Water Quality Analysis in the Chesapeake Bay: from small local waters to the main stem

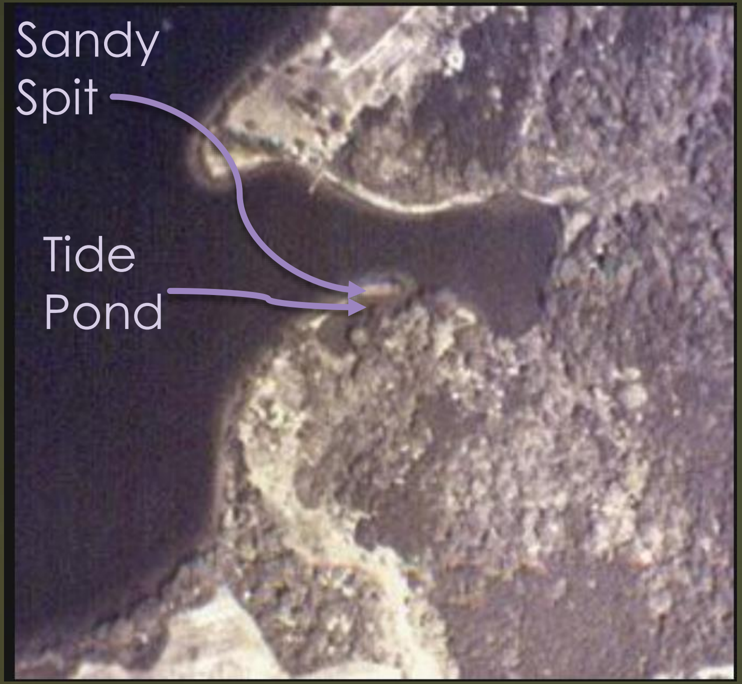
MACKENZIE BODMAN- WATER QUALITY INTERN

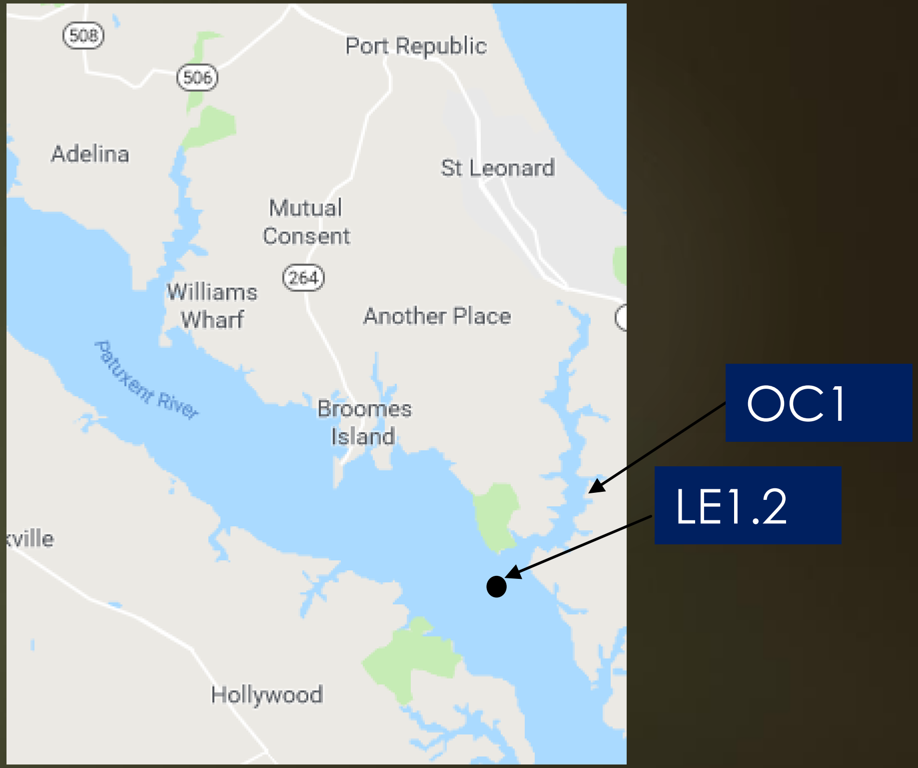
Goals

- Part I: Analyze over 40 years of water quality monitoring data for Osborn Cove
  - Analyze trends over time
  - Analyze seasonal trends
  - Perform statistical analyses
- Part II: Conduct a spatio-temporal analysis on dissolved oxygen over 30 years in the main stem
  - Plot interpolated water quality data in three dimensions and over time
  - Visualize the spatial and temporal change of water quality
  - Calculate magnitude of violation of water quality criteria

Part I: Osborn Cove

- Located on the Saint Leonard Creek, found within the Patuxent River
- Positioned between Grapevine Cove and Rollins Cove
- Geography consists of a sandy spit and tide pond
- A small estuarine embayment
- Open water designated use





Why is Osborn Cove Important?

Recreational area for boating, swimming, and fishing

Habitat for otters, snails and other organisms

Important to study small, local tidal waters

The Study Site: Sea Level Rise

Vegetation Cover

Bar/Spit Change

Sea Level Rise

The Process of Analyzing Osborn Cove

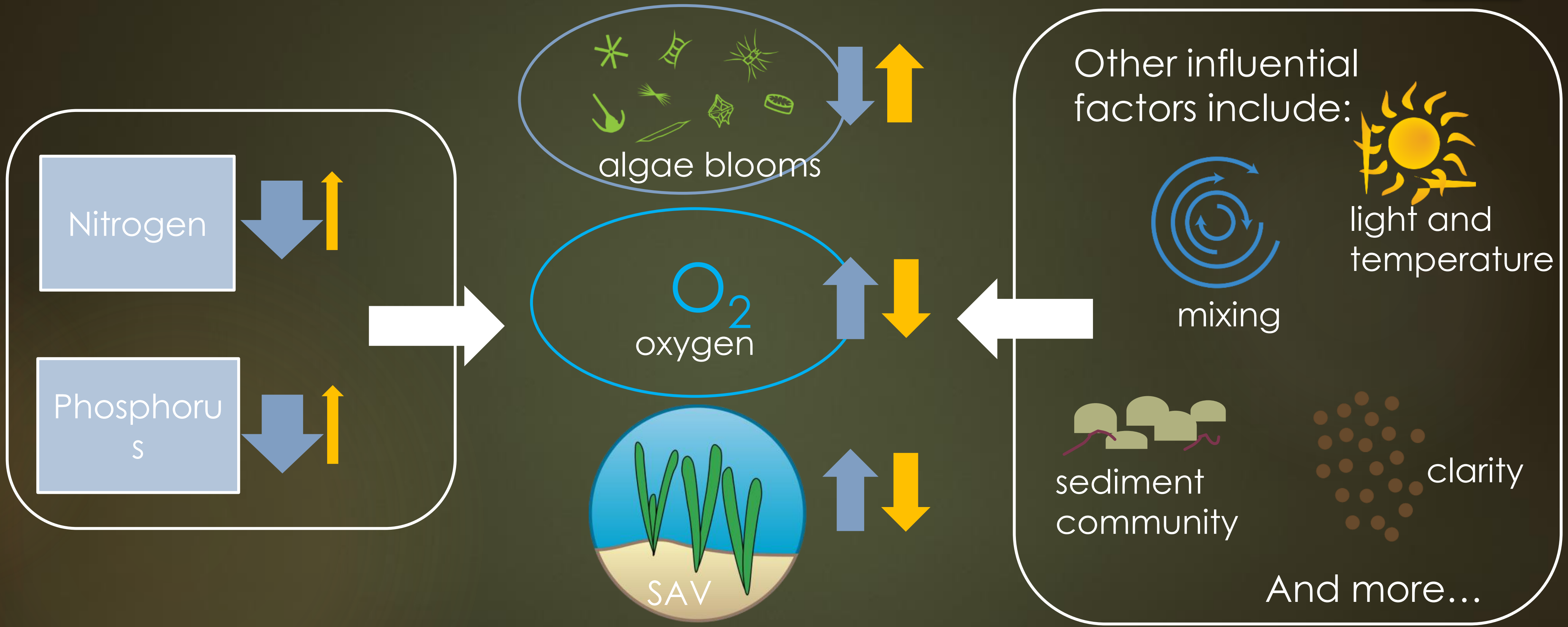
1. 40 Year Long Dataset
2. Analysis of Water Quality Variables
3. Observations of Rapid Change
4. What is causing the change?
5. What do these changes mean?

Analysis Methods

- Organize and compile data into excel sheets
- Quality-check the data
- Graph variety of parameters at Osborn Cove
- Graph variables by season, by month and over forty years
  - took average for every year for seasonal graphs
  - took average for each month for each time period
  - using all data points for forty years graphs
- Generalized Additive Model Analysis (GAMs)
- Spearman's Correlation Analysis

How are other tidal water quality indicators responding?

Slide modified from Jeni Keisman, USGS CBPO

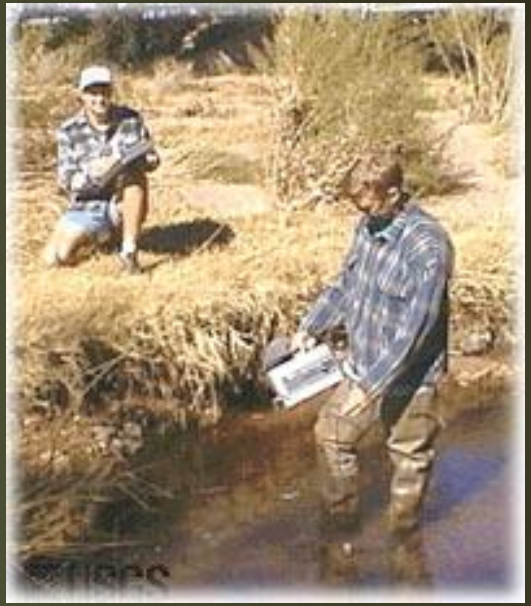


Estuaries are complex environments.
The response to restoration depends on location, season, and physical and biological factors.

Images from: Tracey Saxby, Jane Thomas and Jane Hawkey, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/)

Why Does Dissolved Oxygen Matter?

- Many species require at least 5 mg/L of dissolved oxygen
- Used to assess water quality
- As DO decreases, many species cannot survive long in these hypoxic or anoxic conditions



https://water.usgs.gov/edu/dissolvedoxygen.html

Surface Dissolved Oxygen

Rebecca Murphy

Osborn Cove

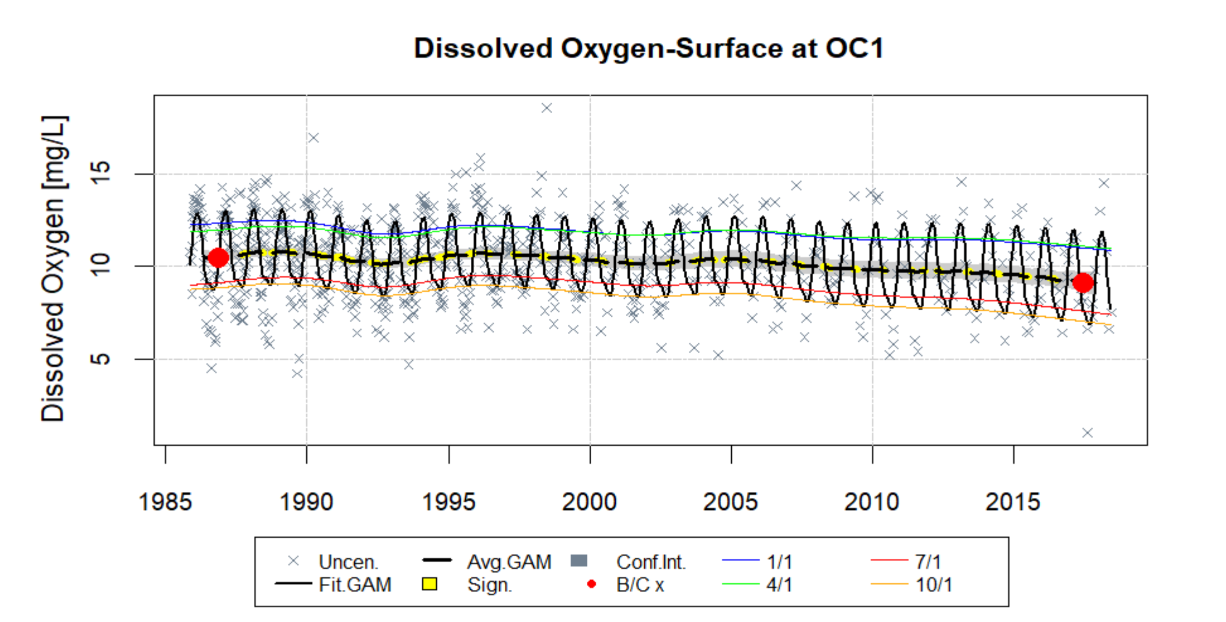


Table: Estimates of Change from 1985-2018.

Calculation	Estimate
Baseline mean	10.4919
Current mean	9.0896
Estimated difference	-1.4023
Std. Err. difference	0.4347
95% Confidence interval for difference	(-2.2543 , -0.5504)
Difference p-value	0.0013
Period of Record Percent Change Estimate (%)	-13.37%

Patuxent River

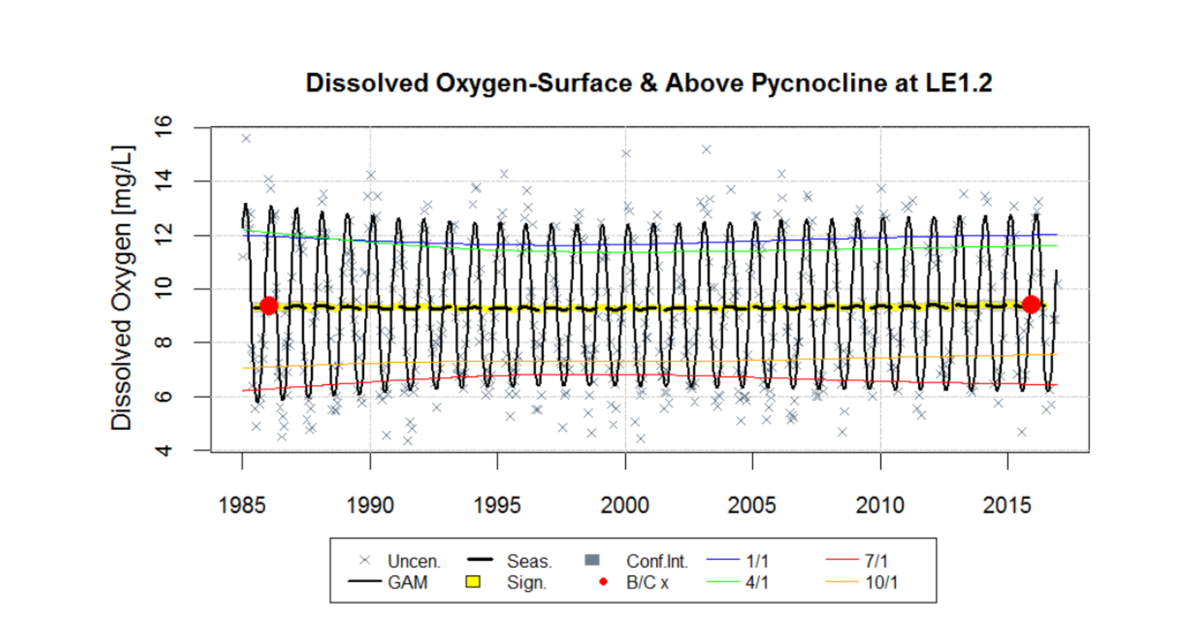


Table: Estimates of Change from 1985-2016.

Calculation	Estimate
Baseline mean	9.3722
Current mean	9.4063
Estimated difference	0.0342
Std. Err. difference	0.1672
95% Confidence interval for difference	(-0.2936 , 0.362)
Difference p-value	0.8381
Period of Record Percent Change Estimate (%)	0.36%

Bottom Dissolved Oxygen

Rebecca Murphy

Osborn Cove

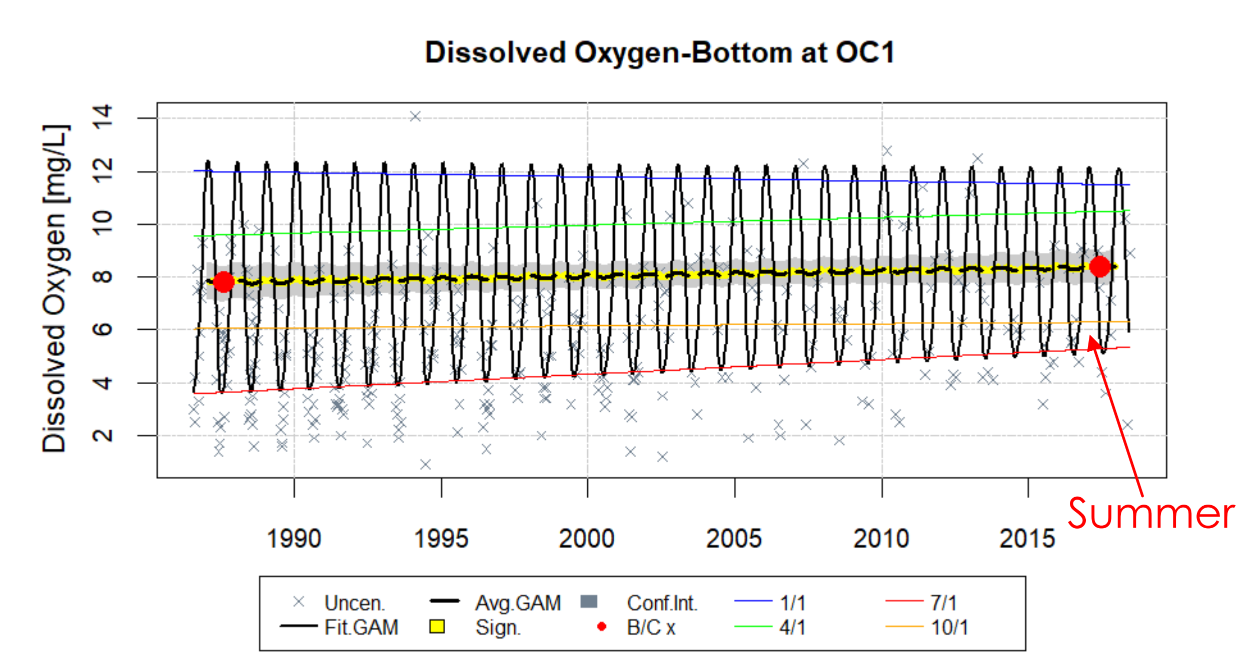


Table: Estimates of Change from 1986-2018.

Calculation	Estimate
Baseline mean	7.798
Current mean	8.3942
Estimated difference	0.5961
Std. Err. difference	0.4798
95% Confidence interval for difference	(-0.3442 , 1.5364)
Difference p-value	0.2149
Period of Record Percent Change Estimate (%)	7.64%

Patuxent River

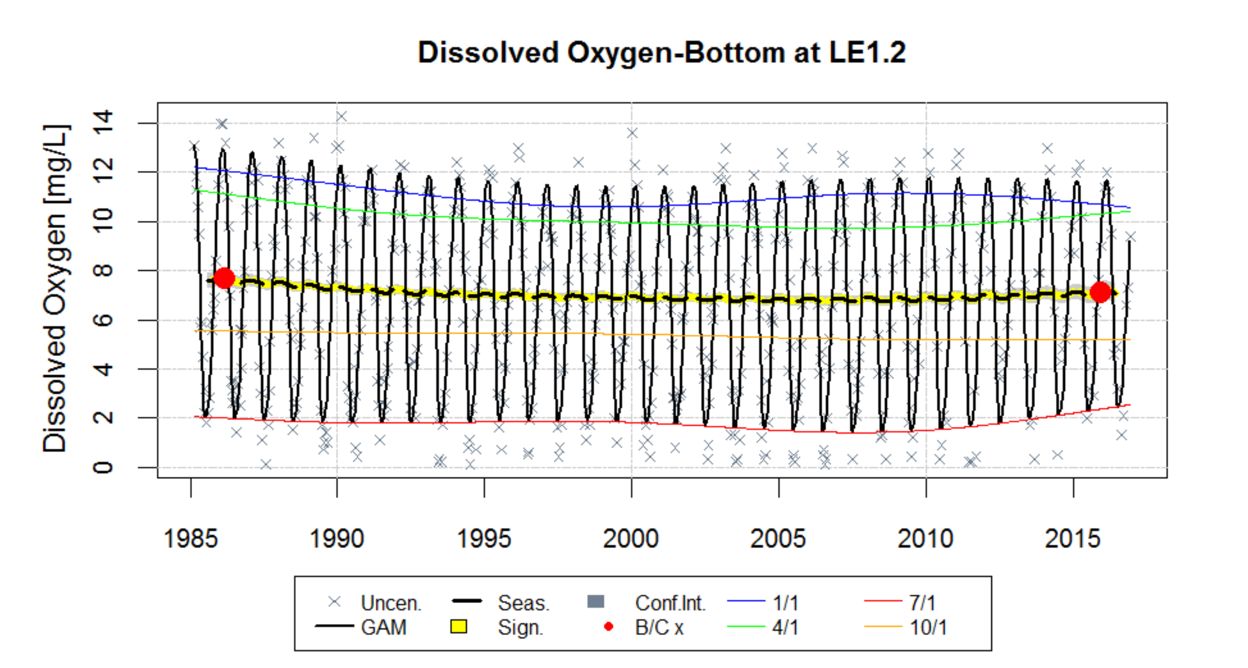


Table: Estimates of Change from 1985-2016.

Calculation	Estimate
Baseline mean	7.6782
Current mean	7.1033
Estimated difference	-0.5749
Std. Err. difference	0.2452
95% Confidence interval for difference	(-1.0555 , -0.0943)
Difference p-value	0.0194
Period of Record Percent Change Estimate (%)	-7.49%

Why Does Water Temperature Matter?

- Affects Dissolved Oxygen Content
  - Chlorophyll a
  - Species diversity
  - Water Quality
- Fewer species can live in warmer waters
- As water temperature rises, DO demand increases (water can't hold as much oxygen the warmer it gets)

Eutrophic conditions, Hartbees River, South Africa
Credit: National Eutrophication Monitoring Programme

https://water.usgs.gov/edu/dissolvedoxygen.html

Water Temperature

Osborn Cove

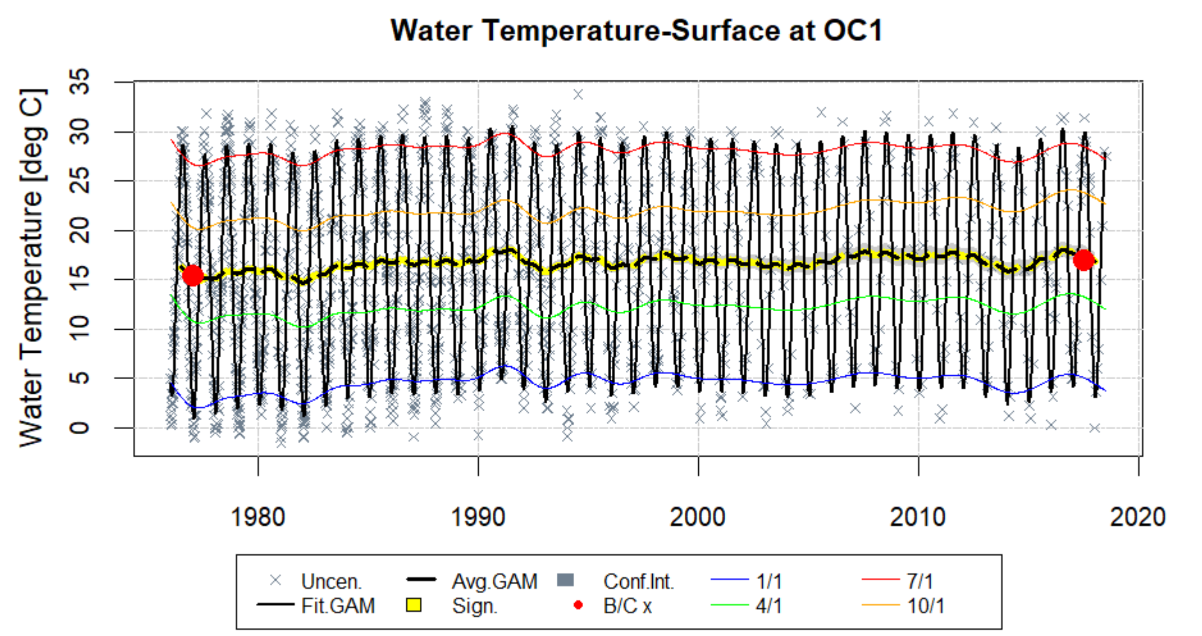


Table: Estimates of Change from 1976-2018.

Calculation	Estimate
Baseline mean	15.4679
Current mean	16.9776
Estimated difference	1.5097
Std. Err. difference	0.5166
95% Confidence interval for difference	(0.4973 , 2.5222)
Difference p-value	0.0035
Period of Record Percent Change Estimate (%)	9.76%

Patuxent River

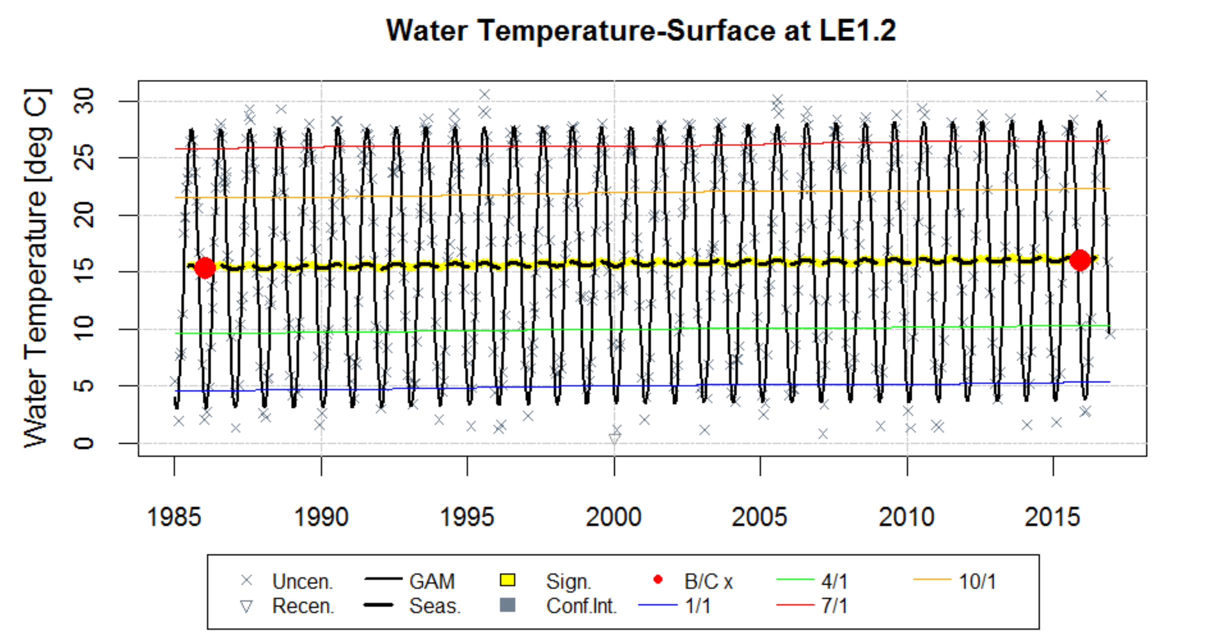


Table: Estimates of Change from 1985-2016.

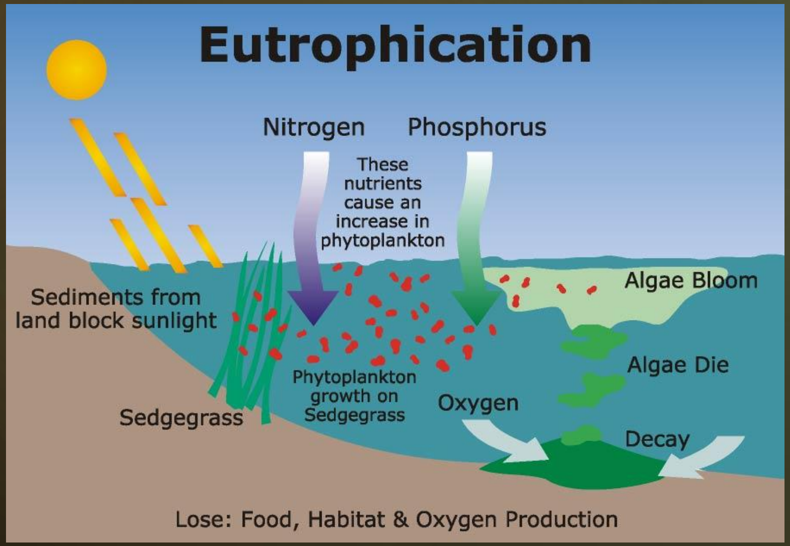
Calculation	Estimate
Baseline mean	15.3207
Current mean	16.0485
Estimated difference	0.7278
Std. Err. difference	0.2191
95% Confidence interval for difference	(0.2984 , 1.1572)
Difference p-value	0.0009
Period of Record Percent Change Estimate (%)	4.75%

Possible Explanations for Change at Osborn Cove

Increase in air temperature → increase in water temperature → decrease in surface DO

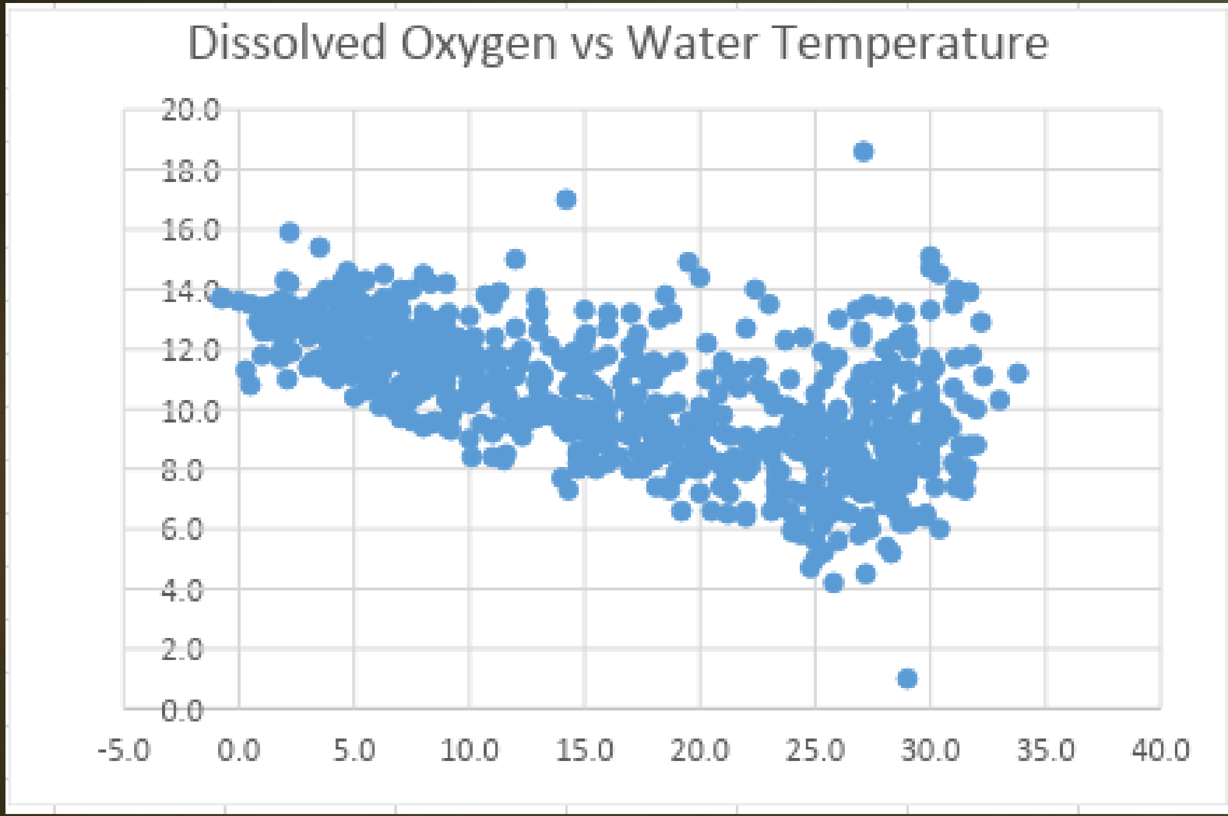
Possible decrease in nutrients → increase in bottom DO

Decrease in secchi depth → decrease in plant life and water clarity



https://lincoln.ne.gov/city/pworks/watershed/home-lawn/fertilizer.htm

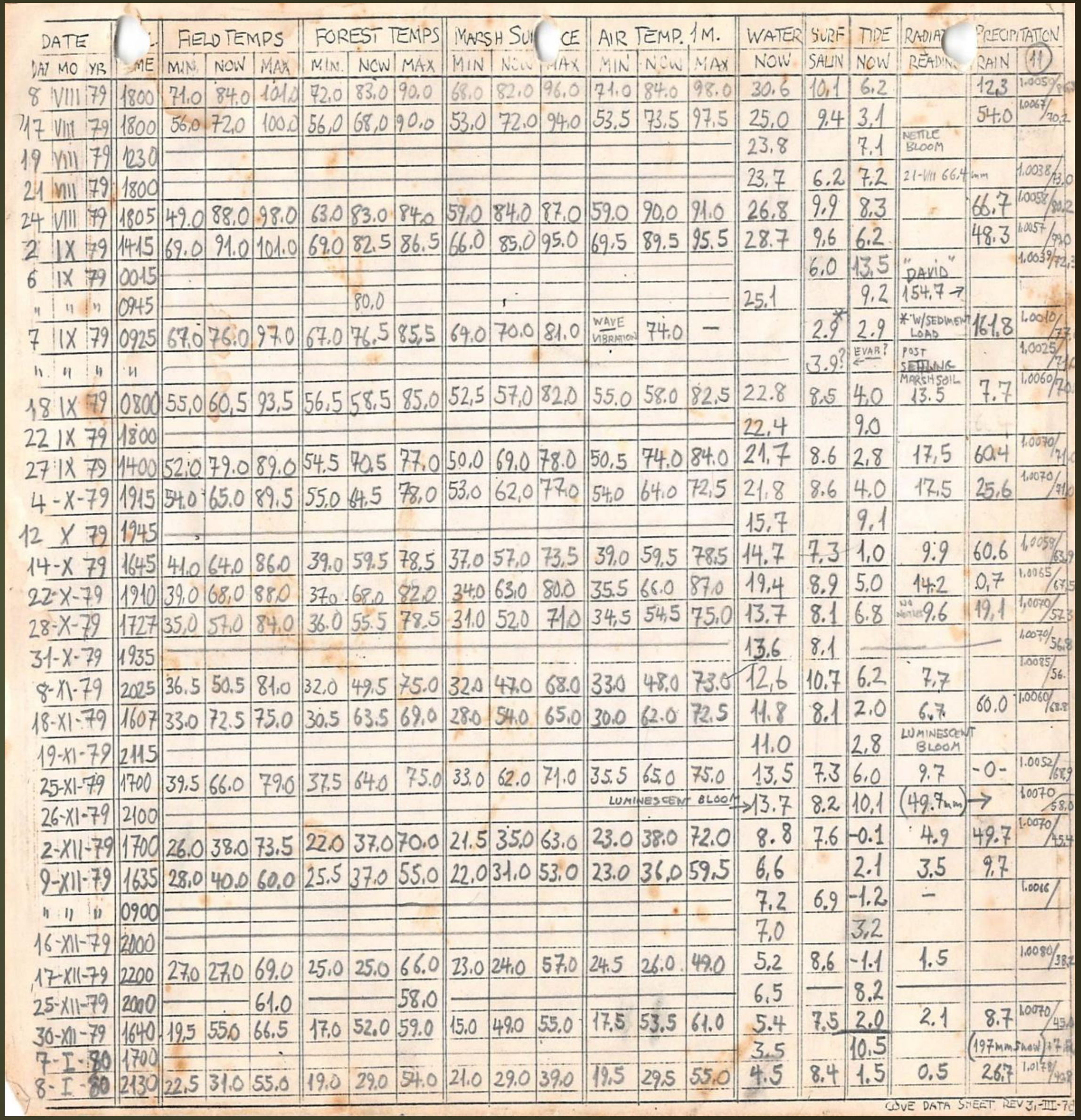
Spearman's Correlation



Rs value = -0.6306

Conclusion

- Everything is connected – but we can tease things apart
- Rapid change at Osborn Cove
- Water quality is rapidly declining at Osborn Cove
- Citizen science monitoring is crucial



DATE (DAY MO YR)	…ME	FIELD TEMPS MIN	NOW	MAX	FOREST TEMPS MIN	NOW	MAX	MARSH SU…CE MIN	NOW	MAX	AIR TEMP. 1M. MIN	NOW	MAX	WATER NOW	SURF SALIN	TIDE NOW	RADIAT… READIN…	PRECIPITATION RAIN	(11)
8 VIII 79	1800	71.0	84.0	101.0	72.0	83.0	90.0	68.0	82.0	96.0	71.0	84.0	98.0	30.6	10.1	6.2		12.3	1.0059/[illegible]
17 VIII 79	1800	56.0	72.0	100.0	56.0	68.0	90.0	53.0	72.0	94.0	53.5	73.5	97.5	25.0	9.4	3.1		54.0	1.0067/70.2
19 VIII 79	1230													23.8		7.1	NETTLE BLOOM		
21 VIII 79	1800													23.7	6.2	7.2	21-VIII 66.4 mm		1.0038/73.0
24 VIII 79	1805	49.0	88.0	98.0	63.0	83.0	84.0	59.0	84.0	87.0	59.0	90.0	91.0	26.8	9.9	8.3		66.7	1.0058/80.2
2 IX 79	1415	69.0	91.0	101.0	69.0	82.5	86.5	66.0	85.0	95.0	69.5	89.5	95.5	28.7	9.6	6.2		48.3	1.0057/79.0
6 IX 79	0015														6.0	13.5	"DAVID"		1.0039/72.3
" " "	0945					80.0								25.1		9.2	154.7 →		
7 IX 79	0925	67.0	76.0	97.0	67.0	76.5	85.5	64.0	70.0	81.0	WAVE VIBRATION	74.0	—		2.9*	2.9	*W/SEDIMENT LOAD	161.8	1.0010/77
" " "	"														3.9?	EVAP? ←	POST SETTLING		1.0025/71
18 IX 79	0800	55.0	60.5	93.5	56.5	58.5	85.0	52.5	57.0	82.0	55.0	58.0	82.5	22.8	8.5	4.0	MARSH SOIL 13.5	7.7	1.0060/70
22 IX 79	1800													22.4		9.0			
27 IX 79	1400	52.0	79.0	89.0	54.5	70.5	77.0	50.0	69.0	78.0	50.5	74.0	84.0	21.7	8.6	2.8	17.5	60.4	1.0070/71
4-X-79	1915	54.0	65.0	89.5	55.0	64.5	78.0	53.0	62.0	77.0	54.0	64.0	72.5	21.8	8.6	4.0	17.5	25.6	1.0070/71
12 X 79	1945													15.7		9.1			
14-X 79	1645	41.0	64.0	86.0	39.0	59.5	78.5	37.0	57.0	73.5	39.0	59.5	78.5	14.7	7.3	1.0	9.9	60.6	1.0058/63.9
22-X-79	1910	39.0	68.0	88.0	37.0	68.0	82.0	34.0	63.0	80.0	35.5	66.0	87.0	19.4	8.9	5.0	14.2	0.7	1.0065/67.5
28-X-79	1727	35.0	57.0	84.0	36.0	55.5	78.5	31.0	52.0	71.0	34.5	54.5	75.0	13.7	8.1	6.8	NO NETTLES 9.6	19.1	1.0070/57.3
31-X-79	1935													13.6	8.1				1.0070/56.8
8-XI-79	2025	36.5	50.5	81.0	32.0	49.5	75.0	32.0	47.0	68.0	33.0	48.0	73.0	12.6	10.7	6.2	7.7		1.0085/56.
18-XI-79	1607	33.0	72.5	75.0	30.5	63.5	69.0	28.0	54.0	65.0	30.0	62.0	72.5	11.8	8.1	2.0	6.7	60.0	1.0060/68.8
19-XI-79	2115													11.0		2.8	LUMINESCENT BLOOM		
25-XI-79	1700	39.5	66.0	79.0	37.5	64.0	75.0	33.0	62.0	71.0	35.5	65.0	75.0	13.5	7.3	6.0	9.7	-0-	1.0052/68.9
26-XI-79	2100										LUMINESCENT BLOOM →			13.7	8.2	10.1	(49.7mm) →		1.0070/58.0
2-XII-79	1700	26.0	38.0	73.5	22.0	37.0	70.0	21.5	35.0	63.0	23.0	38.0	72.0	8.8	7.6	-0.1	4.9	49.7	1.0070/45.4
9-XII-79	1635	28.0	40.0	60.0	25.5	37.0	55.0	22.0	31.0	53.0	23.0	36.0	59.5	6.6		2.1	3.5	9.7	
" " "	0900													7.2	6.9	-1.2	—		1.0016/
16-XII-79	2000													7.0		3.2			
17-XII-79	2200	27.0	27.0	69.0	25.0	25.0	66.0	23.0	24.0	57.0	24.5	26.0	49.0	5.2	8.6	-1.1	1.5		1.0080/38.2
25-XII-79	2000			61.0			58.0							6.5	—	8.2			
30-XII-79	1640	19.5	55.0	66.5	17.0	52.0	59.0	15.0	49.0	55.0	17.5	53.5	61.0	5.4	7.5	2.0	2.1	8.7	1.0070/45.
7-I-80	1700													3.5		10.5		(197mm Snow)	+7.[illegible]
8-I-80	2130	22.5	31.0	55.0	19.0	29.0	54.0	21.0	29.0	39.0	19.5	29.5	55.0	4.5	8.4	1.5	0.5	26.7	1.0178/40.8

COVE DATA SHEET REV 3-III-7[illegible]

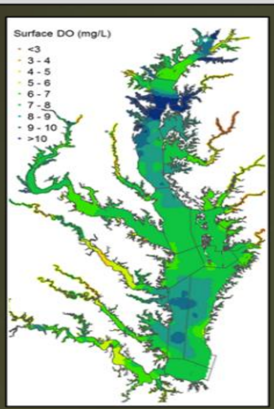
Part II: 3D Mapping Dissolved Oxygen

- Interpolator Data → Format to be used in Arc GIS Pro
- 3D Plots of dissolved oxygen spatially and temporally
  - How is dissolved oxygen changing over time?
  - Where is it changing or not changing?
  - Magnitude of violation?

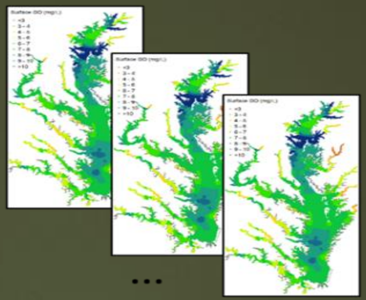
Assessing Water Quality Standards Attainment

1. Collect bi-weekly to monthly data at each monitoring station

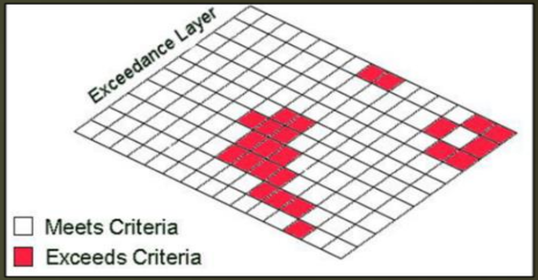
2. Convert the station DO data to Baywide values using the CBP interpolator



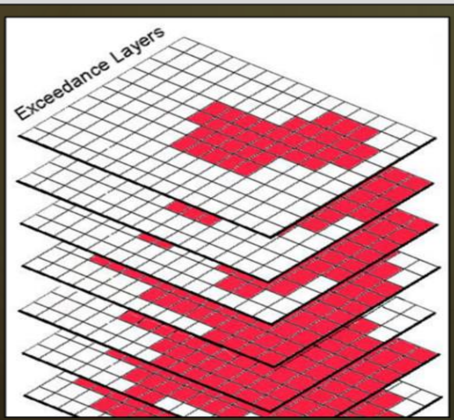
3. Combine interpolations for a season over the 3-year period



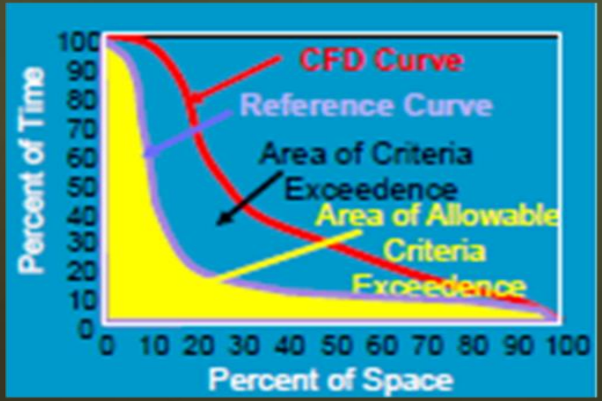
4. Compare the interpolated values with appropriate criterion values to compute the spatial extent of exceedance



5. Repeat Step 4 for each sampling event in the 3-year period to determine the cells' extent of exceedance



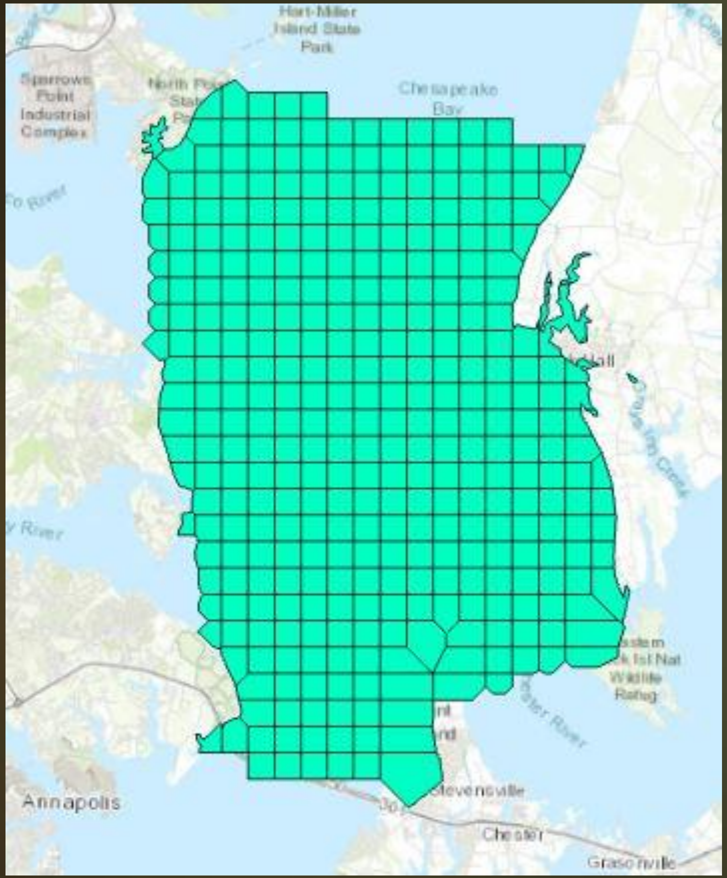
6. Calculate the cumulative probability distribution (CFD) for extent of exceedance for all cells within each segment

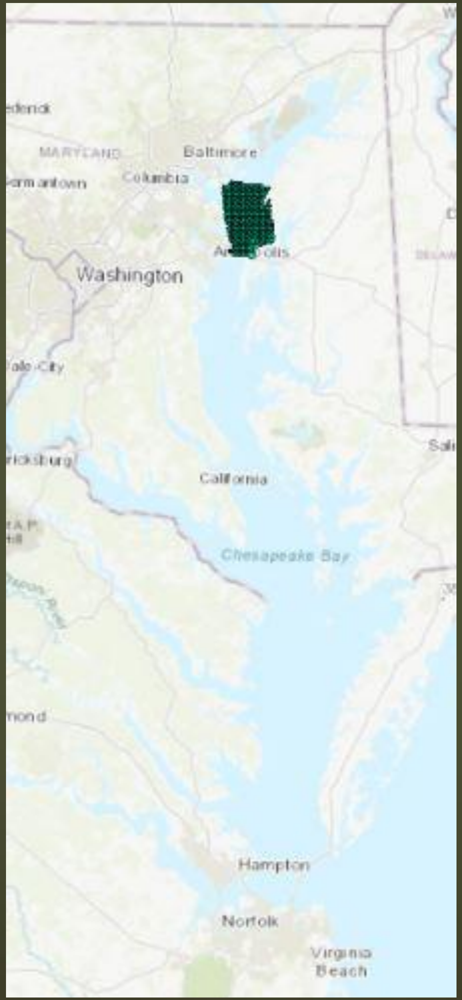


7. Extract the "area of criteria exceedance" from the CFD curve to quantify the "attainment deficit" for the 3-year period

Qian Zhang

Interpreting the Data at CB3MH





- It is a large segment, so you can visualize spatial changes over grid cells
- It is a deep segment, so we can analyze all three dissolved oxygen designated uses
- Its attainment deficit (how far away from attainment it is) is changing over time

Formatting the Data

UTM X | UTM Y | Dimensions

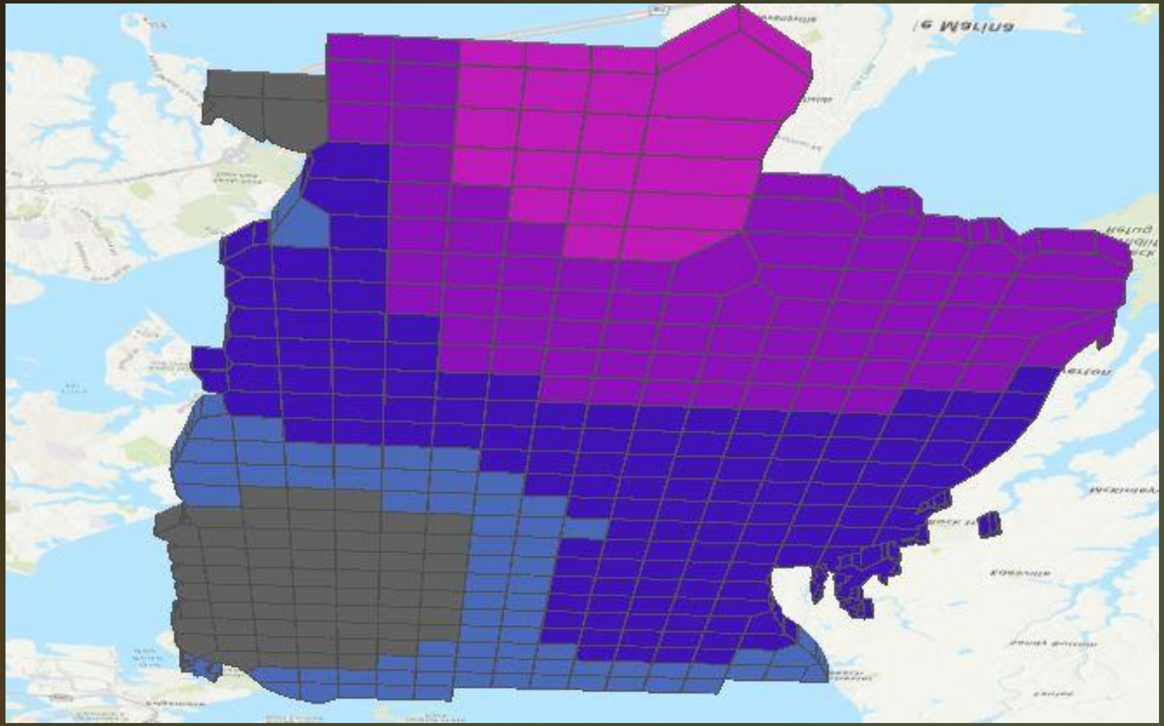
353	1003	CB3MH	1000	1000	1			
378000	4342000	1	7.295					
379000	4342000	4	7.295	6.845	6.63	-8		
380000	4342000	4	7.31	6.86	6.65	-8		
381000	4342000	5	7.325	6.89	6.675	-8	-8	
382000	4342000	5	7.35	6.925	6.715	-8	-8	
376000	4341000	1	7.285					
378000	4341000	4	7.26	6.79	6.575	-8		
379000	4341000	4	7.26	6.795	6.57	-8		
380000	4341000	4	7.275	6.815	6.595	-8		
381000	4341000	5	7.305	6.855	6.63	-8	-8	
382000	4341000	5	7.34	6.905	6.69	-8	-8	
383000	4341000	5	7.39	6.96	6.755	-8	-8	
384000	4341000	5	7.43	7.02	6.82	-8	-8	
385000	4341000	6	7.46	7.07	6.875	-8	-8	-8
386000	4341000	5	7.48	7.1	6.905	-8	-8	
387000	4341000	4	7.475	7.105	6.915	-8		
388000	4341000	3	7.45	7.08	6.89			
389000	4341000	4	7.395	7.035	6.85	6.57		
377000	4340000	2	7.225	6.745				

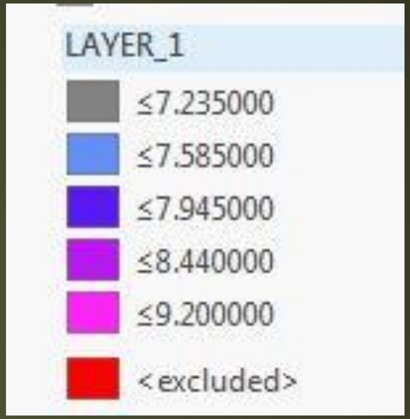
DO values

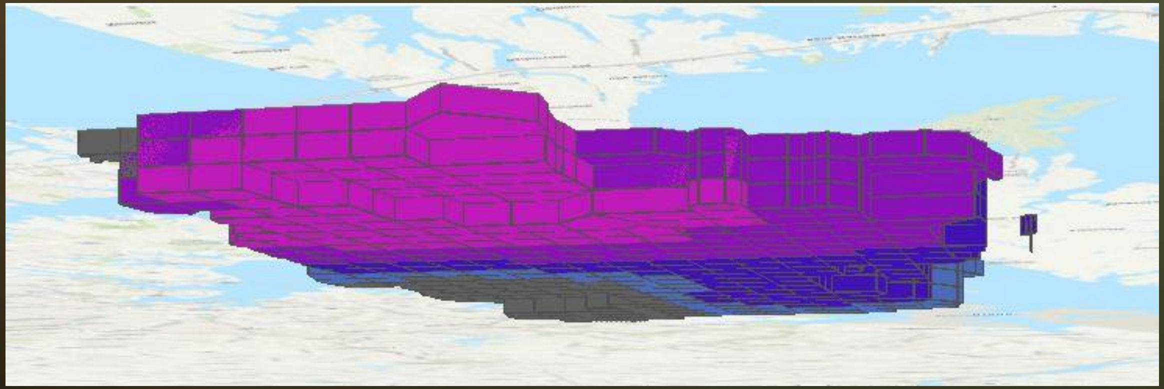
# of layers

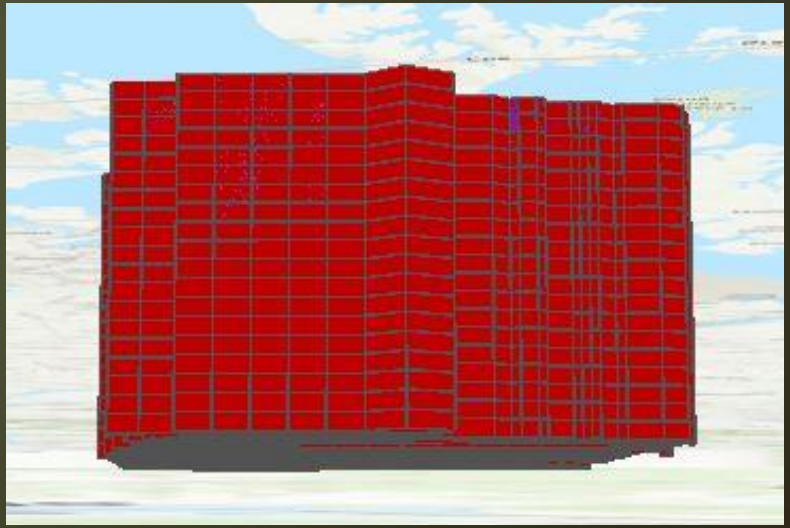
N	CELL	DES_USE	CRITERIA	LAYER_1	LAYER_2	LAYER_3	LAYER_4	LAYER_5	LAYER_6
1	3780004342000	OW	5	7.295	-8	-8	-8	-8	-8
4	3790004342000	OW	5	7.295	6.845	6.63	-8	-8	-8
4	3800004342000	OW	5	7.31	6.86	6.65	-8	-8	-8
5	3810004342000	OW	5	7.325	6.89	6.675	-8	-8	-8
5	3820004342000	OW	5	7.35	6.925	6.715	-8	-8	-8
1	3760004341000	OW	5	7.285	-8	-8	-8	-8	-8
4	3780004341000	OW	5	7.26	6.79	6.575	-8	-8	-8
4	3790004341000	OW	5	7.26	6.795	6.57	-8	-8	-8
4	3800004341000	OW	5	7.275	6.815	6.595	-8	-8	-8
5	3810004341000	OW	5	7.305	6.855	6.63	-8	-8	-8
5	3820004341000	OW	5	7.34	6.905	6.69	-8	-8	-8
5	3830004341000	OW	5	7.39	6.96	6.755	-8	-8	-8
5	3840004341000	OW	5	7.43	7.02	6.82	-8	-8	-8
6	3850004341000	OW	5	7.46	7.07	6.875	-8	-8	-8
5	3860004341000	OW	5	7.48	7.1	6.905	-8	-8	-8
4	3870004341000	OW	5	7.475	7.105	6.915	-8	-8	-8
3	3880004341000	OW	5	7.45	7.08	6.89	-8	-8	-8
4	3890004341000	OW	5	7.395	7.035	6.85	6.57	-8	-8
2	3770004340000	OW	5	7.225	6.745	-8	-8	-8	-8

3D Mapping Dissolved Oxygen



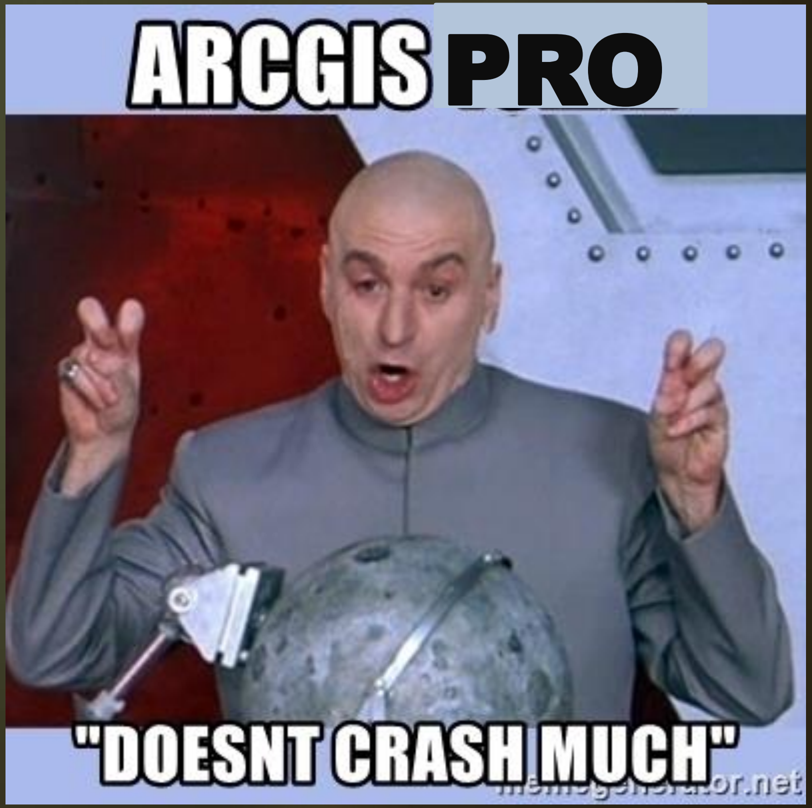






Challenges Faced

- Communicating science in an effective manner
- Bugs in Arc GIS Pro
- Manually creating each layer
  - 22 layers x 3 designated uses x 4 months x 30 years
  - Automating the 3D map making process



Emily Trentacoste

Rebecca Murphy

John Wolf

Angie Wei

Richard Tian

Labeeb Ahmed

Tim Dirks

Justin Barker