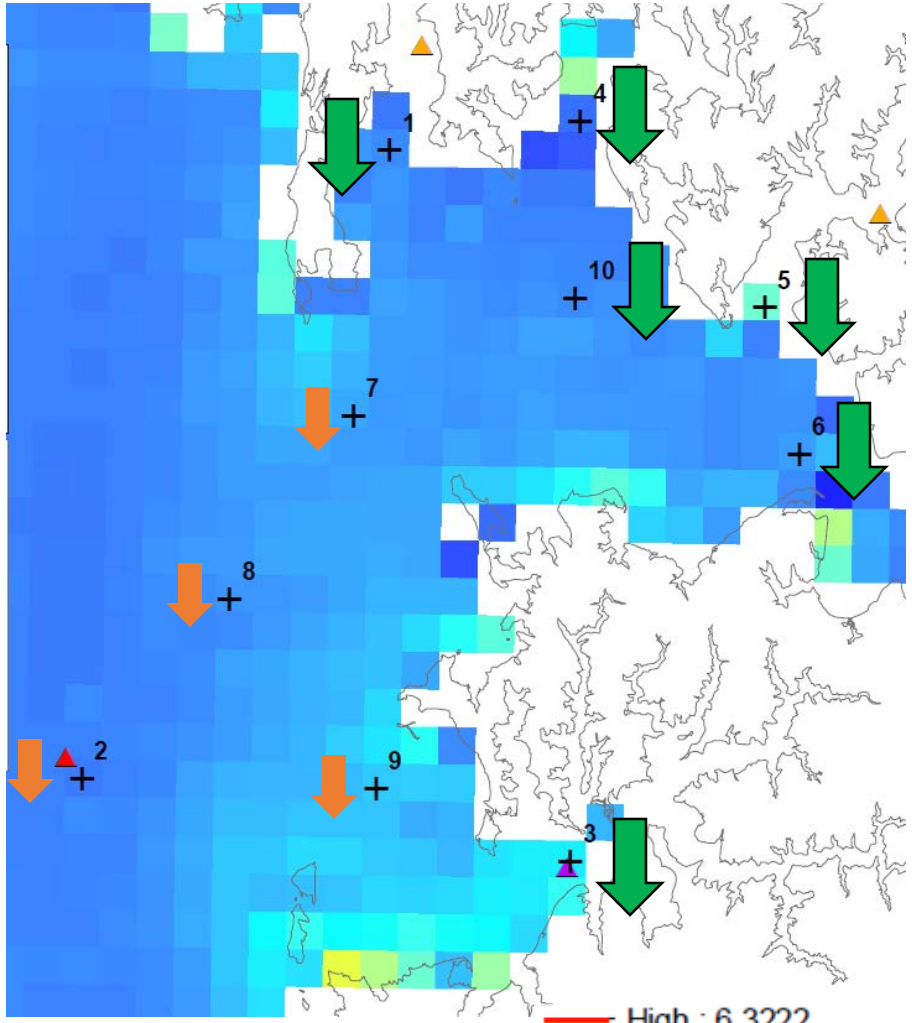
Satellite Turbidity at Selected Stations over Time

Monthly Turbidity Averages Oct 2010 – Mar 2016



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

Creek influenced

2010 – 2013

Small increase in turbidity

2013 – 2016

Decrease in turbidity (few steep drops)

Main stem influenced

2010 - 2013

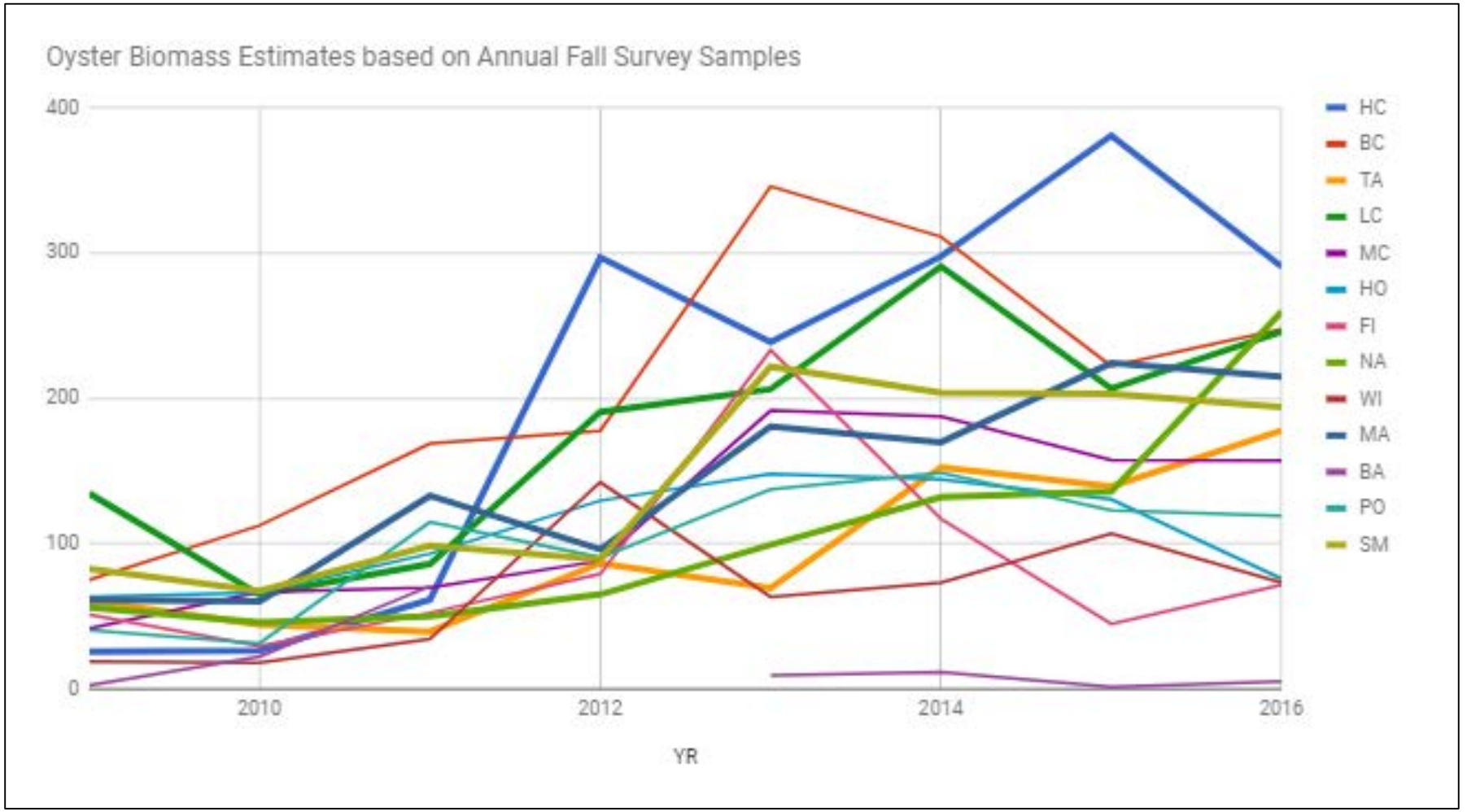
Decrease in turbidity

2013 – 2016

Small decrease or no change

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)

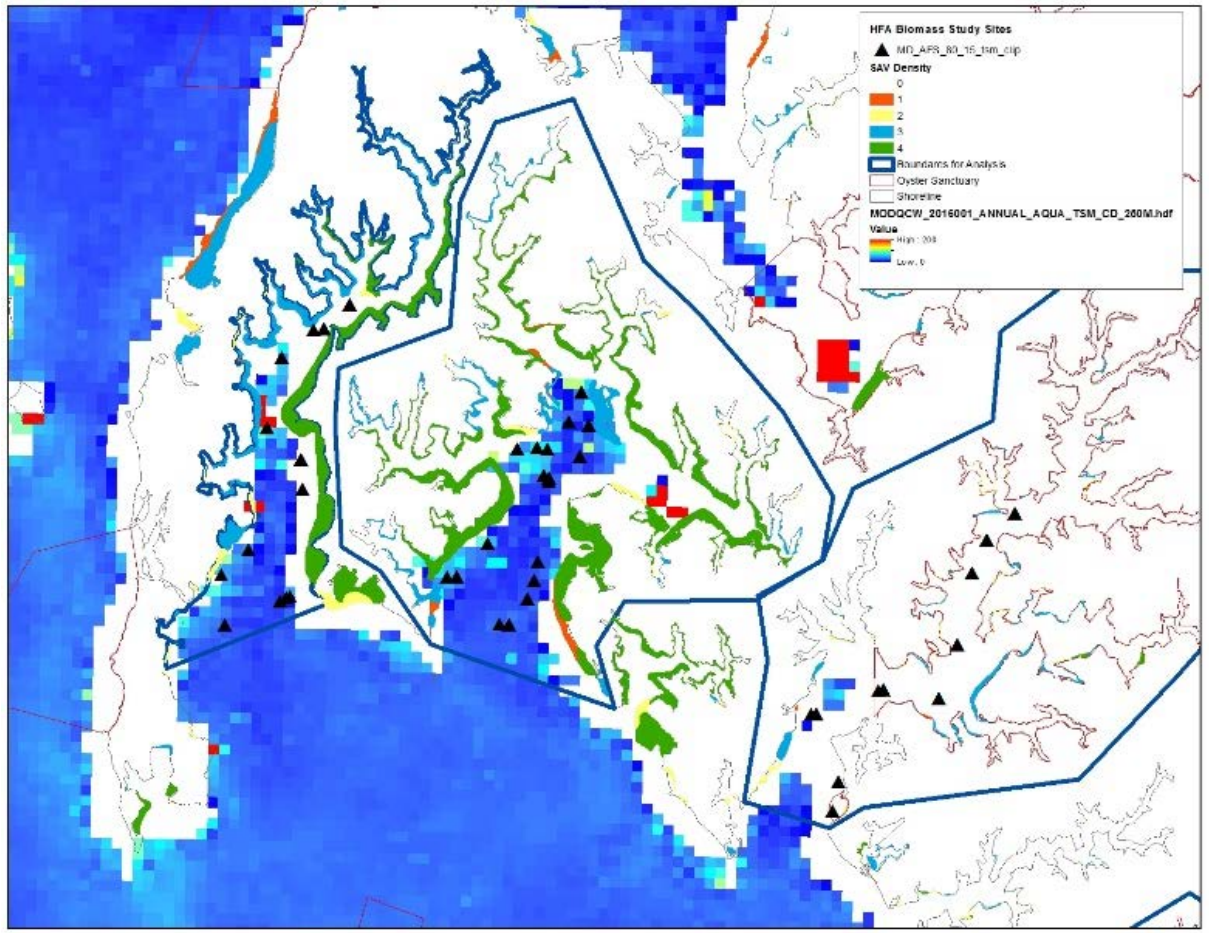


Does oyster restoration improve water clarity?

Public interest in socioeconomic value of oyster restoration

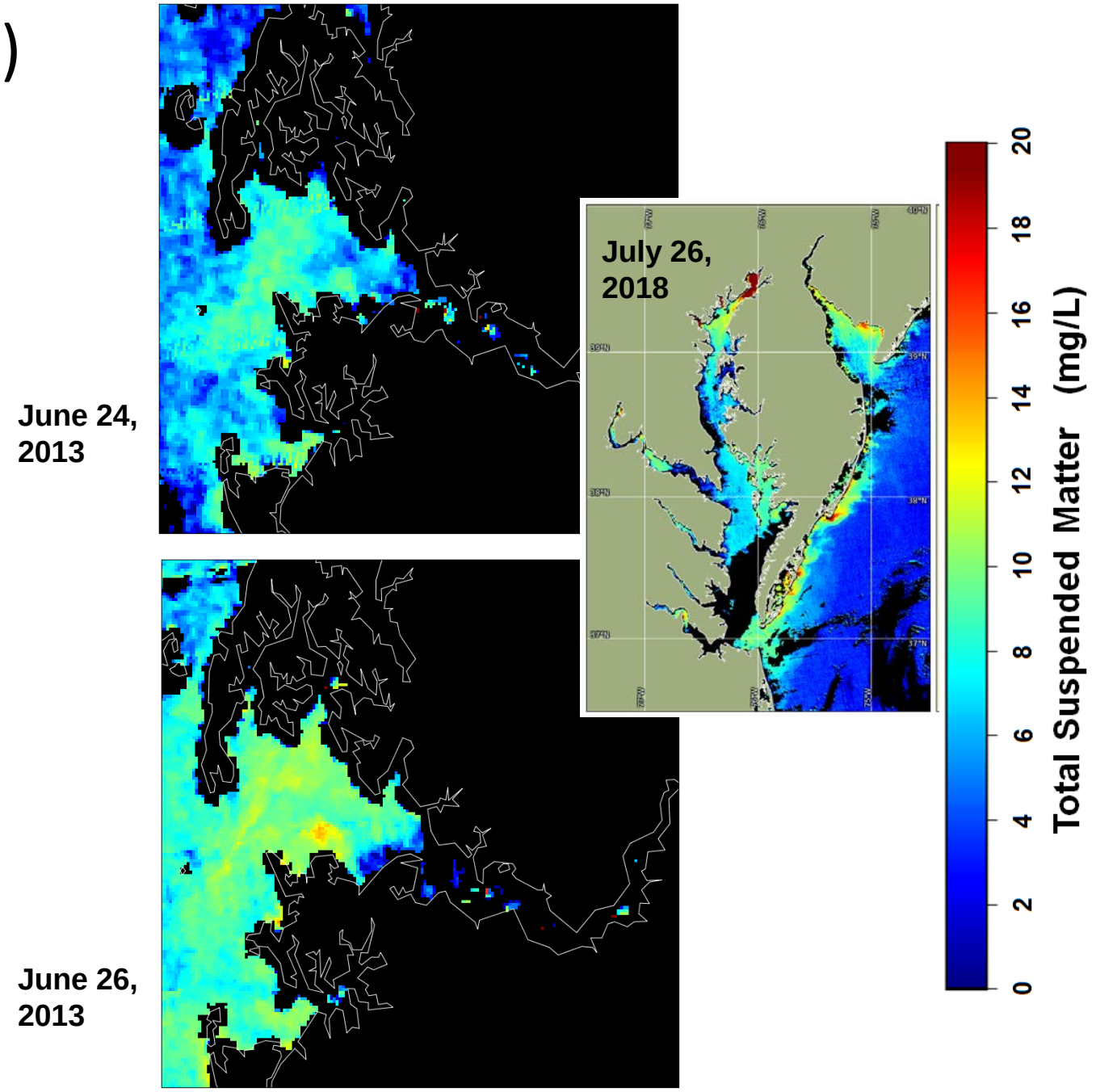
- Use satellite total suspended matter concentration (TSM) as an indicator of water clarity (250m resolution)
- Compare with MD DNR Annual Fall Survey oyster biomass
- Compare with VIMS aerial overflight SAV coverage
  - SAV has increased substantially in the region over this time period
- Comparisons over 8 years: 2009-2016

Suspended Matter map, SAV density, Oyster sample locations



Total Suspended Matter (TSM) from Satellite

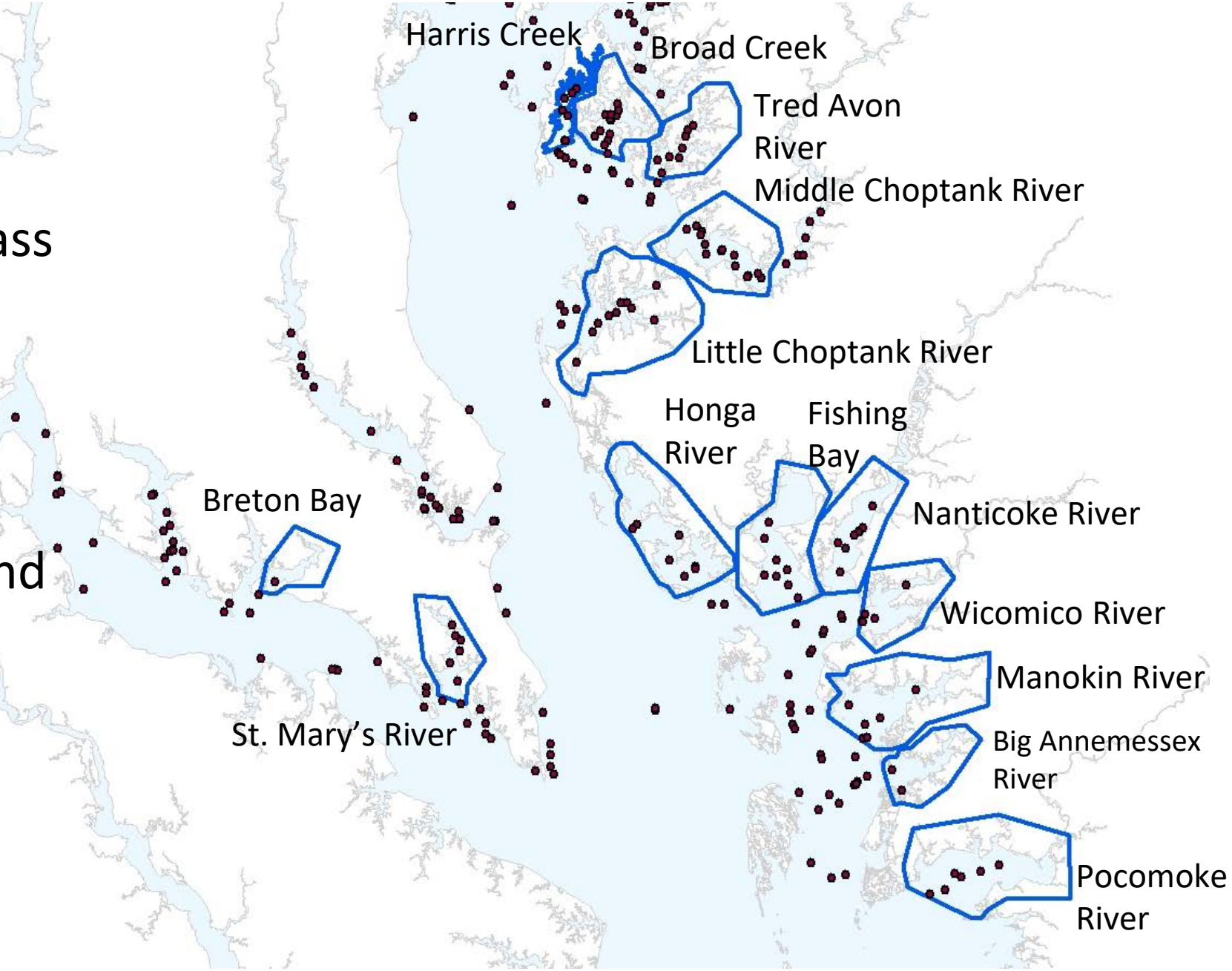
- Sediment concentration (mg/L) in surface water (top 1m)
- TSM algorithm specifically developed by NOAA for Chesapeake Bay (Ondrusek et al., 2012)
- Once daily observation (from a single satellite)
  - Clouds cause missing data
- Provides spatial overview
  - Detect spatial patterns
- Monitor change over time
- 250 m spatial resolution
- Data from NASA's Aqua satellite, MODIS instrument



“13 Trib” Study Design

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

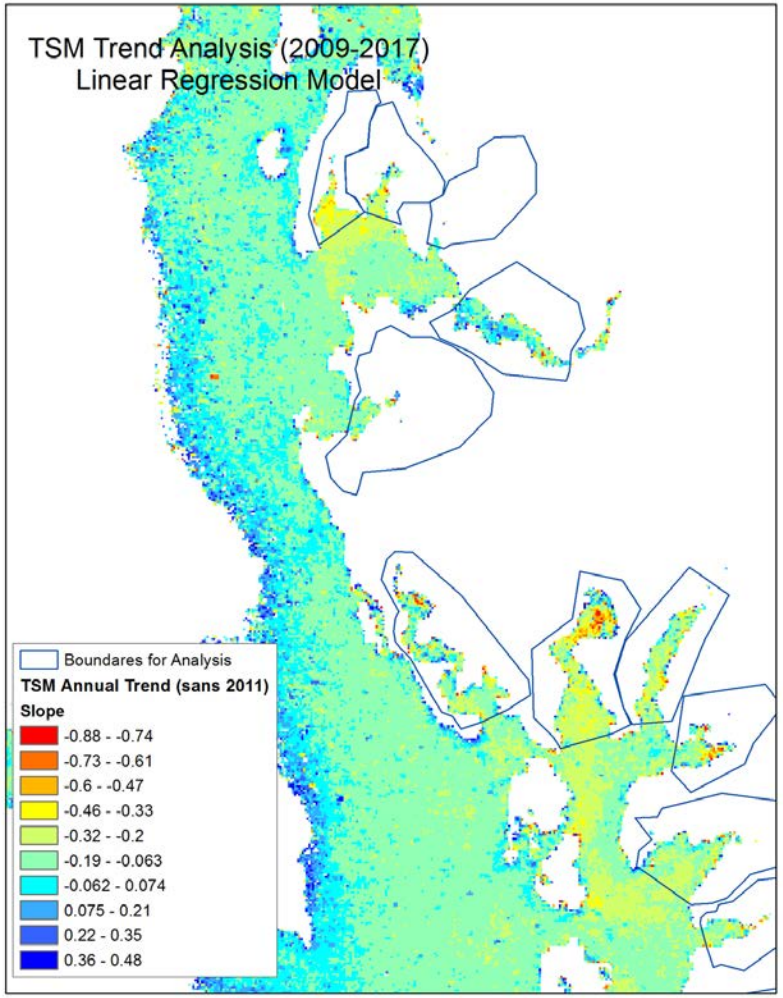
14 Tributaries originally identified
(Breton Bay excluded for too little data)

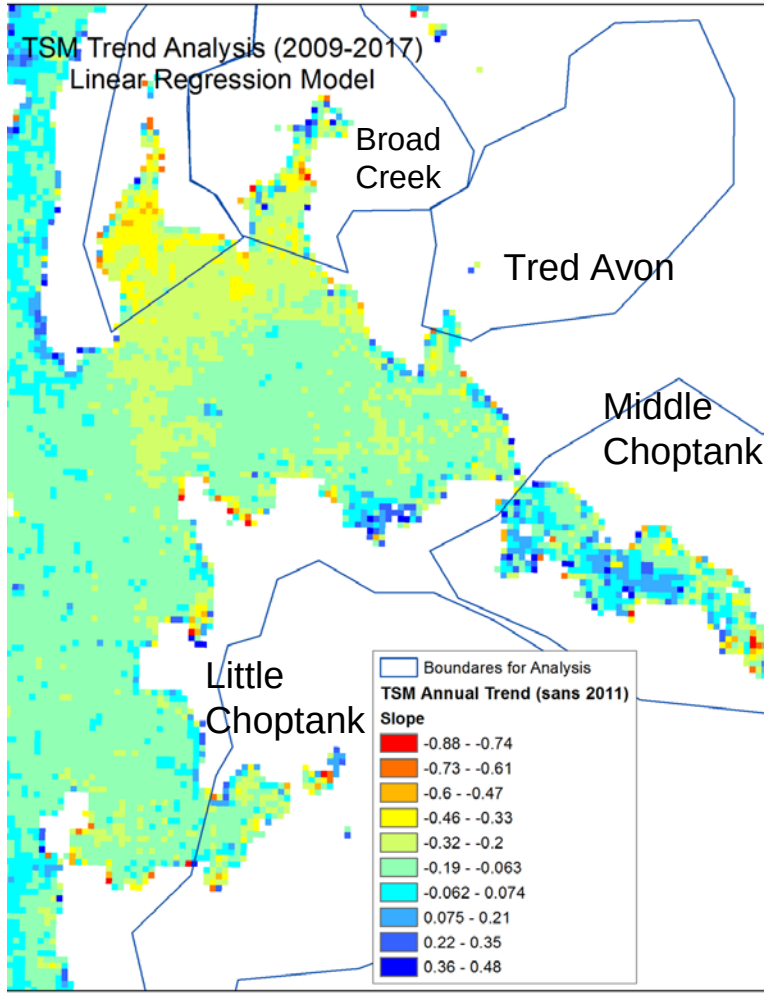


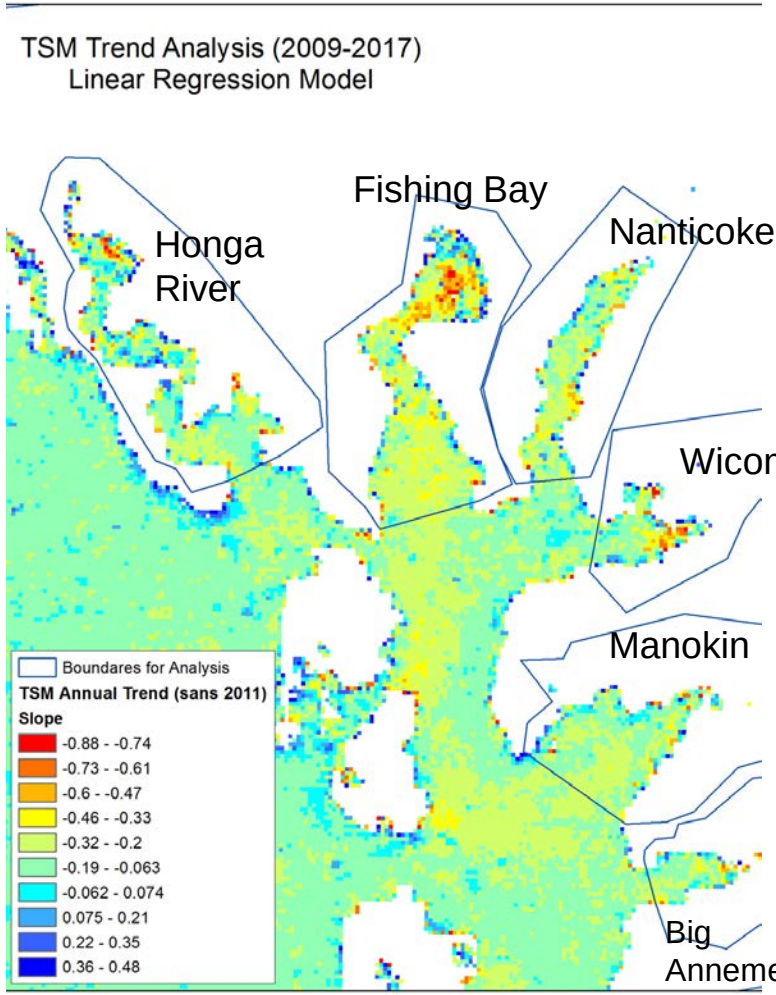
TSM Over Time:

TSM annual trend for each satellite grid cell, 2009-2017

Slope (mg/L / year)





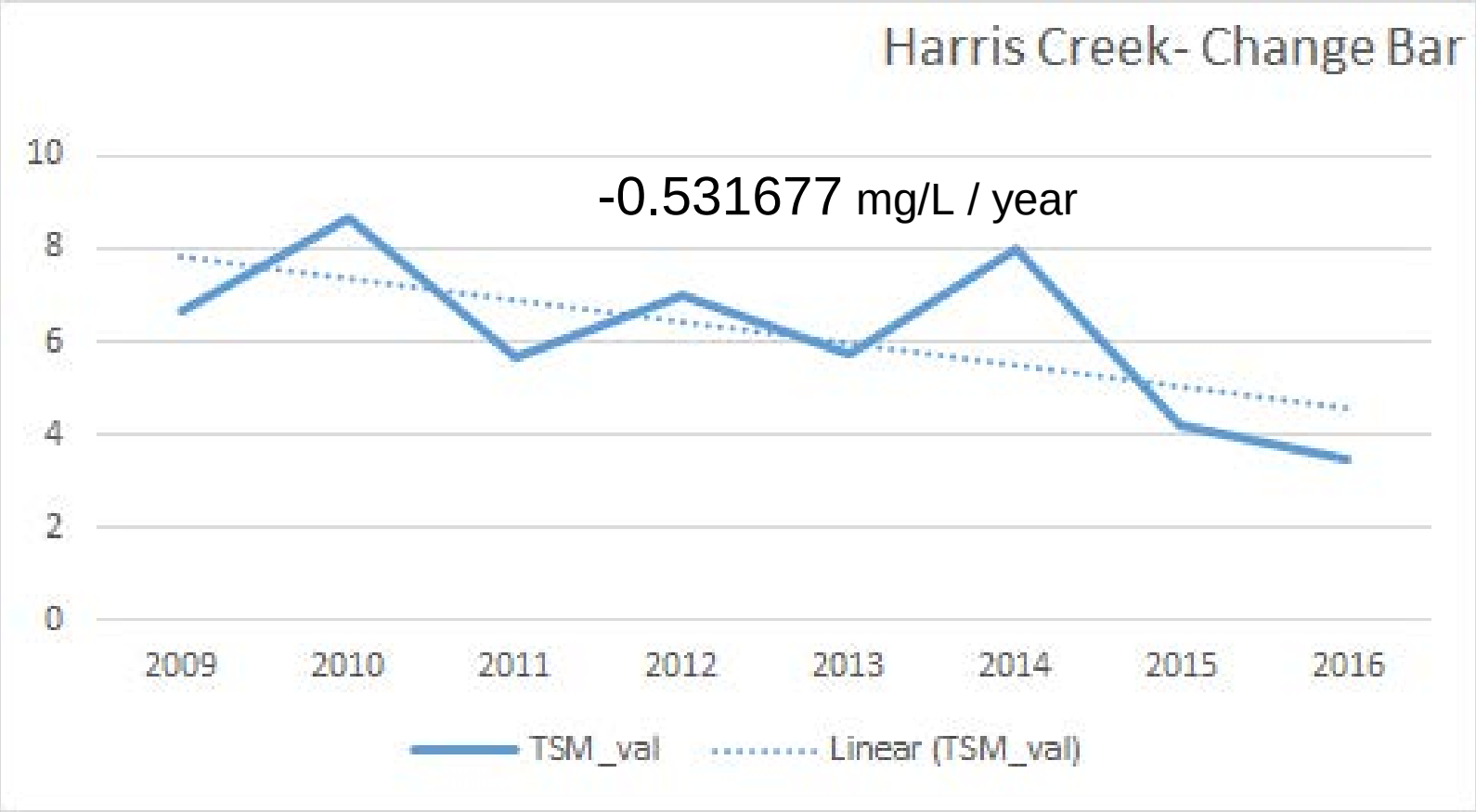


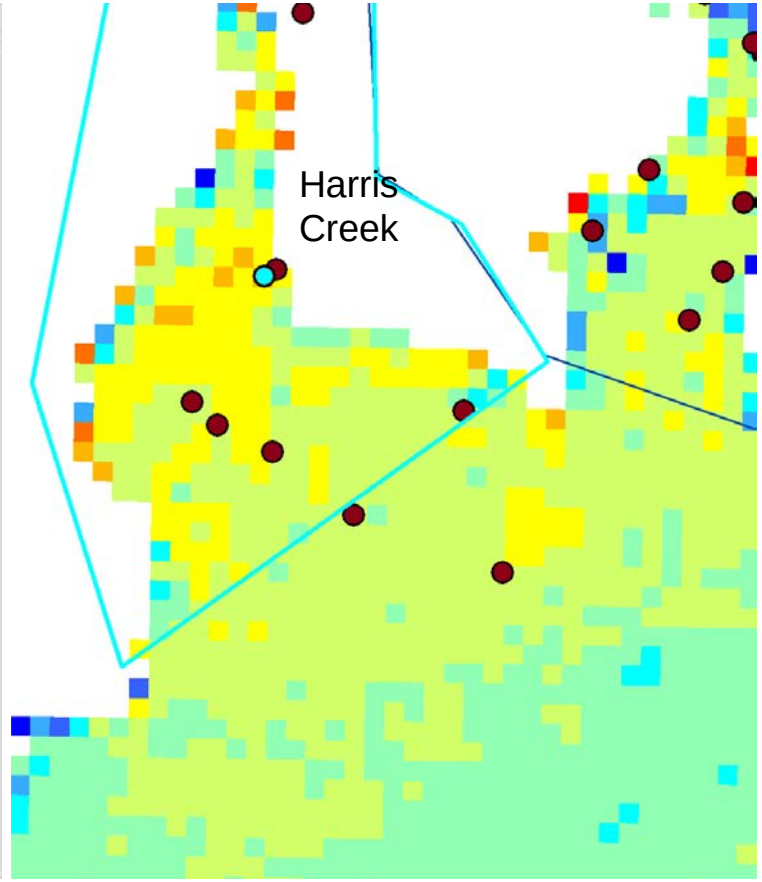
Decreasing TSM slope in Choptank and Tangier Sound

TSM Over Time:

TSM annual trend for each satellite grid cell, 2009-2017

Slope





Single grid cell annual trend at AFS sample location (blue circle) on Change Bar oyster restoration site.

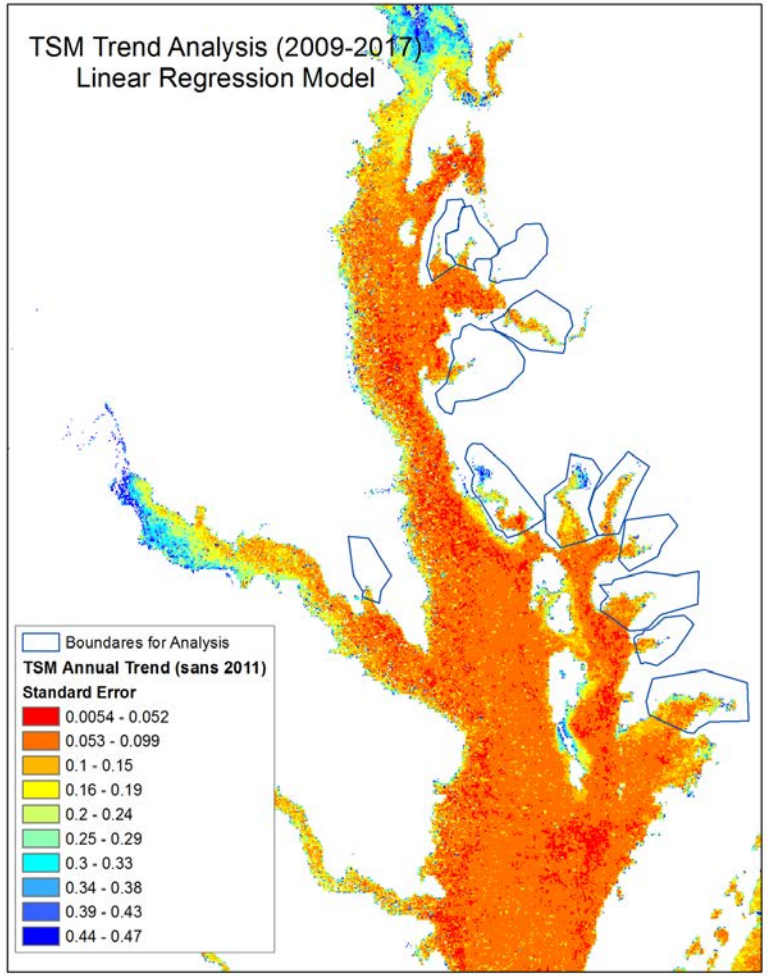
Perimeter grid cells have a high amount of variability.

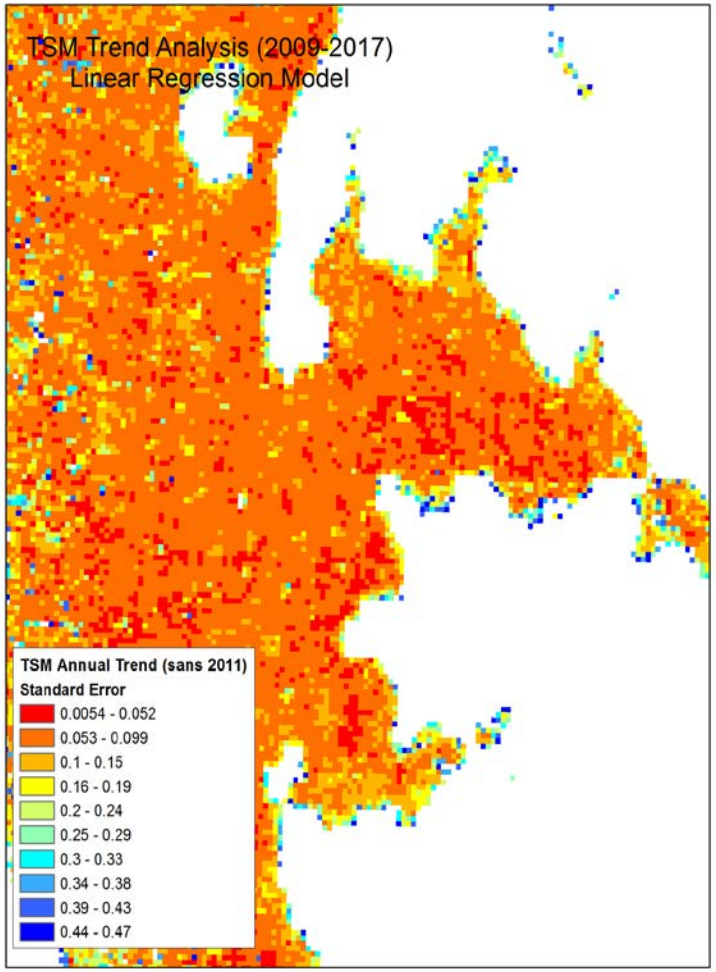
Spatial aggregations of grid cells with consistently high slopes might suggest real TSM decrease.

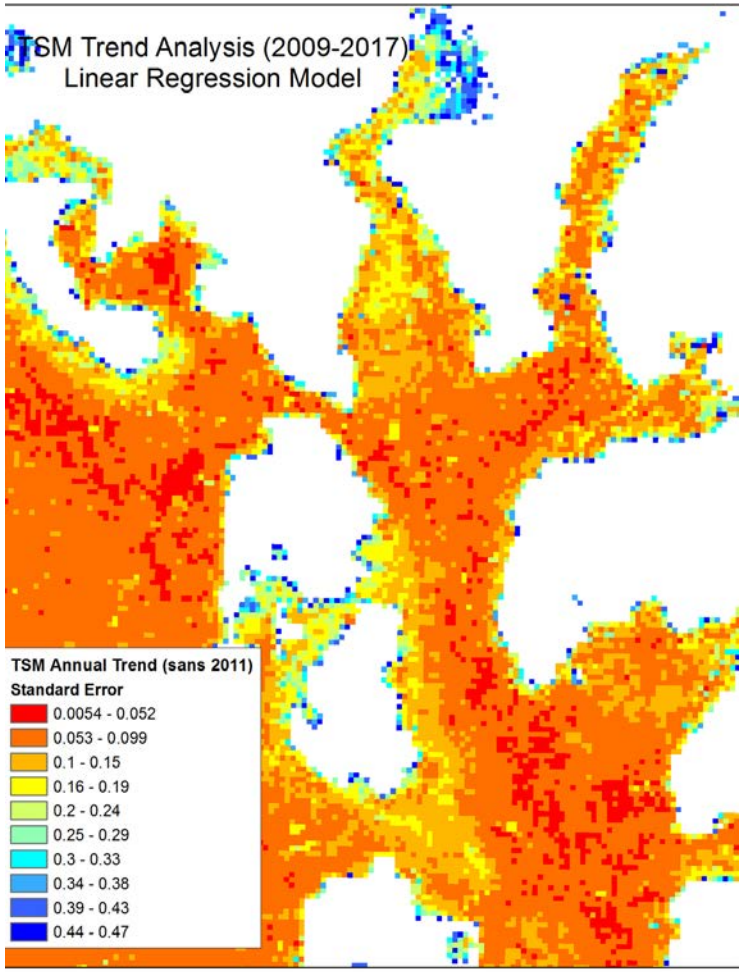
TSM Over Time:

TSM annual trend for each satellite grid cell, 2009-2017

Slope Standard Error (SE) - measure of how well points fit on TSM/yr line





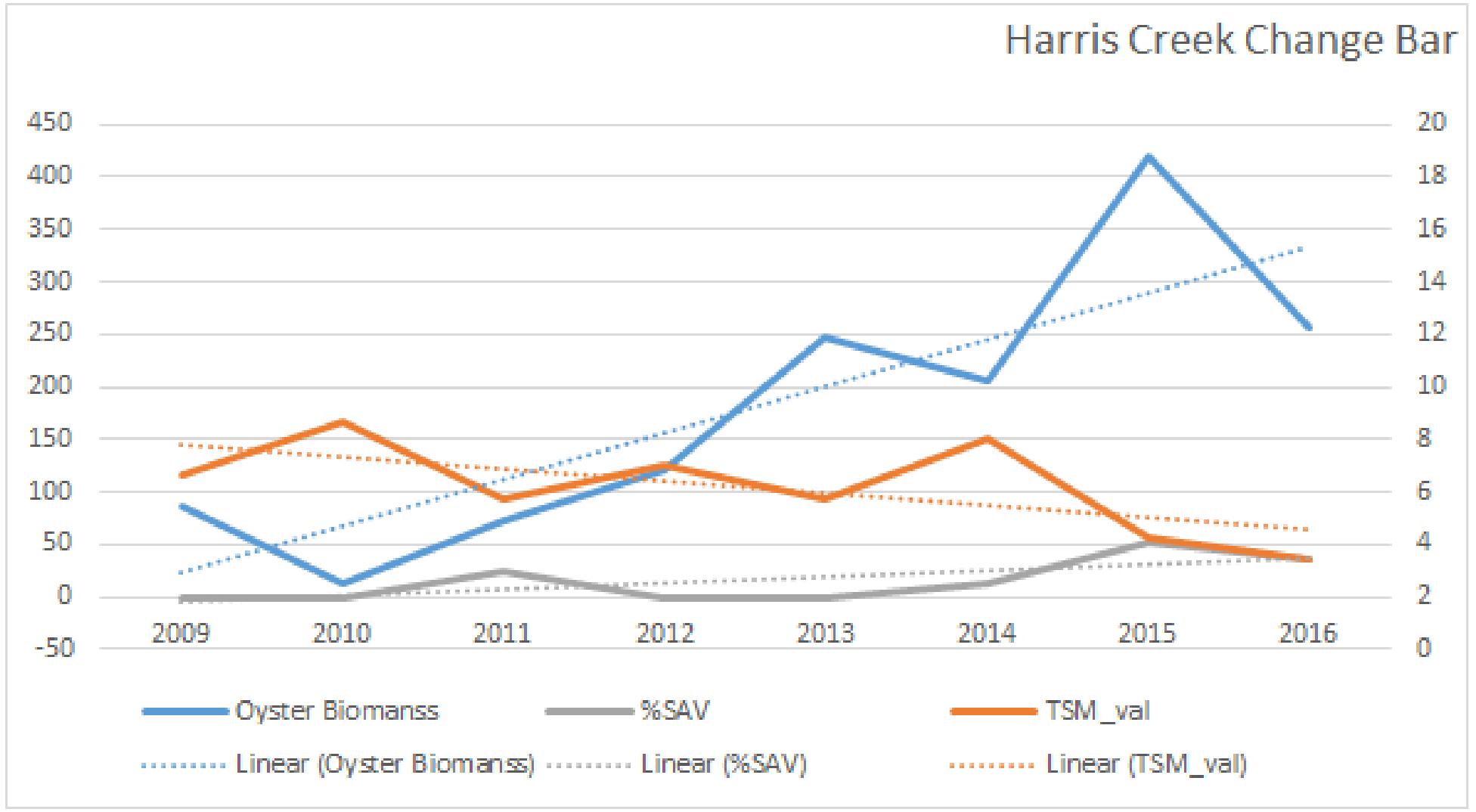


Decreasing TSM slope in Harris and Broad Creeks with small slope SE implies confidence in TSM decrease.

Decreasing TSM slope in Fishing Bay with large slope SE -- TSM decrease not reliable.

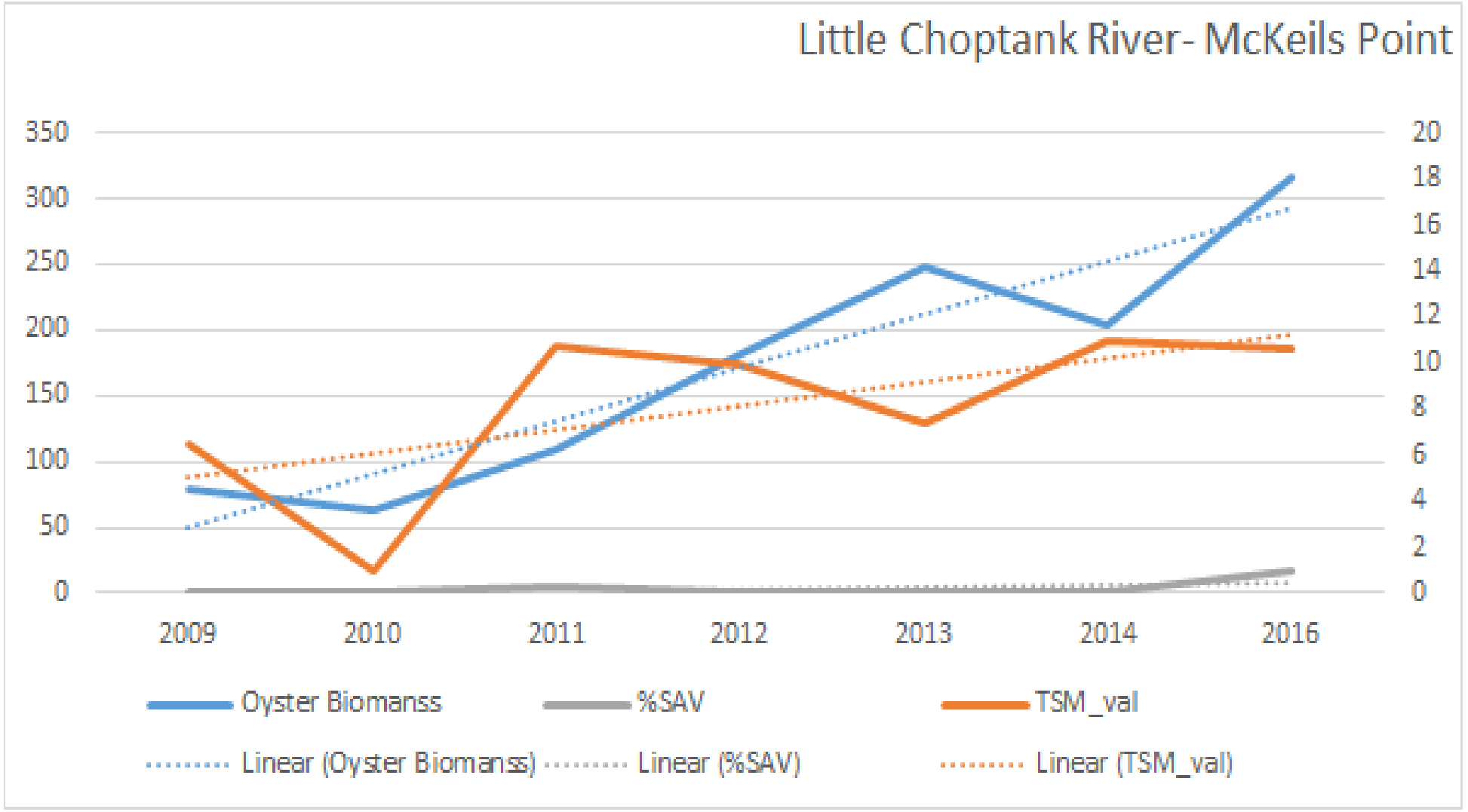
Individual Temporal Trend Plots

(2009-2016, stronger relationships)



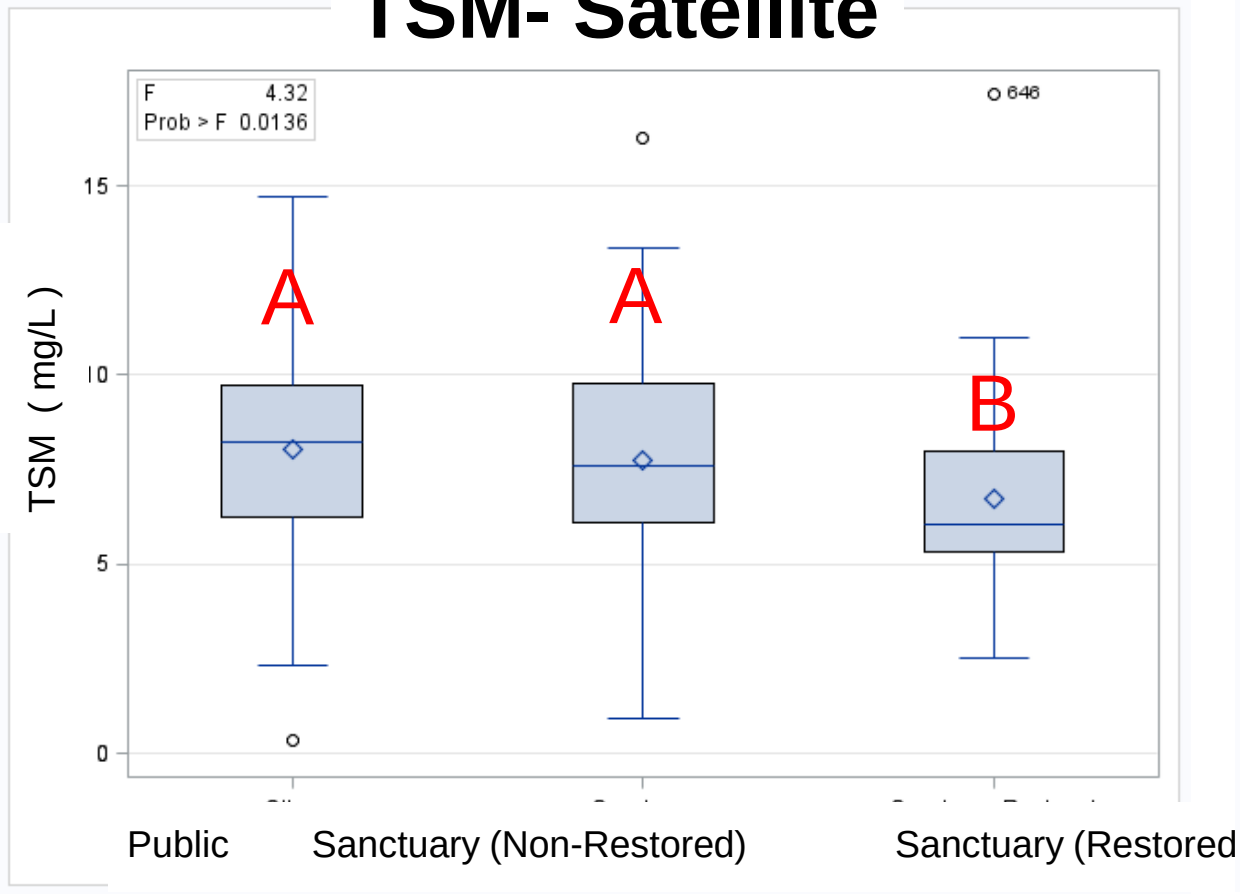
Individual Temporal Trend Plots

(2009-2016, relationships are unclear)

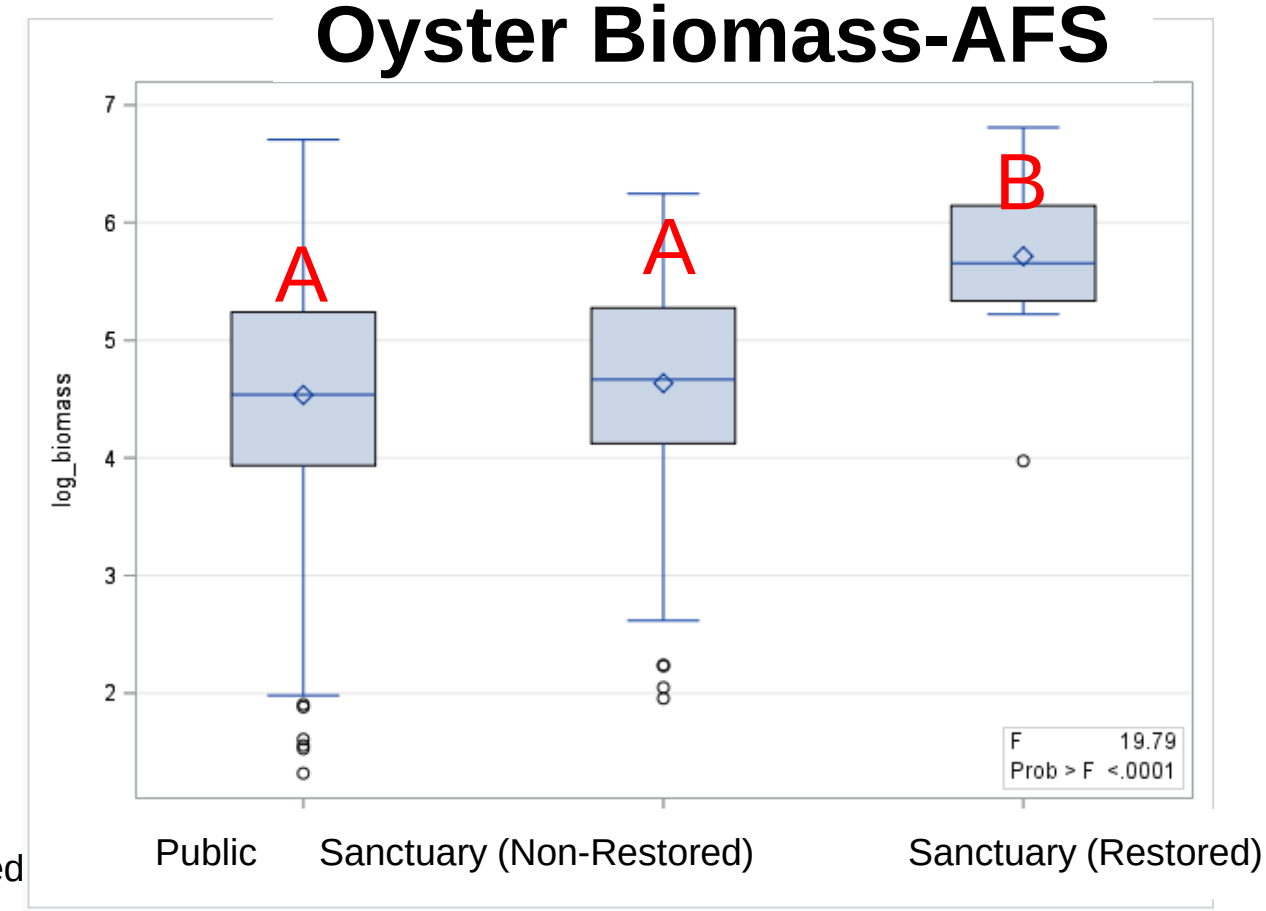


TSM and Oyster Biomass Relative to Oyster Fishery Management Regime

TSM- Satellite

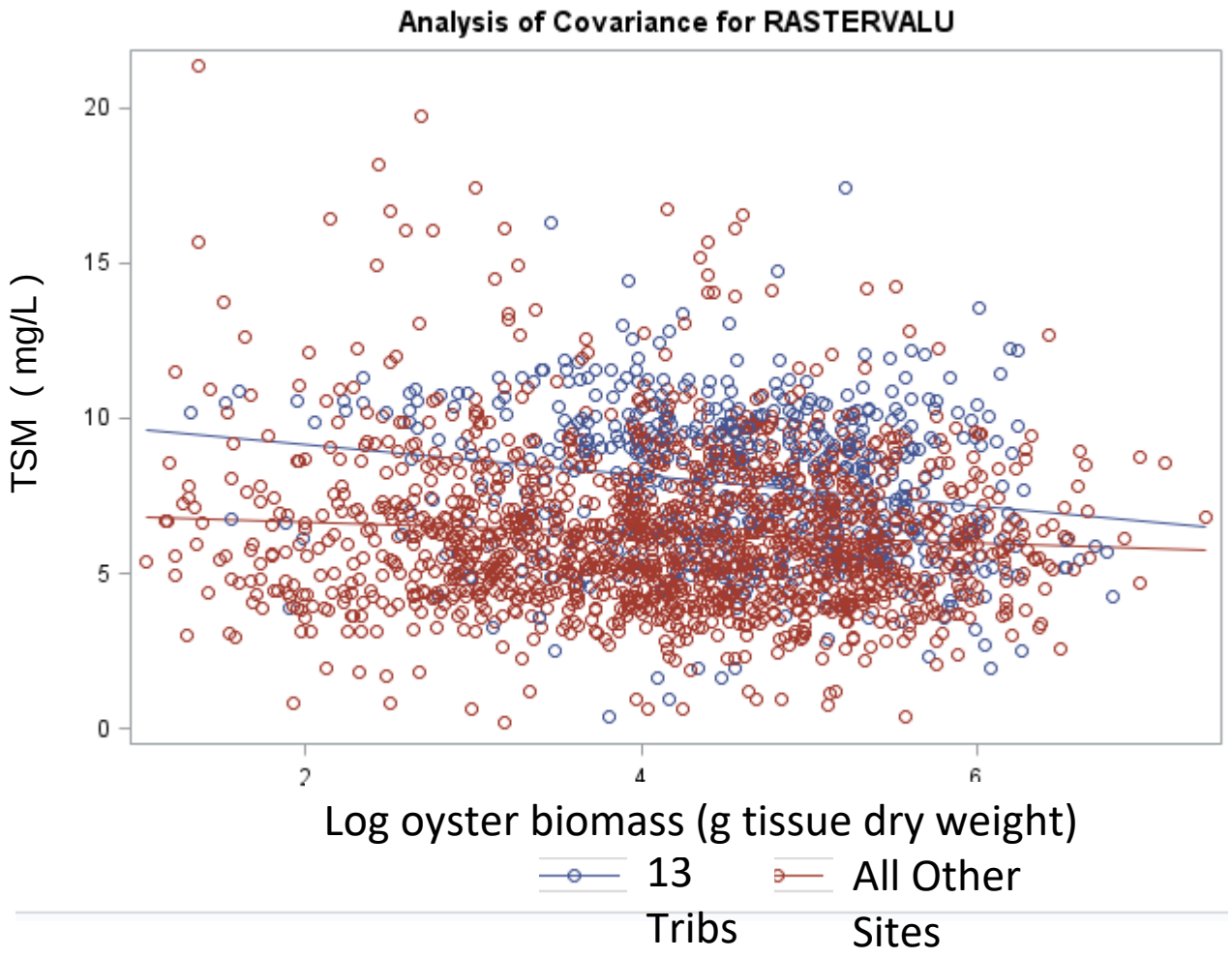


Oyster Biomass-AFS



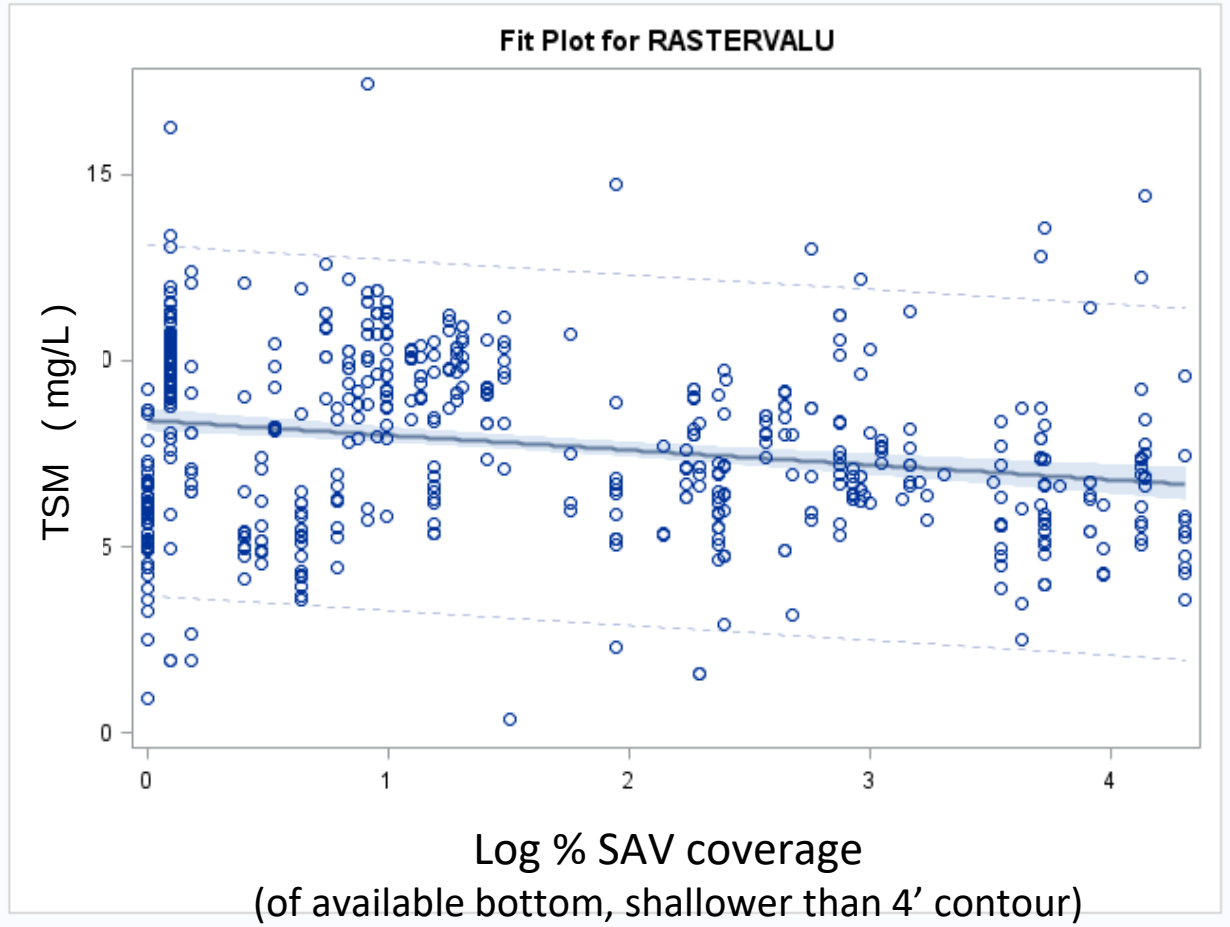
Pairwise comparison (Tukey): different letters have different mean values (alpha = 0.05)

Is there a relationship between TSM and Oyster Biomass?



- Simple regression: TSM = log_biomass
  - 13 Trib sites (blue)
    - Slope = -0.49, p <0.0001
    - n=601
    - r2 = 0.04 (4% of TSM variation is explained by oyster biomass)
  - Non-trib sites (red)
    - Slope = -0.17, p <0.0024
    - n=1468
    - r2 = 0.0006 (0.06% of TSM variation explained by oyster biomass)
- ANCOVA: the two slope parameters are significantly different (p=0.0052)

Is there a relationship between TSM and SAV coverage?



- 13 Trib sites (blue)
- Simple regression: TSM = log % SAV coverage
  - Slope = -0.39, p <0.0001
    - n=570
    - r2 = 0.05 (5% of TSM variation is explained by SAV coverage)

What Other Factors contribute to TSM variability?

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

General Linear Model (GLM) analysis: Evaluate TSM against Time, Location, Oyster Biomass, SAV

Sum of Squares statistics(SS)

<u>Type III SS:</u> 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)

What Other Factors contribute to TSM variability: Location

Q: Does TSM vary relative to location?
Model: Rastervalu = 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	11	1802.444453	163.858587	56.27	<.0001
Error	589	1715.253592	2.912145		
Corrected Total	600	3517.698045			

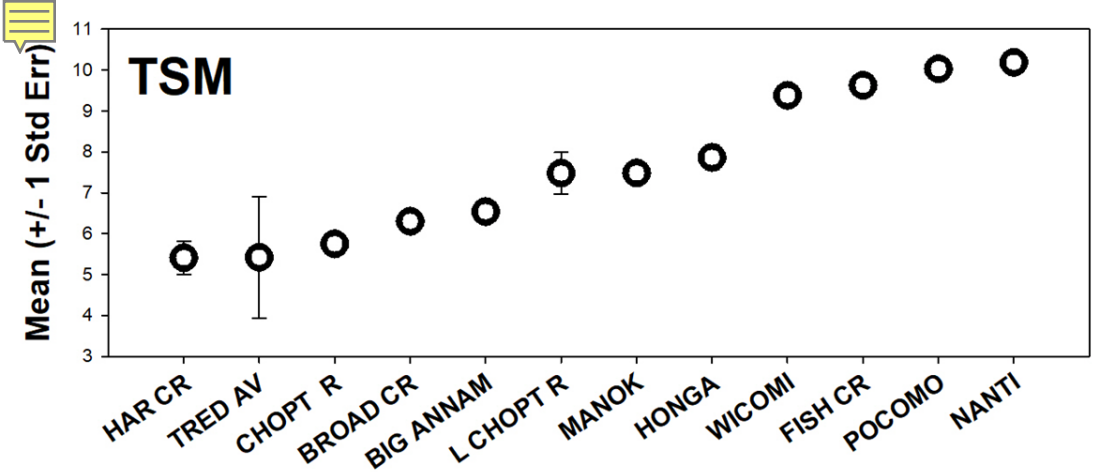
R-Square	Coeff Var	Root MSE	RASTERVALU Mean
0.512393	21.74199	1.706501	7.848871

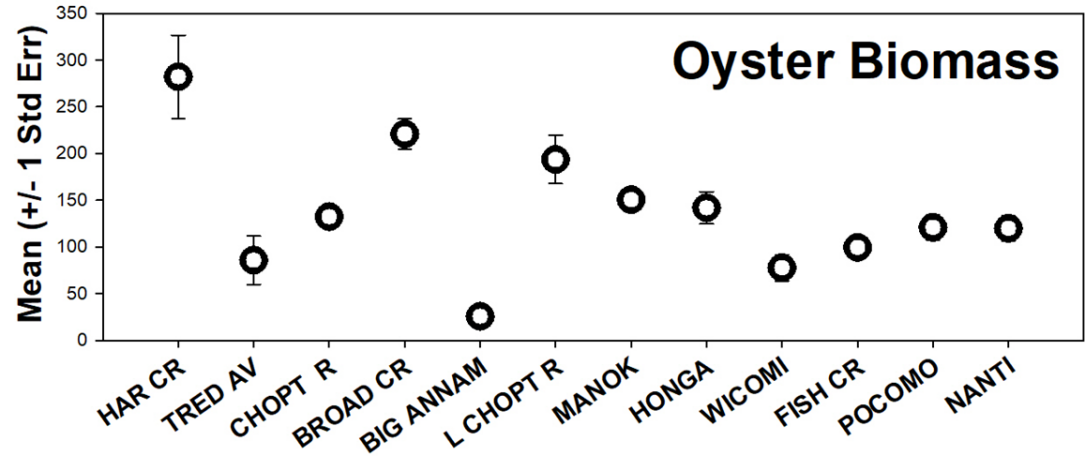
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Zones_13	11	1802.444453	163.858587	56.27	<.0001

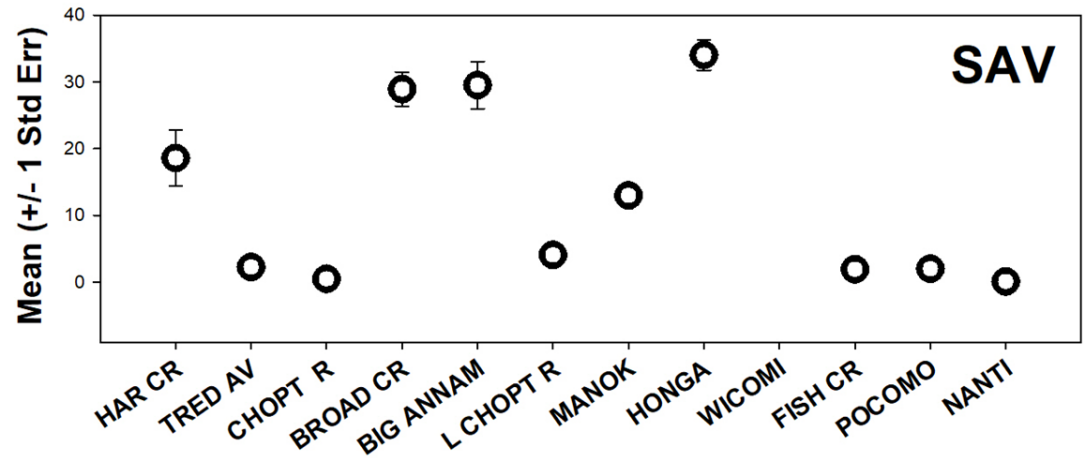
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Zones_13	11	1802.444453	163.858587	56.27	<.0001

Single Term GLM: Location Only

R2 – Location (Zones_13) explains **51%** of the variation in TSM



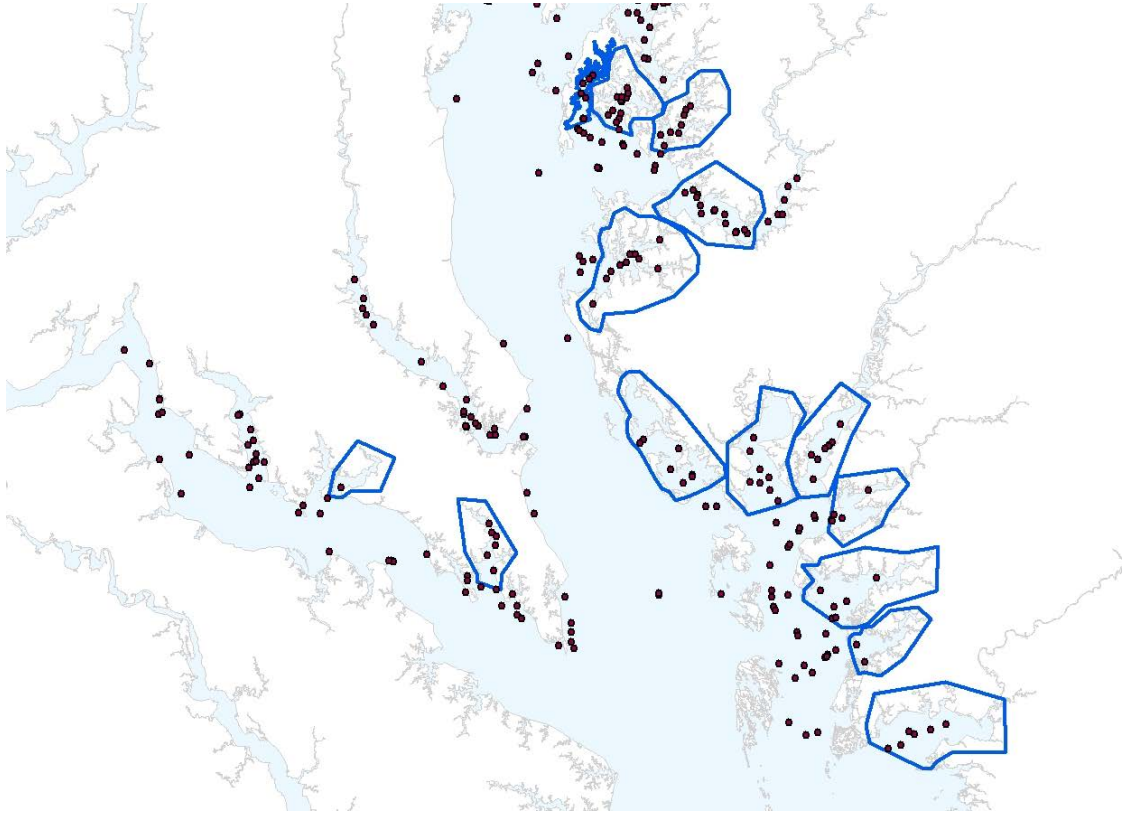




Data Summary by location "13 Tribs"

Lowest TSM values:

Harris Creek, Tred Avon River, Choptank River, Broad Creek, & Big Anamessex River



Summary

- Satellites are a good method of observing large-scale spatial and temporal patterns in water clarity
- Recent Oyster Biomass and SAV trends are improving over time (AFS & VIMS survey)
- Temporal TSM trend suggests a water quality improvement in Harris and Broad Creeks, and some parts of Tangier Sound, but no cause is implied
- TSM values are significantly higher on Public areas than Restored Sanctuary Management Areas. Inverse relationship for oyster biomass
- TSM decreases significantly with increased Oyster Biomass and increased SAV
- Oyster Biomass explains 4% of TSM variability; SAV explains 5% of TSM variability; unknown Location effects explain 51% of TSM variability

Next Steps?

- Examine additional location effects: land use, precipitation, basin morphology, wind vs. water depth, bay circulation patterns

- Explore using oyster abundance datasets other than AFS that are increasingly becoming available from Sanctuary and Restoration monitoring efforts
    - AFS may not do a great job of quantifying oyster biomass (length converted to biomass may introduce error)

- Revisit the TSM/oyster relationship in a few years when restored reefs are mature and restoration is complete

Backup Slides

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

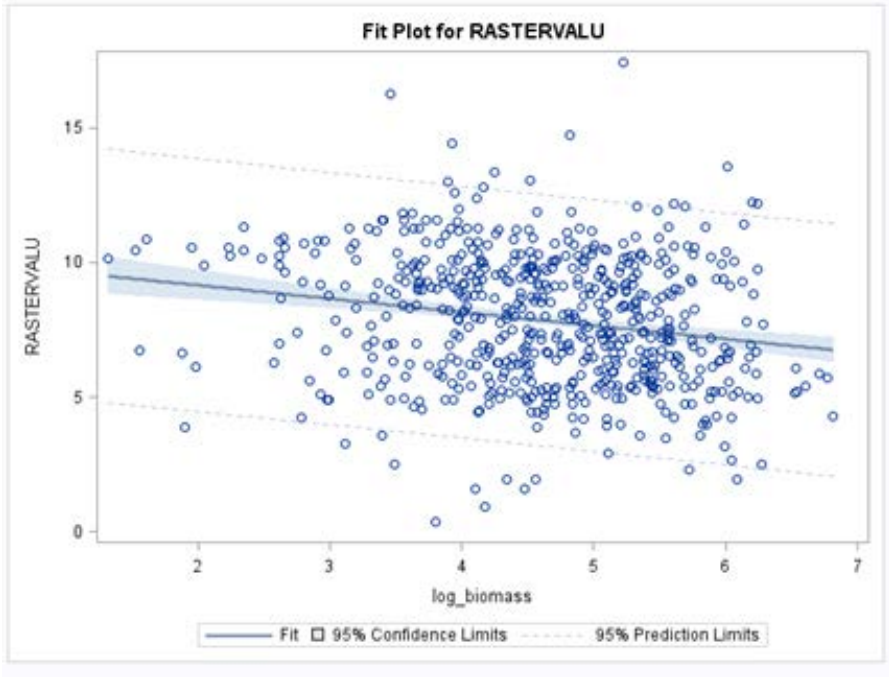
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	136.335268	136.335268	24.15	<.0001
Error	599	3381.362777	5.645013		
Corrected Total	600	3517.698045			

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

Question: 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

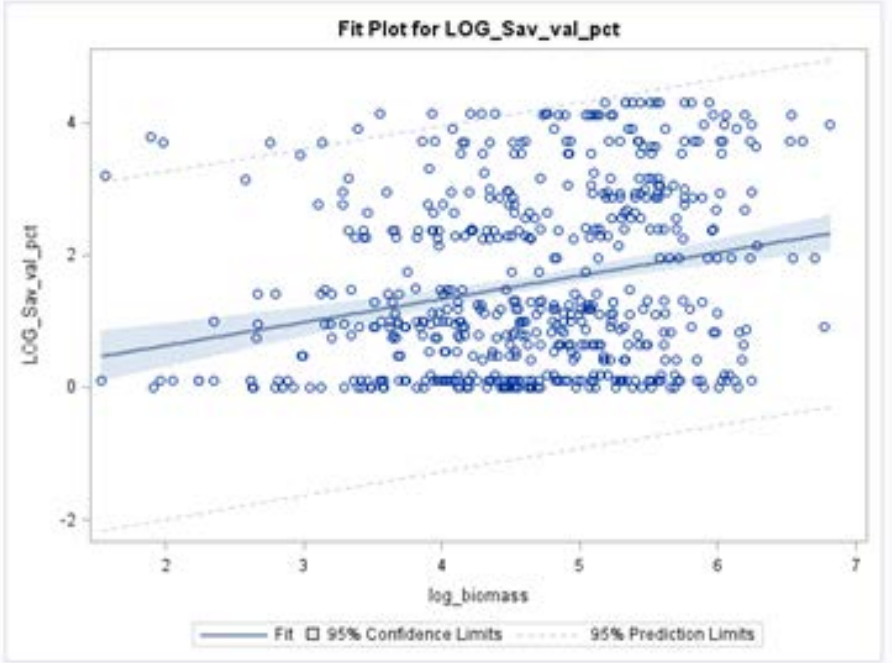
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	61.614405	61.614405	34.86	<.0001
Error	568	1004.059720	1.767711		
Corrected Total	569	1065.674125			

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

Question: If Management type is significant, and we're managing for oysters, does relationship between TSM and oyster biomass vary by managment type?

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

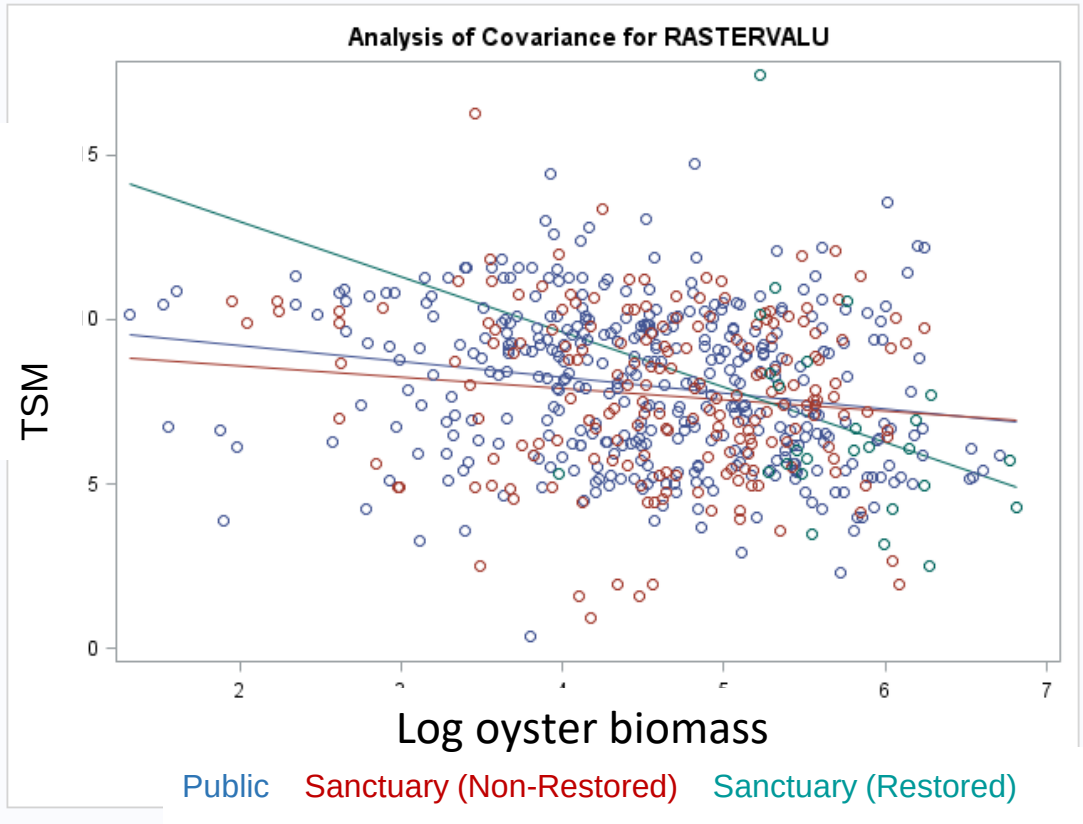
STERVALU

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

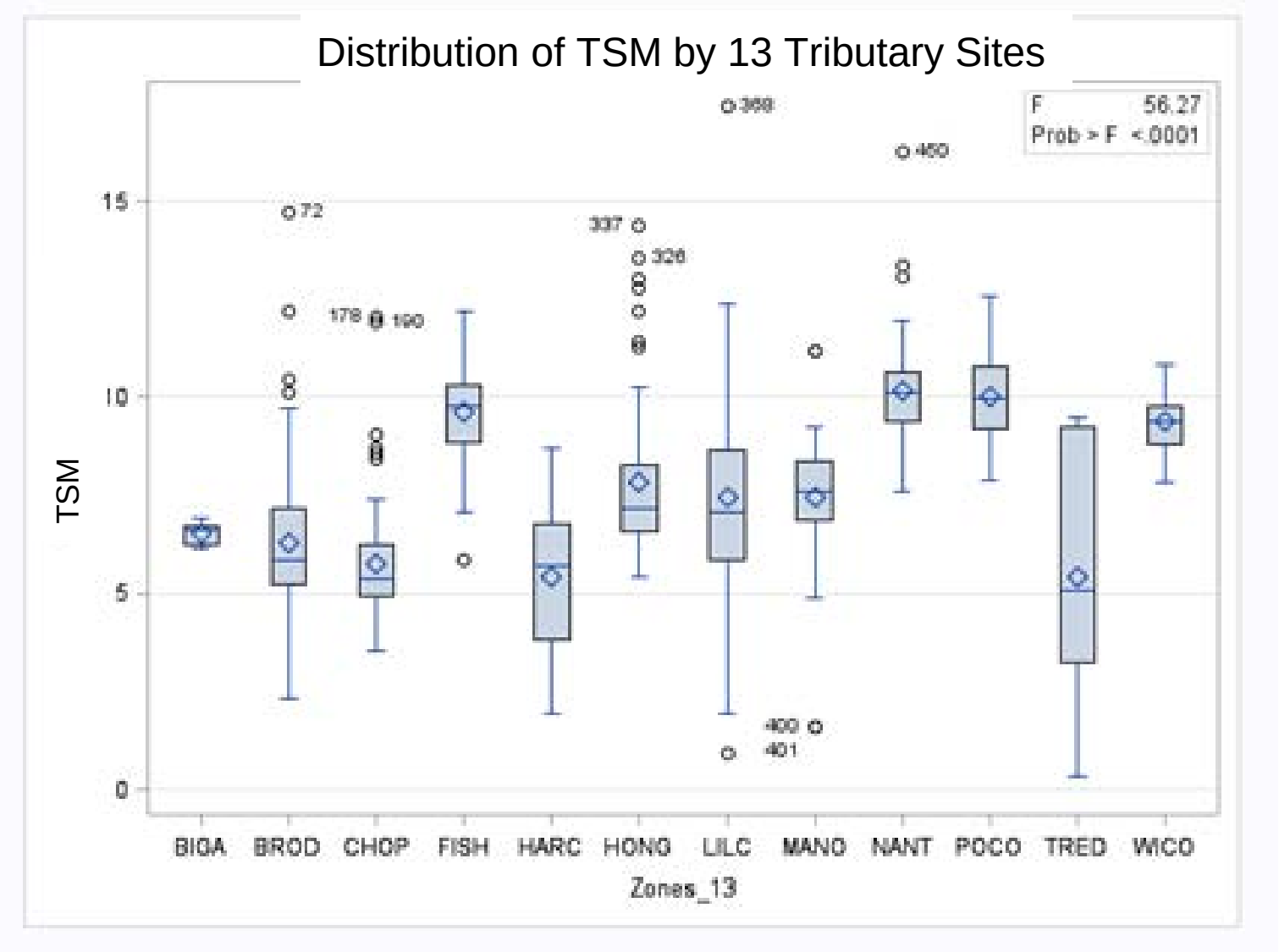
Source	DF	Type I SS	Mean Square	F Value	Pr > F
log_biomass	1	136.3352676	136.3352676	24.22	<.0001
Management	2	17.3004118	8.6502059	1.54	0.2160
log_bioma*Management	2	14.4971224	7.2485612	1.29	0.2767

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



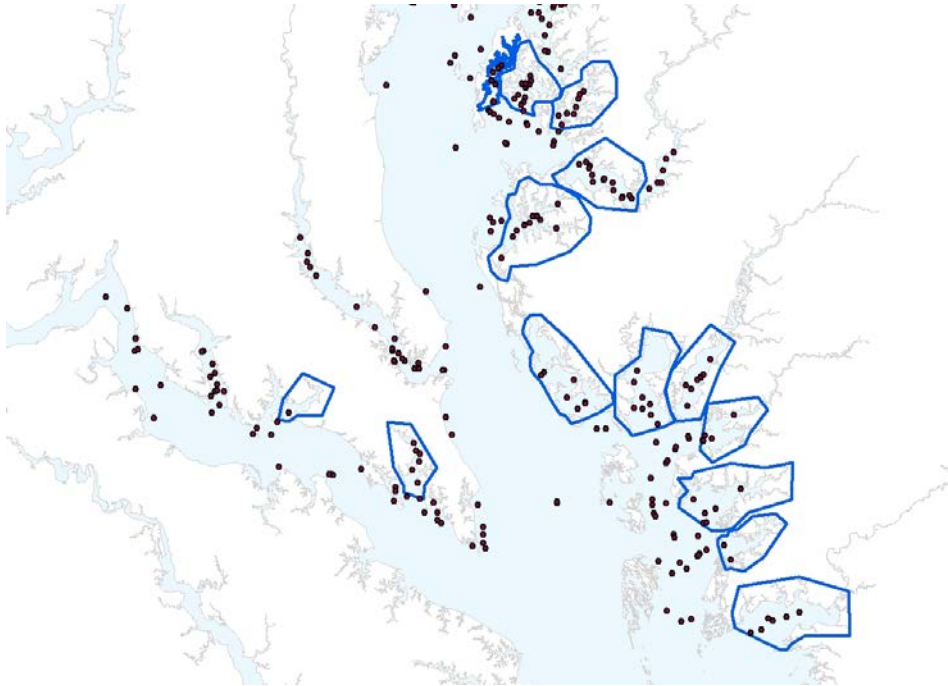
- ANCOVA Results: A significant relationship exists between TSM and biomass but it is not affected by management regimen.

Data Distribution by Area- “13 Tribs”

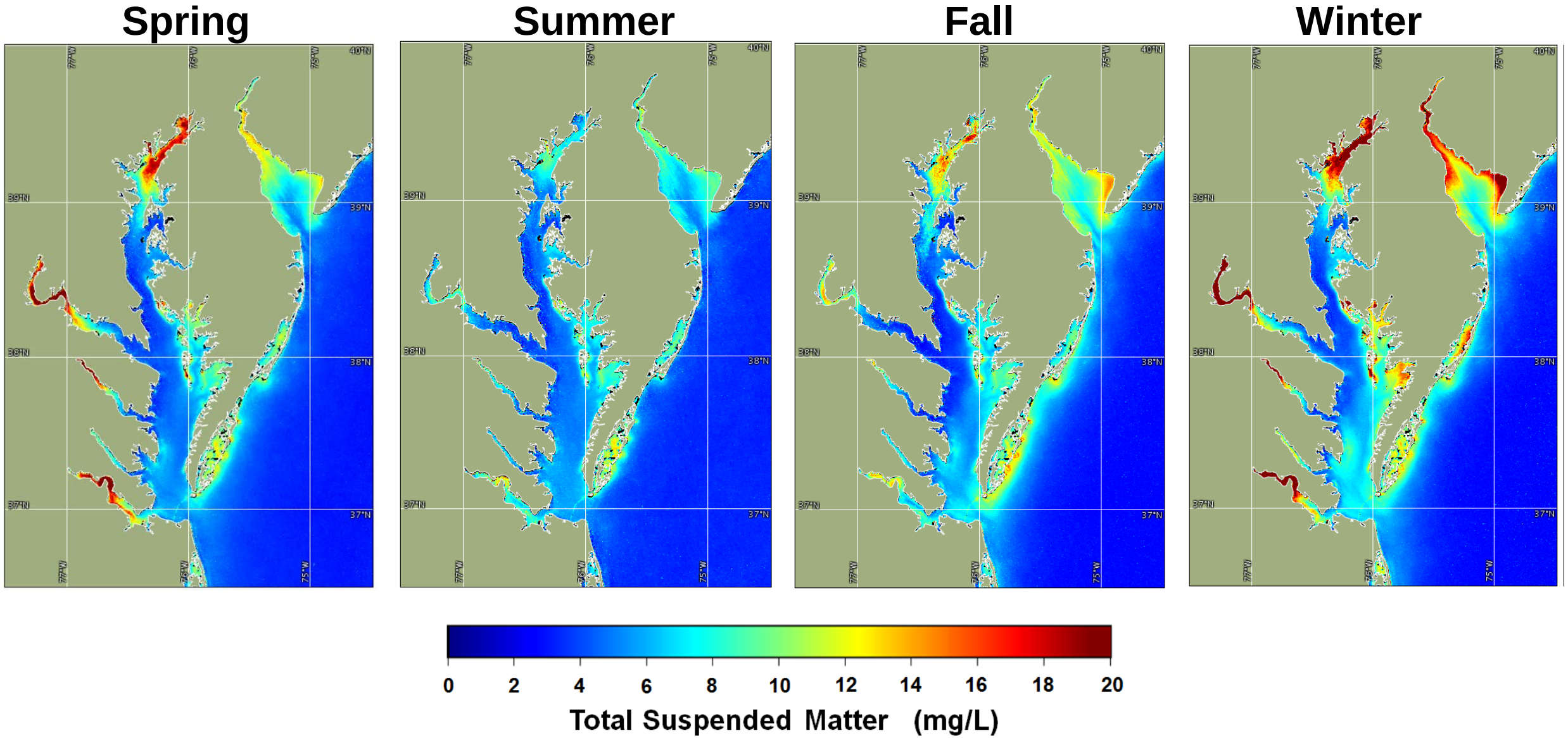


Lowest TSM values:

Big Anamesssex, Broad Creek, Choptank River, Harris Creek, and Tred Avon River



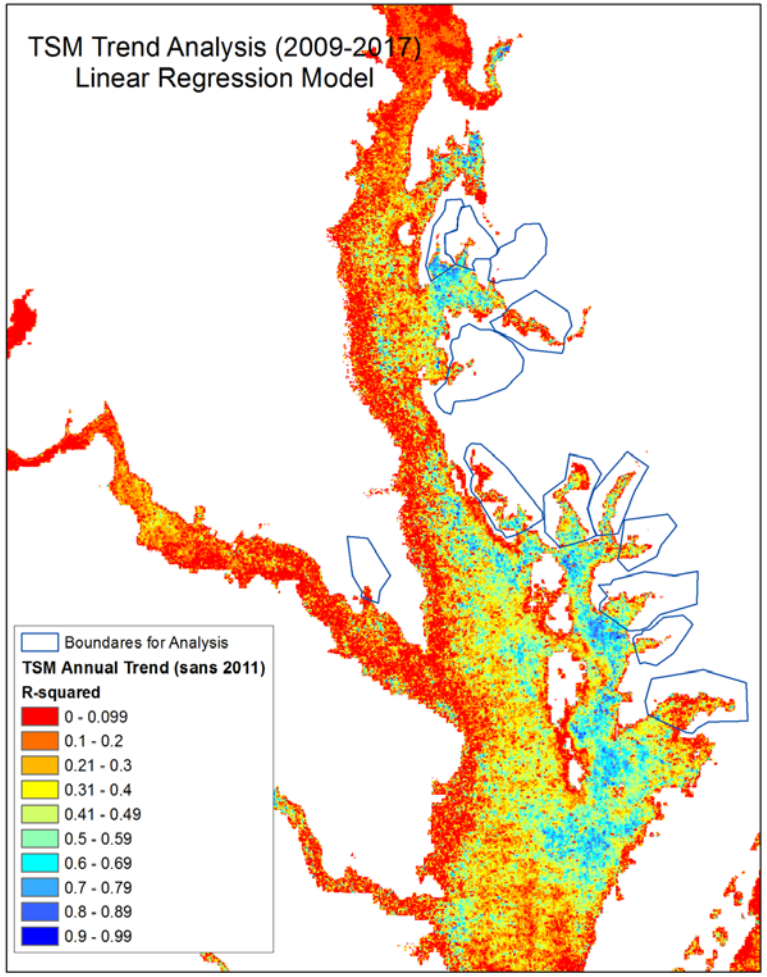
Satellite TSM Seasonal Averages, 2009-2015

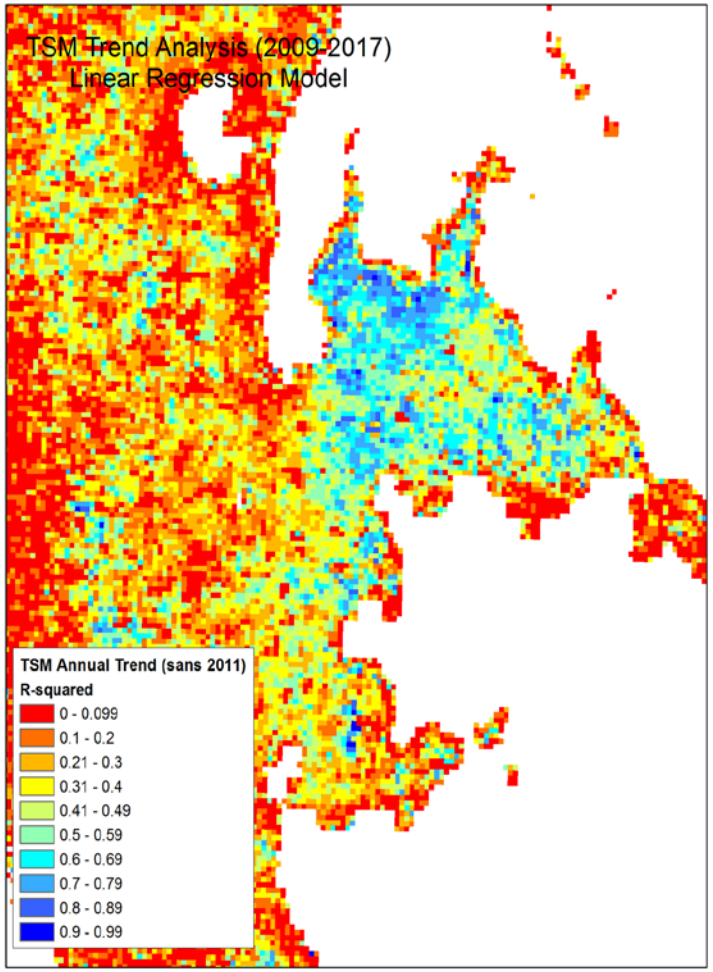


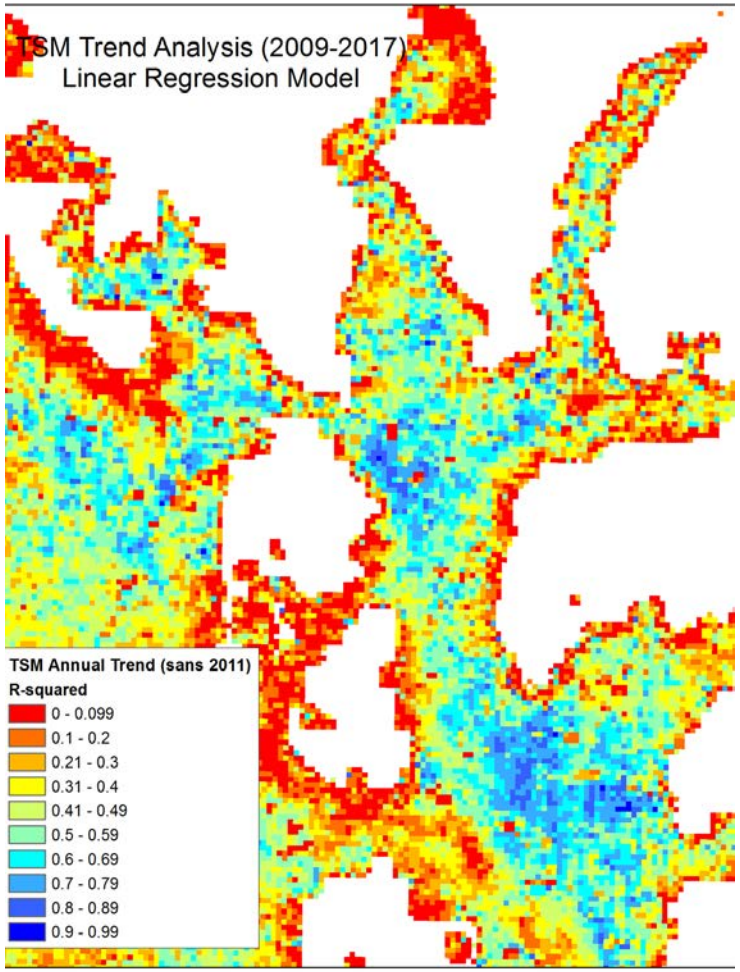
TSM Over Time:

TSM annual trend for each satellite grid cell, 2009-2017

R-Squared

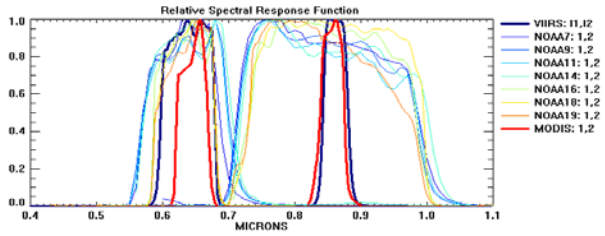


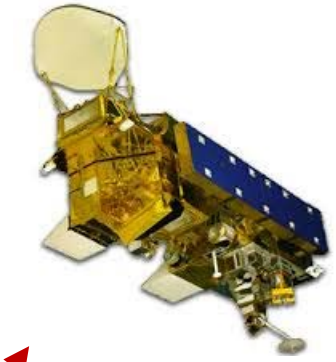




Decreasing TSM slope in Harris and Broad Creek with small slope SE and high R^2 suggests a water quality improvement but with no cause implied. Some areas of Tangier Sound also show this (but not Fishing Bay).

How a satellite instrument measures the earth surface





Emitted radiation

Solar reflected radiation

Atmo-spheric correction

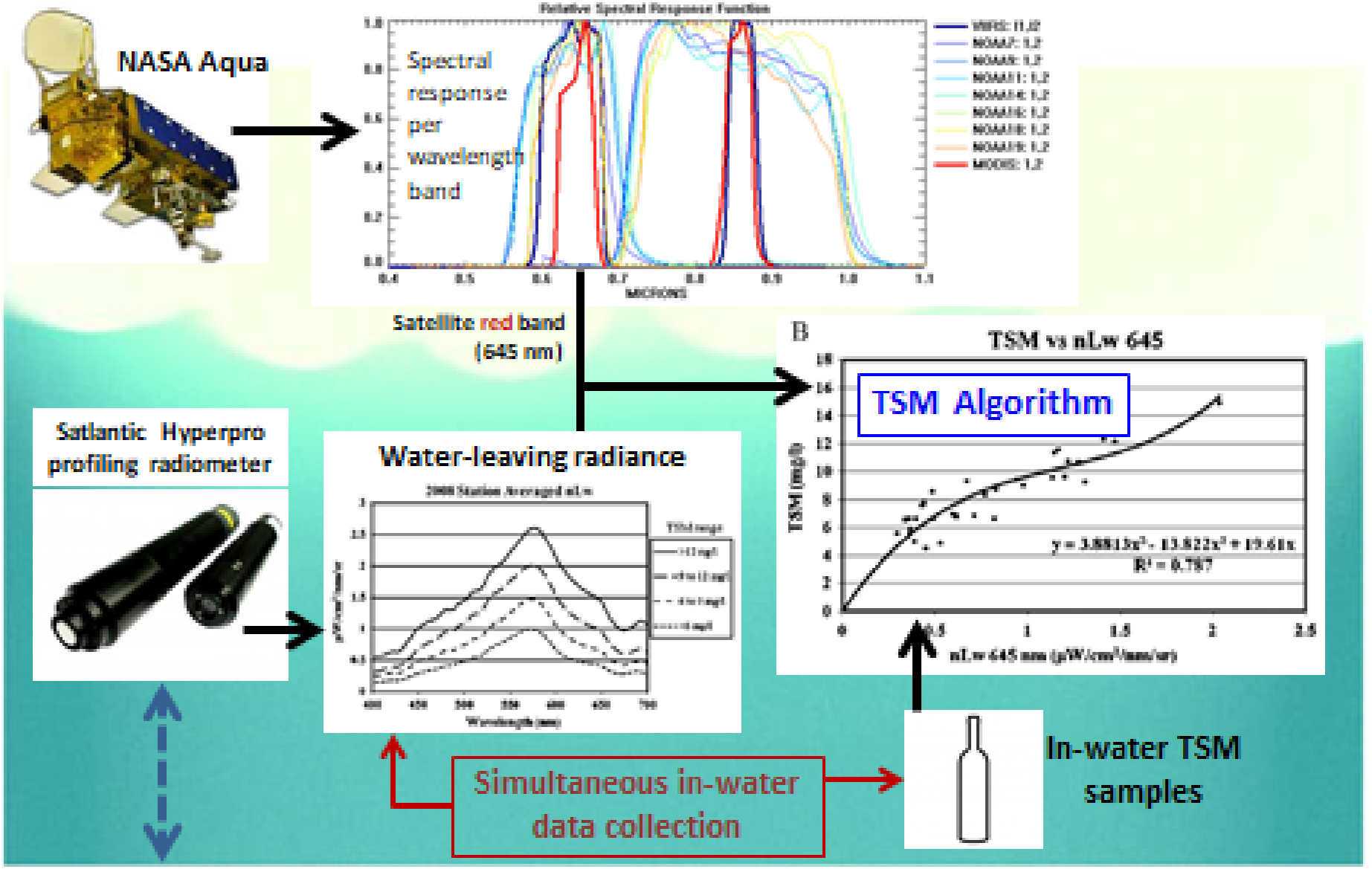
Heat energy

Particles in the Water

plankton
sediment
organic matter
debris

Algorithm Description

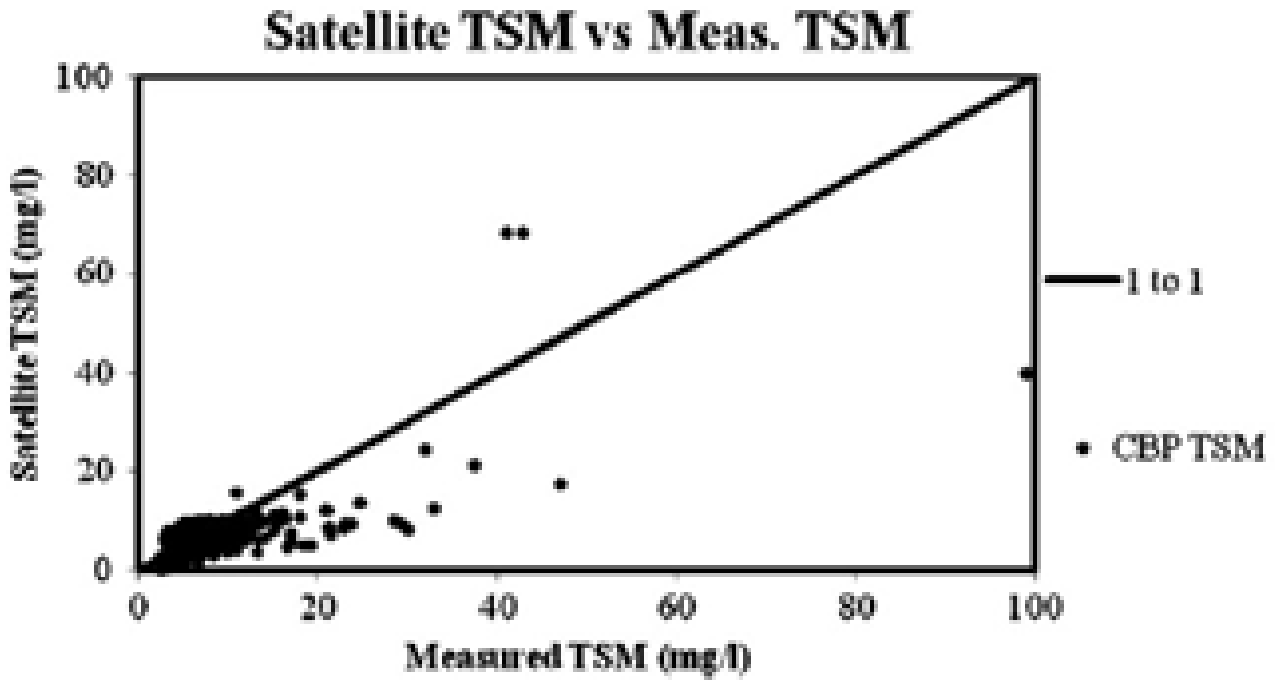
Ondrusek et al., 2012, Remote Sensing of Environment



Satellite TSM Accuracy

Chesapeake Bay Program in-water TSM samples were spatially & temporally matched to satellite TSM values at single pixels, Bay-wide for one year: 2009

(Ondrusek et al., 2012, Remote Sensing of Environment)



Bias (mg/L):	-1.82443
RMSE (mg/L):	6.93795
Mean Rel Diff:	-4.2%
Mean Rel Abs Diff:	36%
N:	241

TSM values <20 mg/L are more accurate than values >20 mg/L