Diagnosing causes of degradation in benthic communities of Chesapeake Bay: accomplishments, approaches and interpretations

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Delaware Bay
Chesapeake Bay
Atlantic Ocean
Pamlico Sound

The Chesapeake Bay Benthic Experience

I. Program Accomplishments

II. Benthic Communities

III. Determining causes of degradation

A. Contamination

B. Low Dissolved Oxygen

C. Moderate Eutrophication

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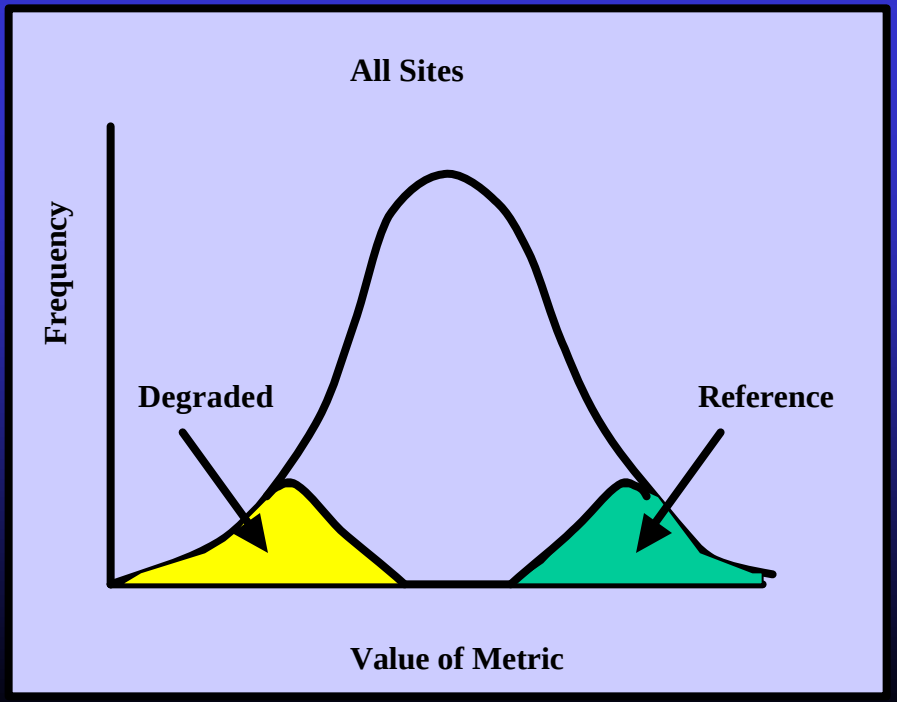

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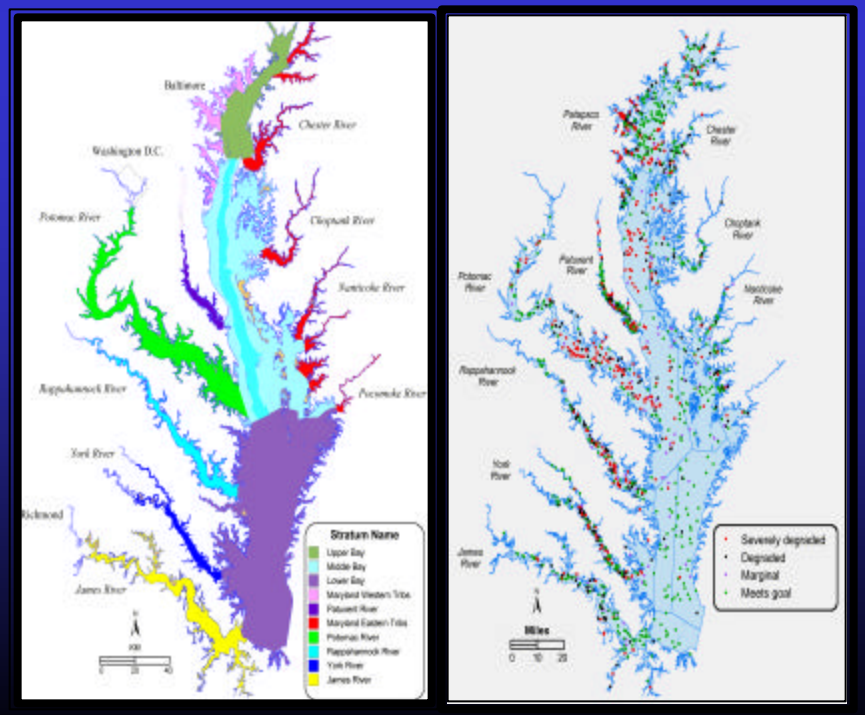

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(4) **Quantifying the relationship between benthic biotic integrity and benthic habitat quality.**

(Diaz et al. 2003. Journal of Experimental Marine Biology and Ecology)

(5) Impaired waters designations of Maryland DNR and Virginia DEQ.

303d

305b

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(6) Diagnostic approaches to causes of degradation of benthic communities.

Eutrophication

Sediment Contamination

(Dauer et al. 2002. EPA Technical Report)

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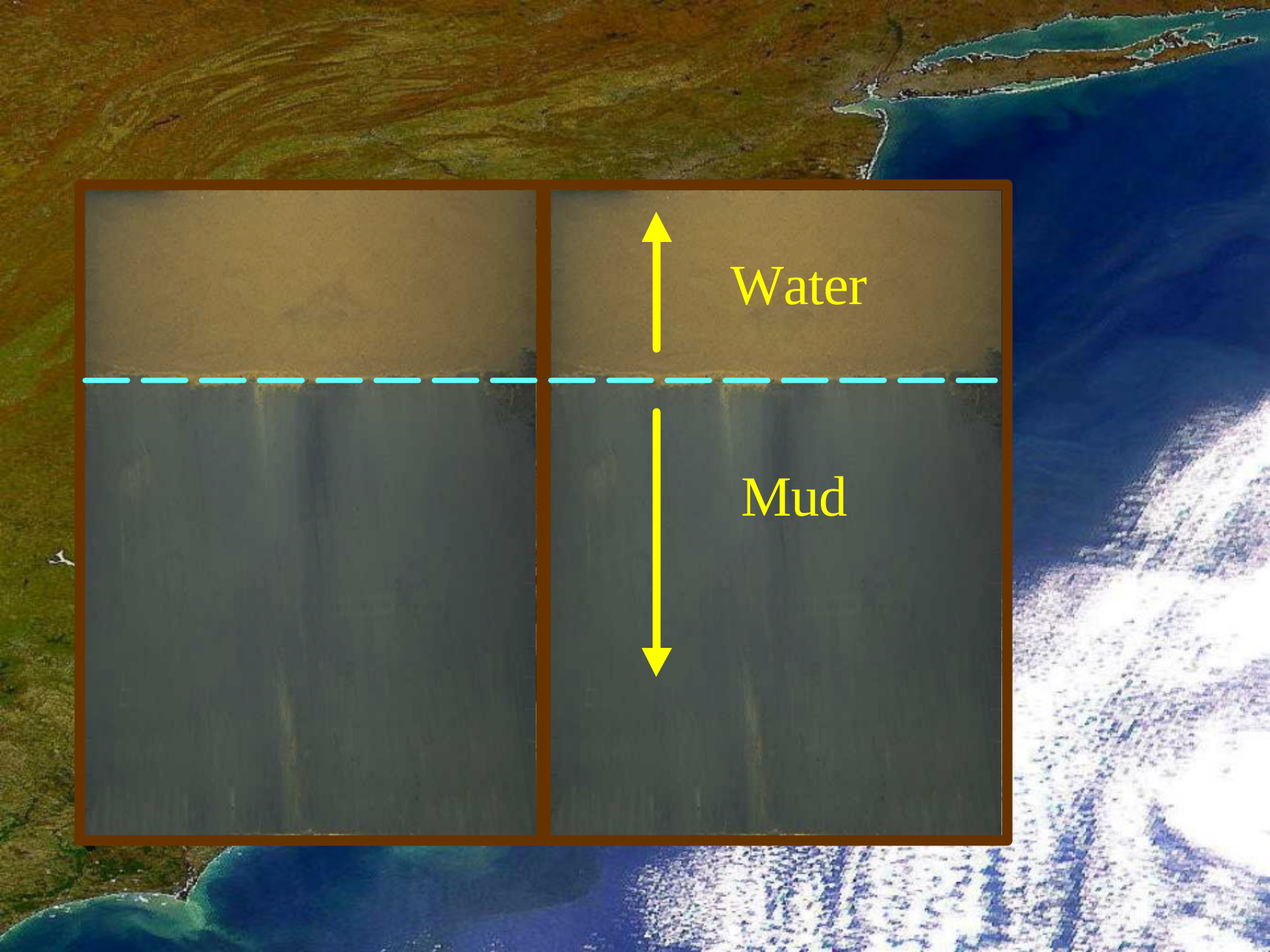
What are benthic communities?

Crabs & Shrimp

Clams & Snails

Worms


Water
Mud

Benthic communities consist of a diversity of species

Benthic communities consist of a diversity of species

Crustaceans

Crabs

Shrimp

Amphipods

Molluscs

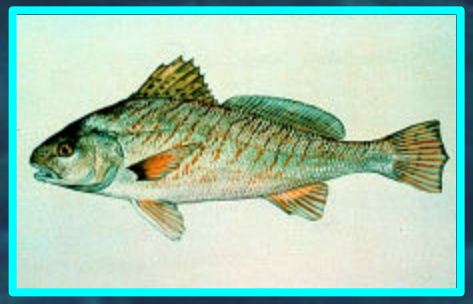
- Clams
- Oysters
- Snails

Worms

- Ragworms
- Baitworms
- Red gilled worms

Why use benthos in environmental monitoring?

- **They are good monitoring tools**
  - **Limited mobility**
  - **High exposure to common stresses**
  - **Sensitive to a variety of stresses**
  - **Integrate stress effects over time**
  - **Integrate the effects of multiple stresses**
- **They are ecologically important**
  - **Serve as forage for bottom-feeding fish**
  - **Feed on plankton in the water column**
  - **Affect nutrient recycling**



Many species of fish, crabs and birds feed on the bottom

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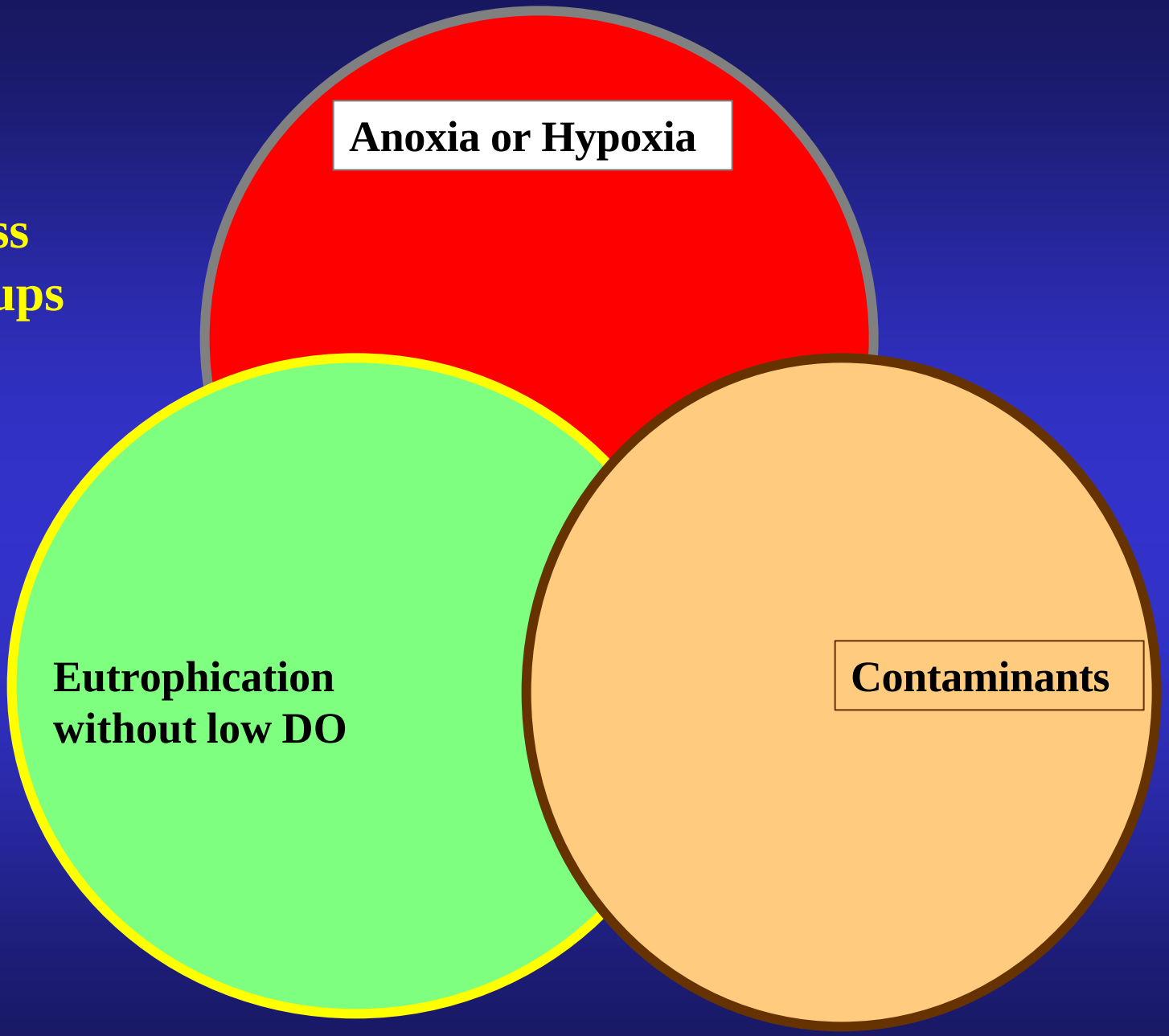
Stress Groups



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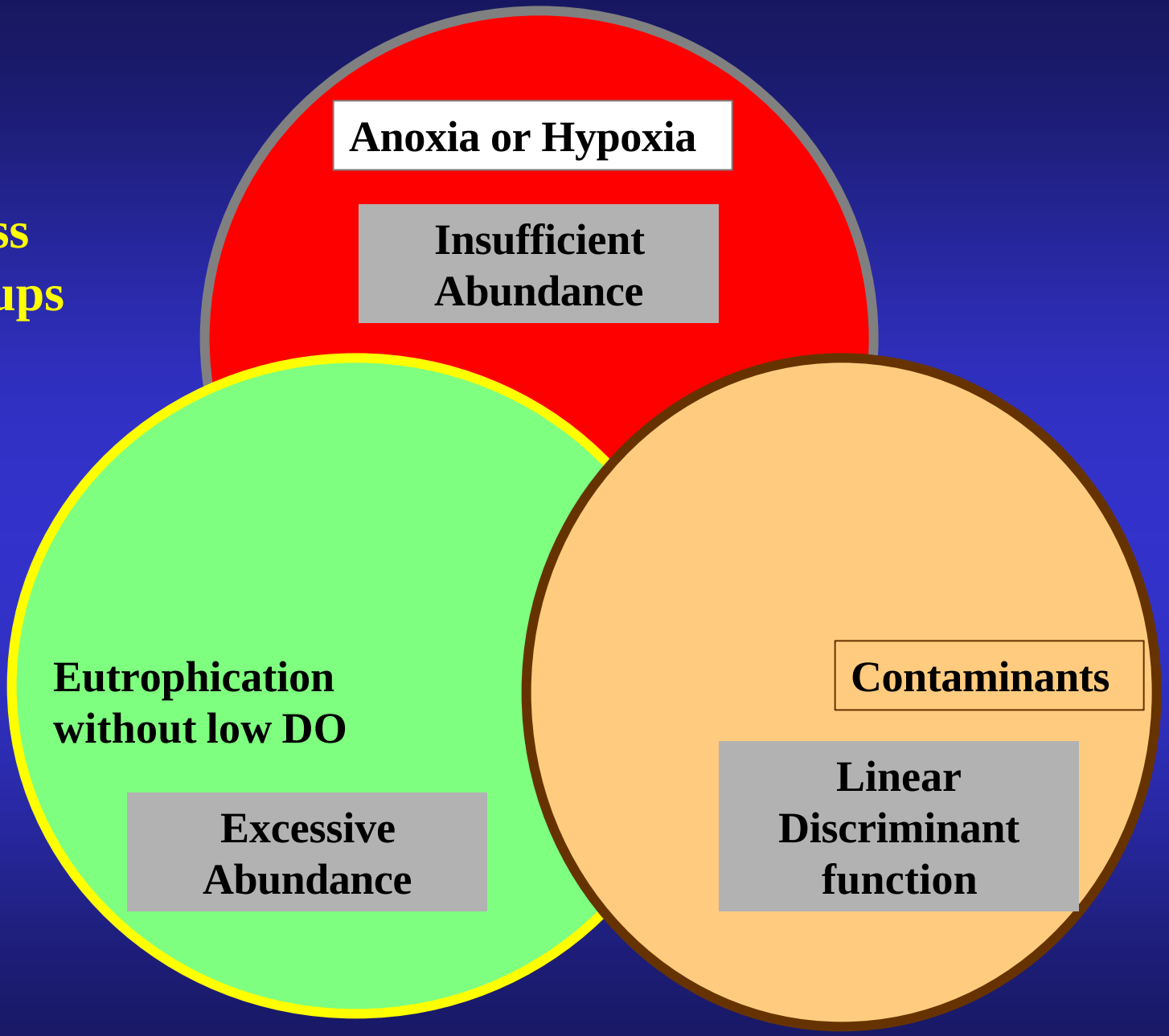

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Objective

Develop multivariate statistical tool(s) for classifying benthic samples collected in Chesapeake Bay into categories of environmental stress.

Analytical Methods : Databases Used

All data were:

(1) collected within geographic boundaries of the Bay

(2) collected using a Young grab

(3) collected during B-IBI index period

(4) collected with concurrent D.O. and contaminant data

(5) BIBI values $\geq$ 2.6 (degraded or severely degraded)

Number of sampling location/date combinations for each monitoring program within Chesapeake Bay.

Monitoring Program	Sampling Locations
EMAP Virginian Province	290
Mid-Atlantic Integrated Assessment	121
CBP Long-term Benthic Monitoring	48
Tidal Freshwater Goals Program	47
CBP Long-term Benthic Monitoring	46
Ambient Toxicity Program (Maryland)	36
Ambient Toxicity Program (Virginia)	20

Distribution of Observations With Respect to Status

Status	Number of Obs.	% of Obs.	Mean Benthic IBI
Meets Goals	272	44.66	3.6
Marginal	69	11.33	2.8
Degraded	110*	18.06	2.4
Severely Degraded	158*	25.94	1.6
Overall	609		2.8

Analytical Methods : Stress Groups

- **Four Stress Groups**
  Contaminant, Low DO, Combined and Unknown
- **Three Stress Groups**
  Contaminant, Combined and Unknown
- **Two Stress Groups**
  Contaminant vs Others (without low DO Sites)
- **Two Stress Groups**
  Contaminant vs Others (with low DO Sites)

Analytical Methods : Spatial Scales

- **Within Habitat Type**

  7 habitat types (Weisberg et al. 1997)

- **Within Salinity Regime**

  Tidal Fresh/Oligohaline, Mesohaline and Polyhaline

- **Baywide**

  Across all habitat types and salinity regimes

Analytical Methods : Contaminant criteria

- **Single contaminant > ERM value**

  ERM exceedance classification criterion

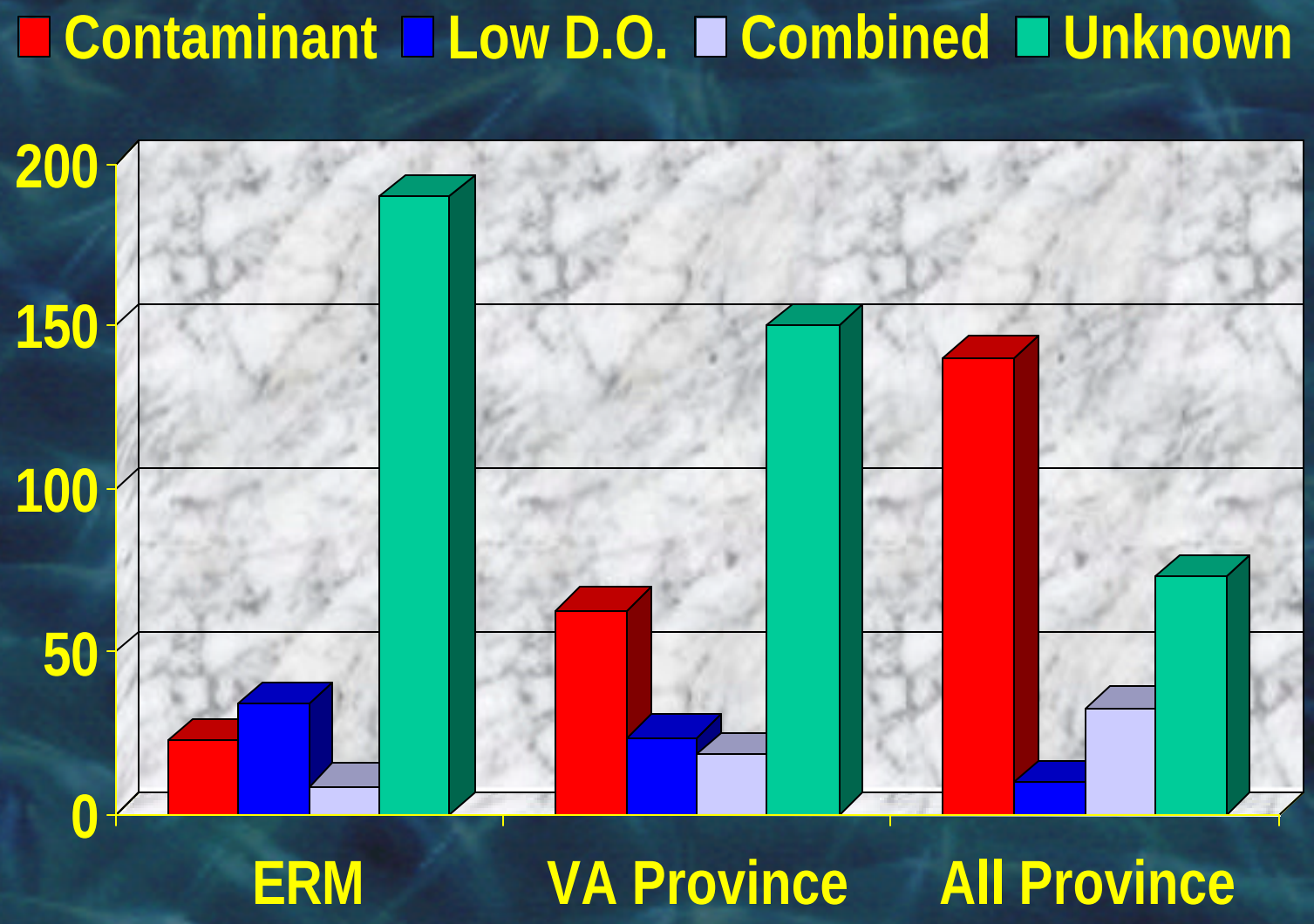
- **Mean SQG Quotient > 0.098**

  VA Province contaminant classification criterion (Hyland et al. 2003)

- **Mean SQG quotient > 0.044**

  All Province contaminant classification criterion (Hyland et al. 2003)

Frequency of Observations in Each Stress Group



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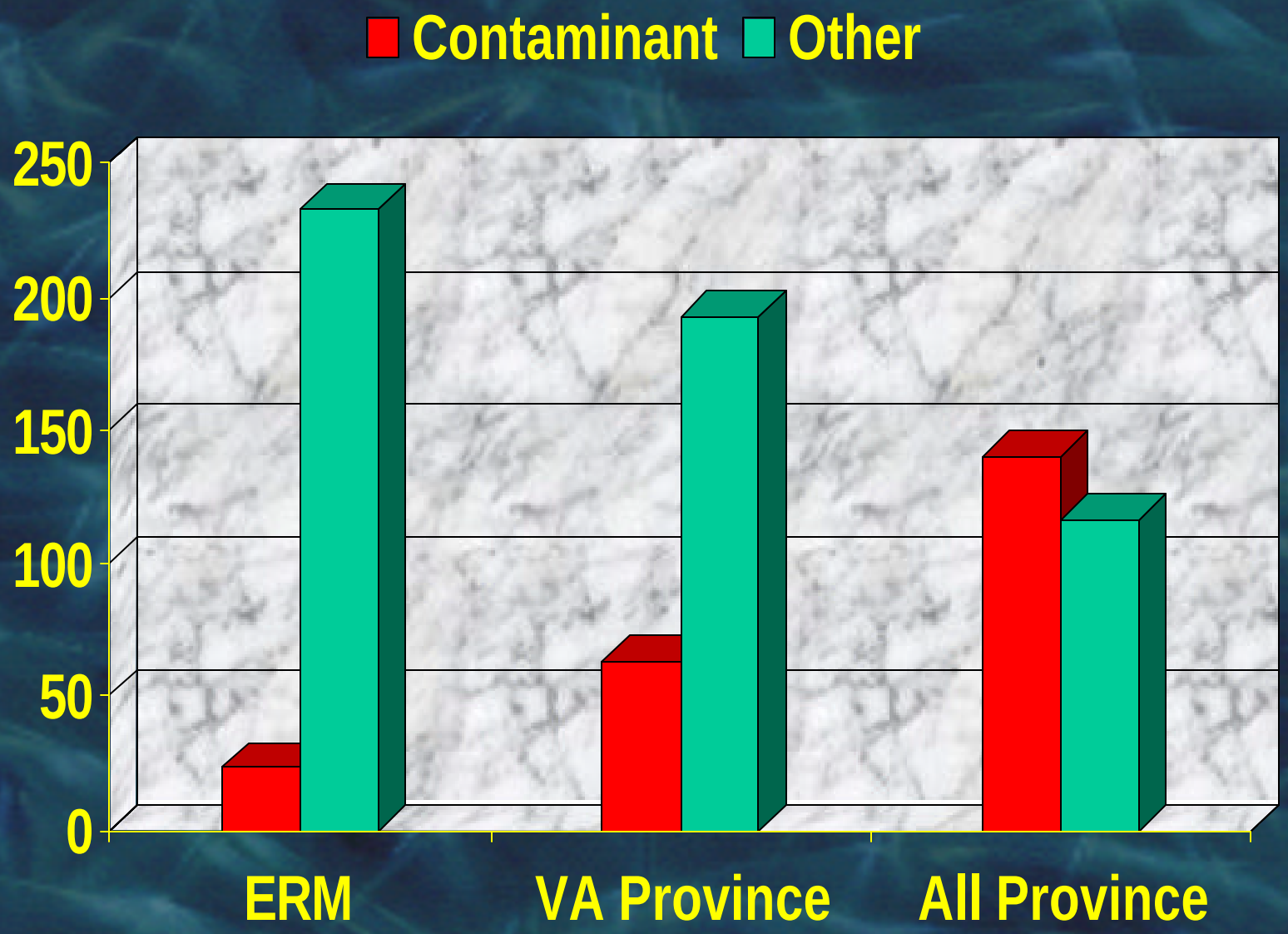

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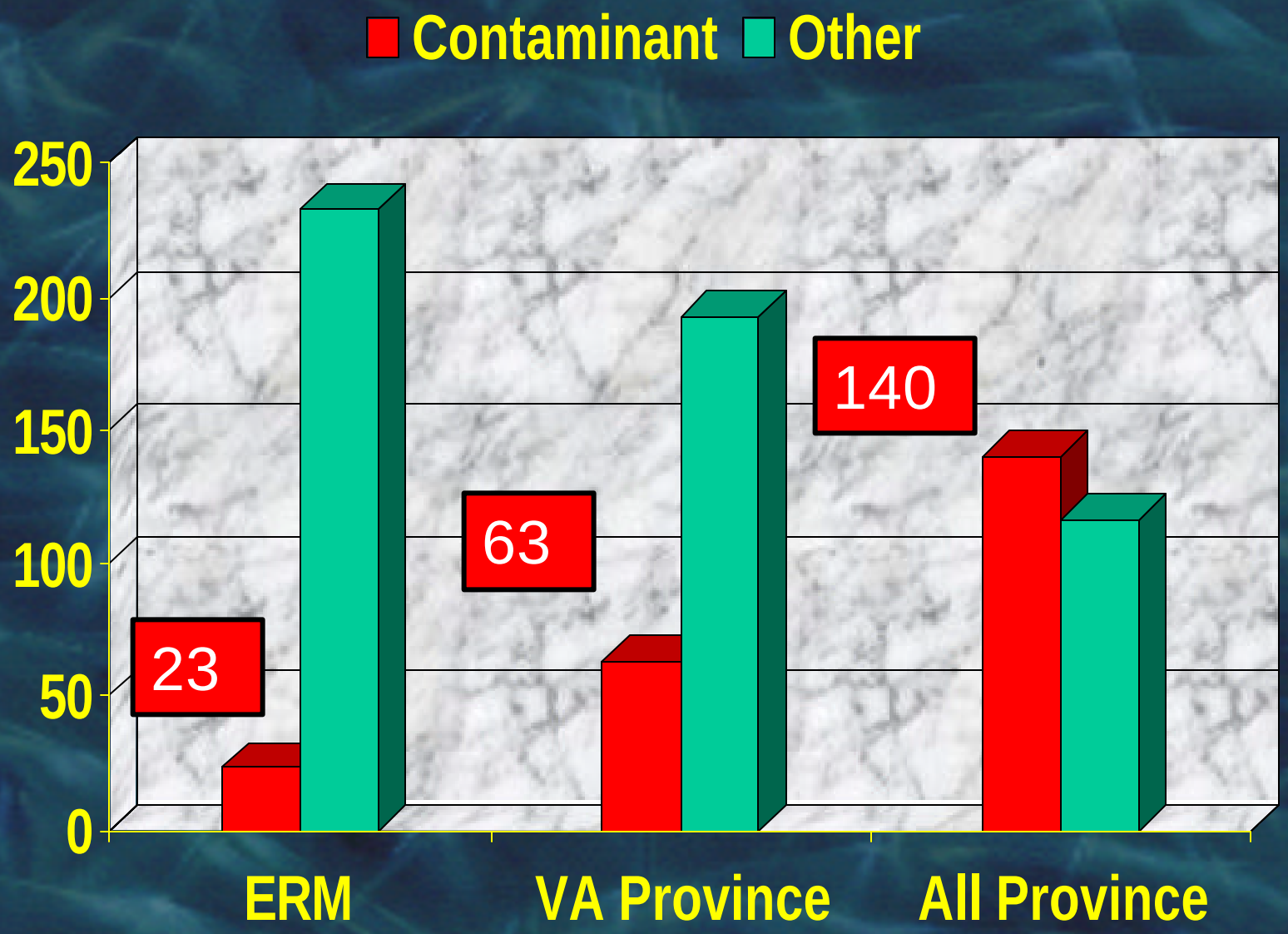

Analytical Methods : Level of Benthic Degradation

- **Severely degraded sites only**
- **Severely degraded and degraded sites combined.**

Analytical Methods : Scenarios

Spatial Scales		Stress Group Combinations		Contaminant Criteria		Level of degradation
11	x	**4**	x	**3**	x	**2**
7 Habitat Types 3 Salinity Regimes 1 Baywide		All Stress Groups Without Low D.O. Cont. vs Others (No LDO) Cont. vs Others		ERM Exceedance VA Province All Province		Severely Degraded Only (BIBI <= 2.0) Severely Degraded and Degraded (BIBI <= 2.6)

264 Total

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Analytical Methods : Tool Development

Linear discriminant analysis

Functions developed using "hold-out" procedure

- **$^{2}/_{3}$ of data used for calibration and**
- **$^{1}/_{3}$ for validation (random selection)**

Proportional prior probabilities

- **takes into account the proportion of observations in each group within the calibration data set**

Variable Reduction Procedures

- **Stepwise canonical discriminant analysis**
- **ANOVA between stress groups**

Analytical Methods : Candidate Metrics

Metric Categories	Abundance	Richness	Relative Abundance	Species Diversity	Dominance	Biomass
Taxonomic Categories						
Isopoda	*	*	*			
Amphipoda	*	*	*			
Haustoriidae	*	*	*			
Ampeliscidae	*	*	*			
Gammaridae	*	*	*			
Corophiidae	*	*	*			
Mollusca	*	*	*			
Bivalvia	*	*	*			
Gastropoda	*	*	*			
Polychaeta	*	*	*			
Spionidae	*	*	*			
Capitellidae	*	*	*			
Nereidae	*	*	*			
Oligochaeta	*	*	*			
Tubificidae	*	*	*			
Life History Categories						
Infaunal species	*	*		*	*	
Epifaunal species	*	*	*	*	*	
Infaunal and epifaunal species						*
Trophic Categories						
Deep Deposit feeder	*	*	*			
Suspension feeder	*	*	*			
Interface feeder	*	*	*			
Carnivore/Omnivore	*	*	*			

A "*" indicates that a given metric for the category listed was evaluated for use in the analytical tool.

Conclusions

- **Final Function – Validation Classification Efficiency**

Contaminant Group	Other Group	Overall
82%	67%	75%
Posterior p = 0.9	89%	

- **Baywide Scale – although attempted salinity corrections did not improve classification efficiencies.**

- **Regardless of spatial scale or scenario, variable reduction procedures did not improve classification efficiencies.**
-

Sediment contaminant DA function

Discriminant function tool

- Linear discriminant function
- 63 benthic metrics
- Two stress groups
  - Contaminant
  - Others
- Validation rate – 75%

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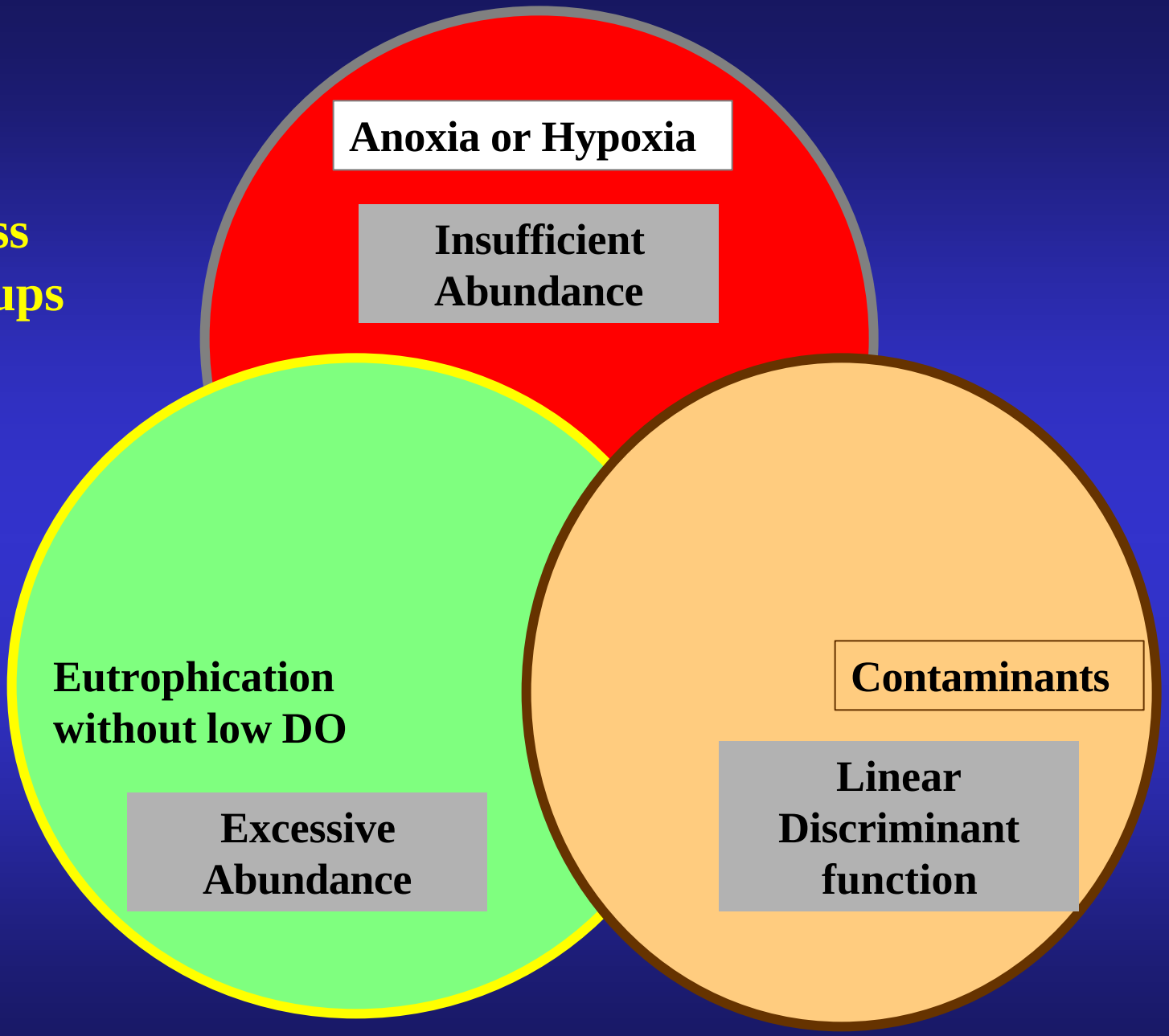


Benthic Index of Biotic Integrity (B-IBI)

Multi-metric index

- Diversity
- Abundance
- Biomass
- Functional groups

Metrics scored relative to values of reference samples

Metric selection and scoring thresholds habitat-specific

(7 habitats determined)

Metric scoring 1, 3, 5 allows interhabitat comparisons

Chesapeake Bay - B-IBI

Communication Advantages

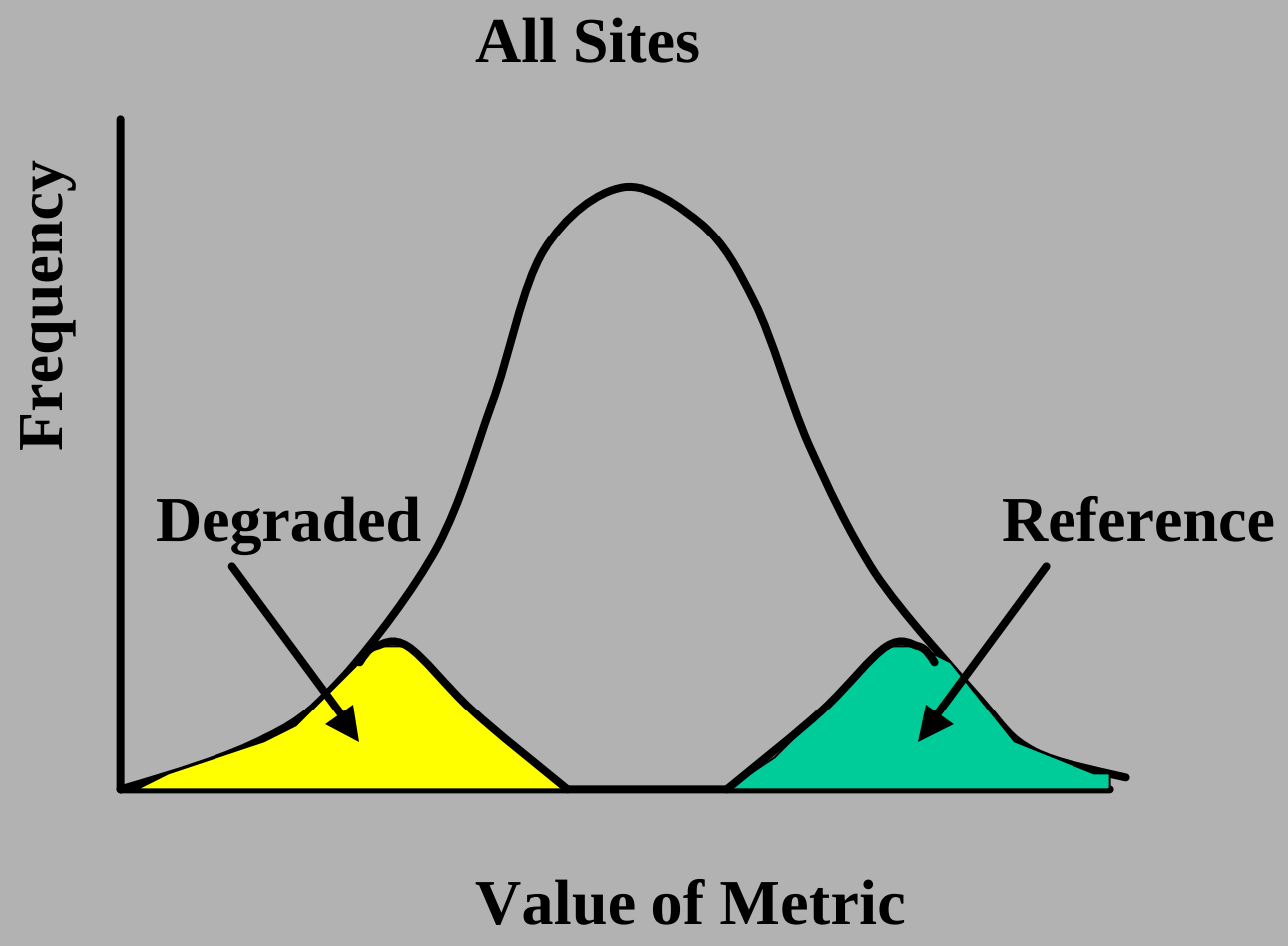
- Values
  - **< 3 represent degraded condition**
  - **= 3 represent undegraded condition**
- Metric thresholds become restoration goals
- Metrics can be examined for additional insight into causes of degradation

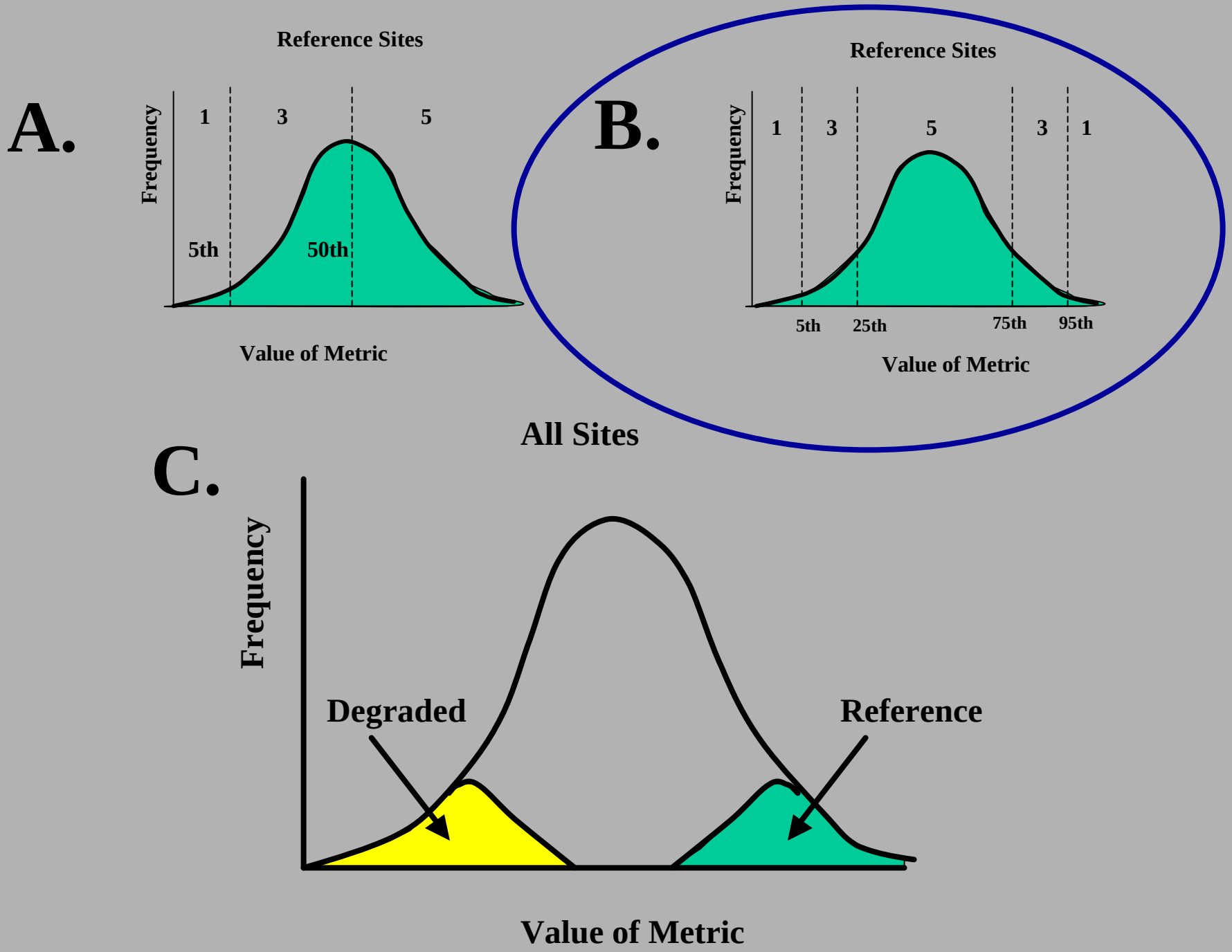
Causes of benthic community degradation

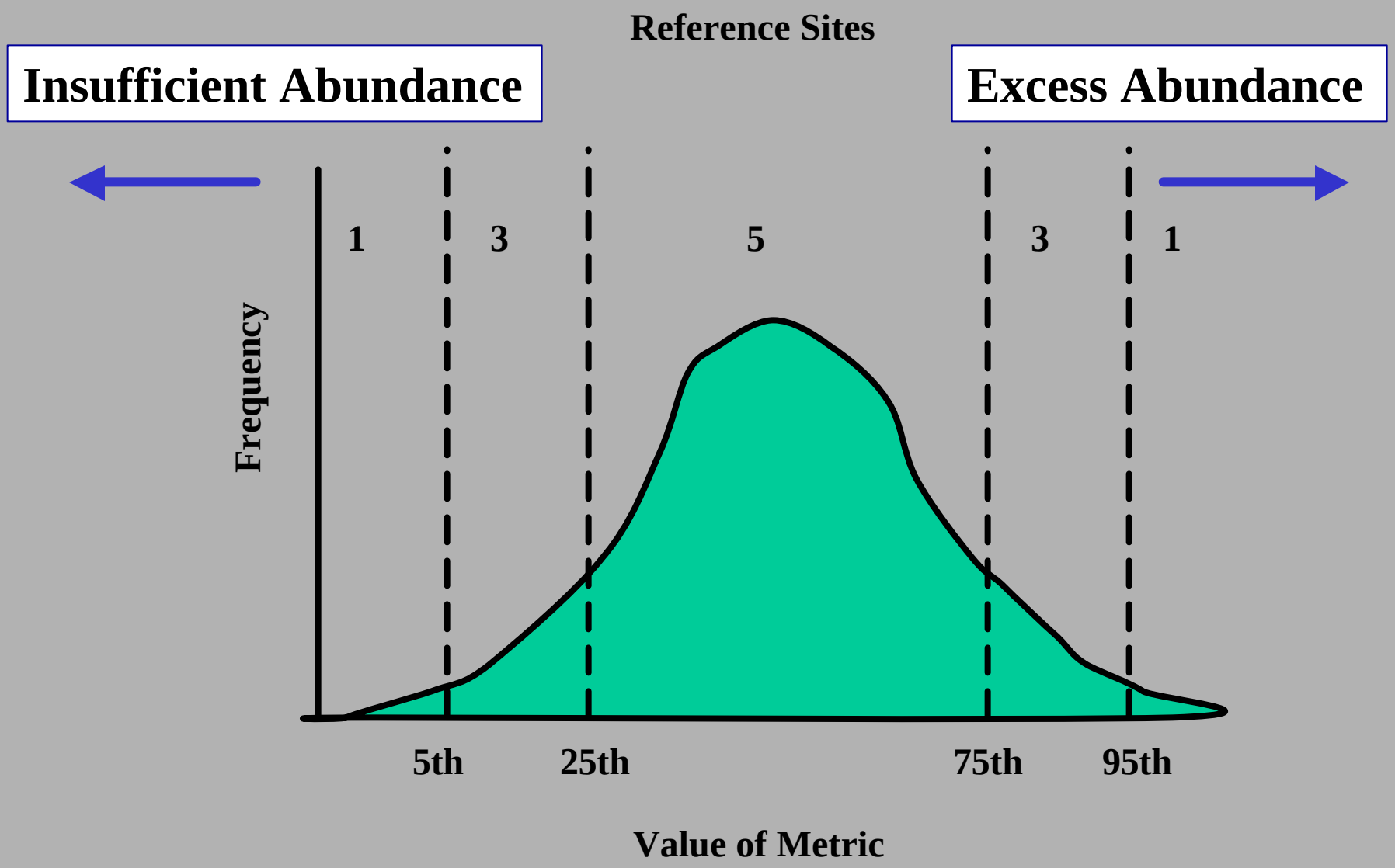
Organic enrichment effect

Excessive abundance

BIBI


All Sites
Frequency
Degraded
Reference
Value of Metric


A.
Reference Sites
Frequency
1
3
5
5th
50th
Value of Metric
B.
Reference Sites
Frequency
1
3
5
3
1
5th
25th
75th
95th
Value of Metric
All Sites
C.
Frequency
Degraded
Reference
Value of Metric


Reference Sites
Insufficient Abundance
Excess Abundance
1
3
5
3
1
Frequency
5th
25th
75th
95th
Value of Metric

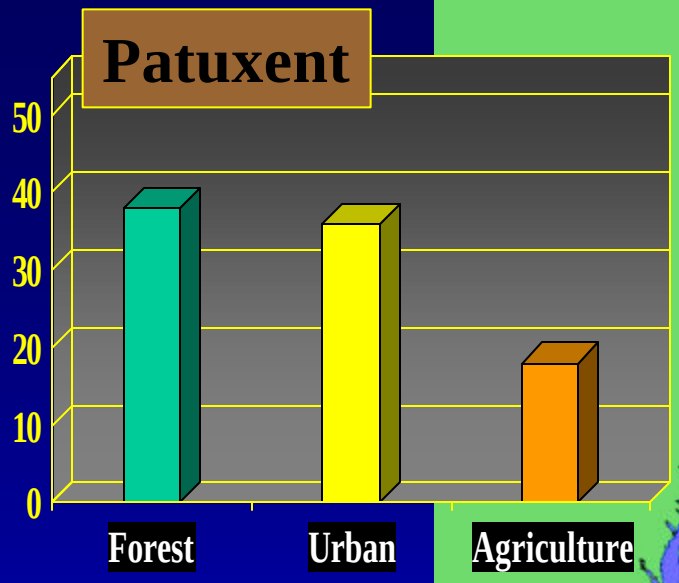
Validation of

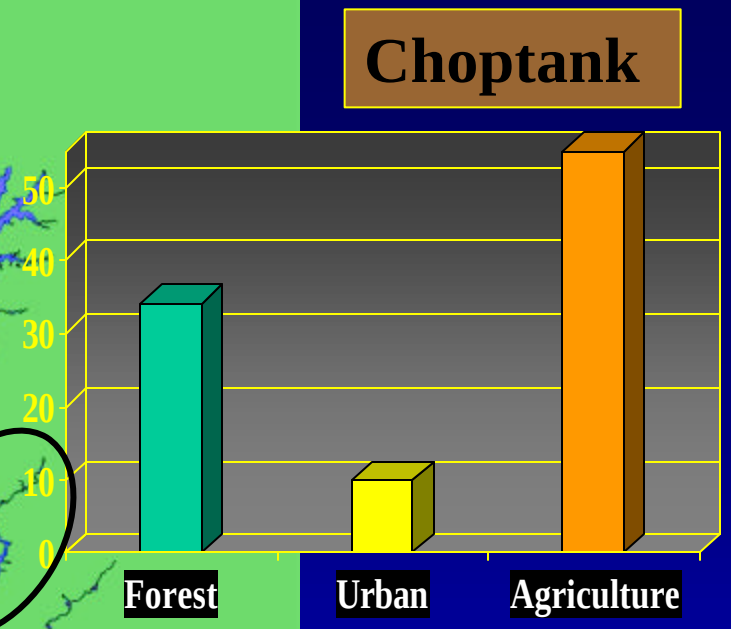
excessive abundance

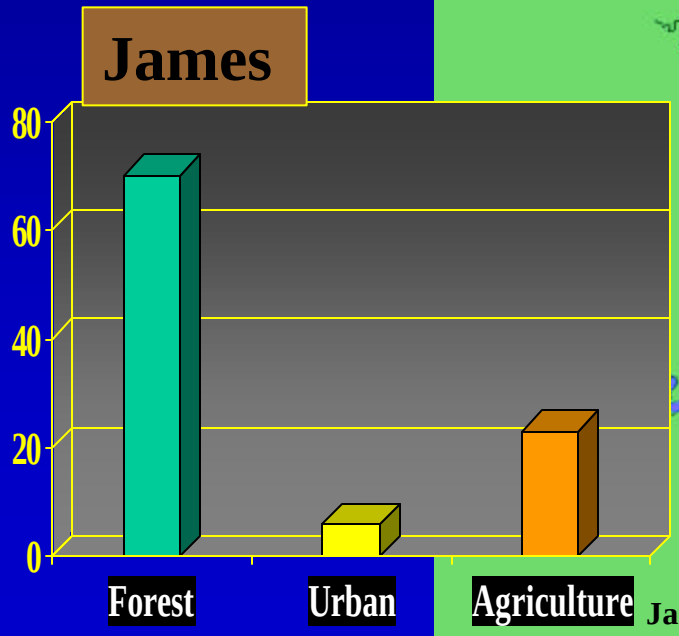
as an indicator of moderate eutrophication

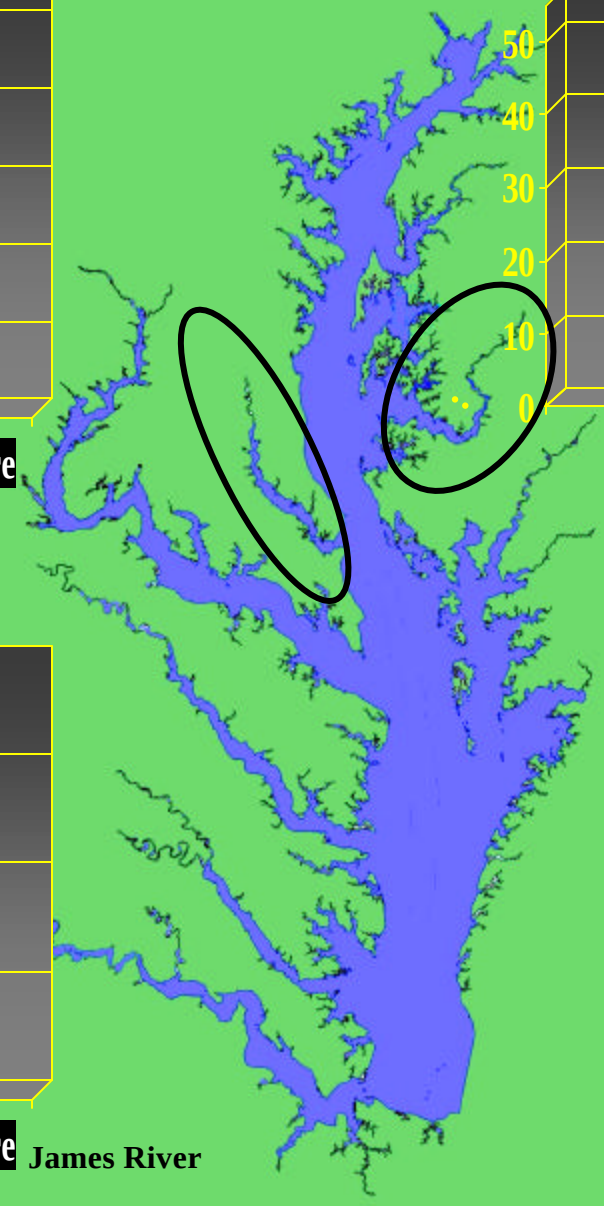
Patterns of nutrients and chlorophyll in selected tributaries

Landuse

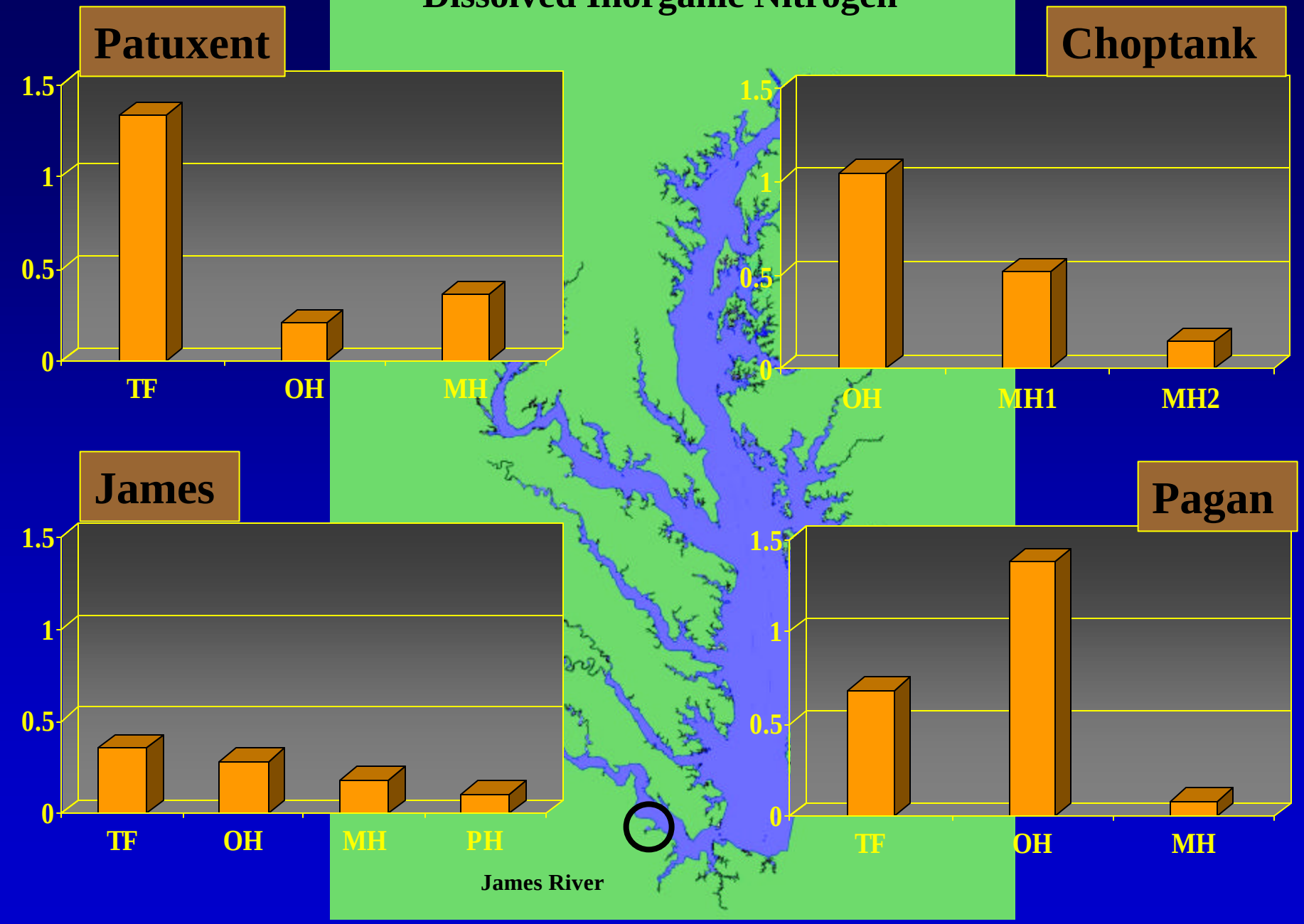

Patuxent
50
40
30
20
10
0
Forest
Urban
Agriculture


Choptank
50
40
30
20
10
0
Forest
Urban
Agriculture


James
80
60
40
20
0
Forest
Urban
Agriculture


James River

Dissolved Inorganic Nitrogen

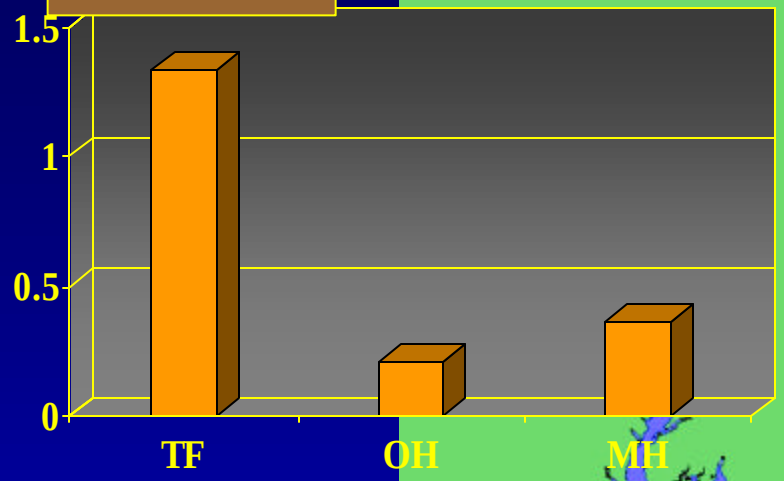


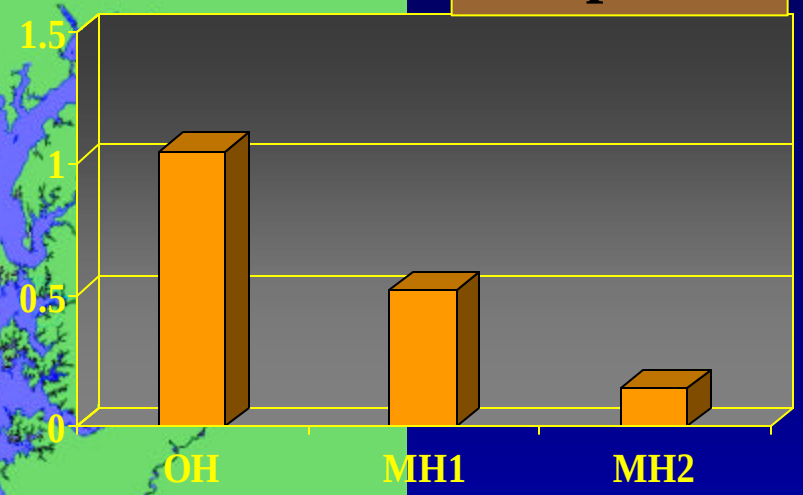
Dissolved Inorganic Nitrogen

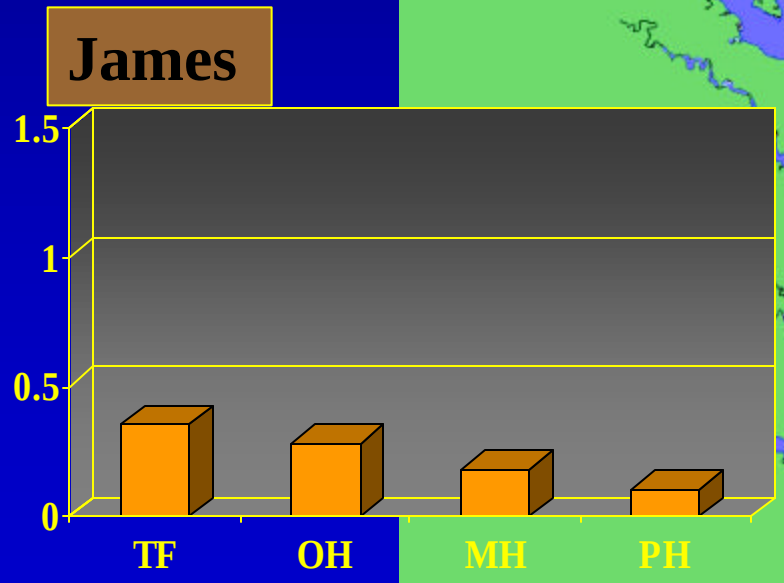
Pagan

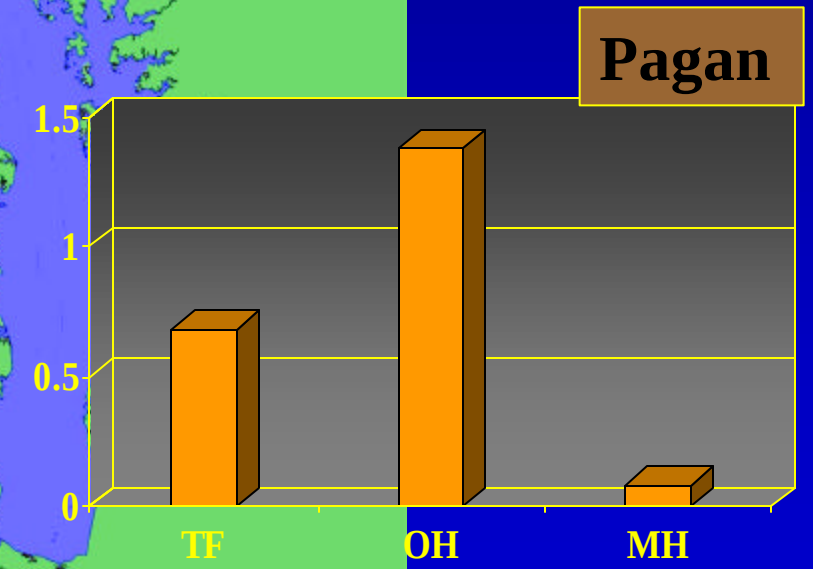
James River

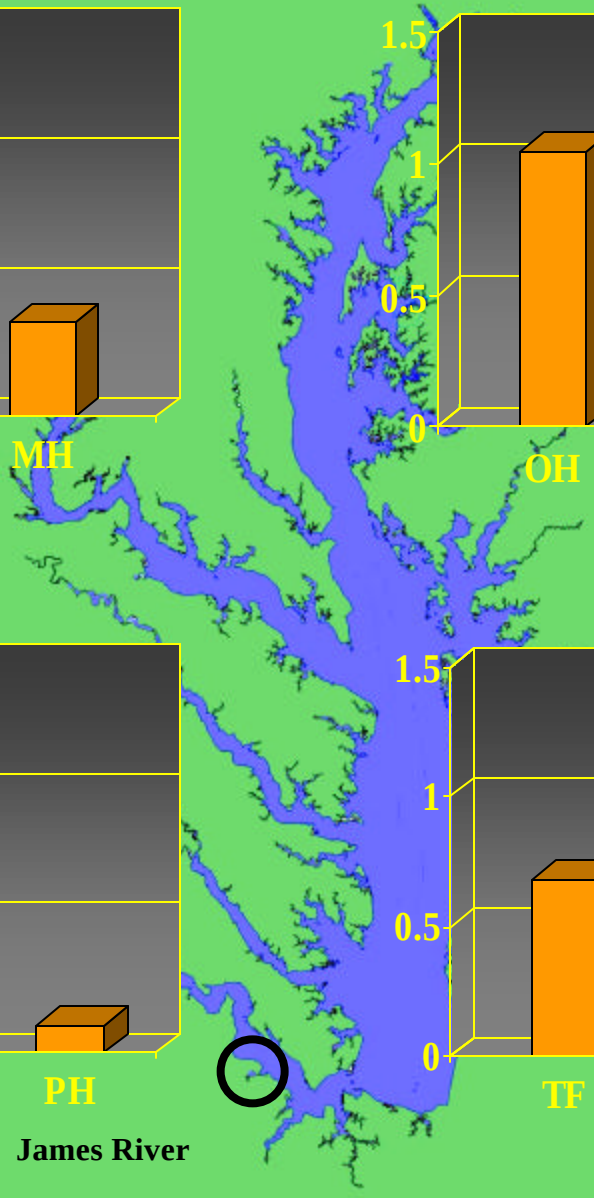
Dissolved Inorganic Nitrogen











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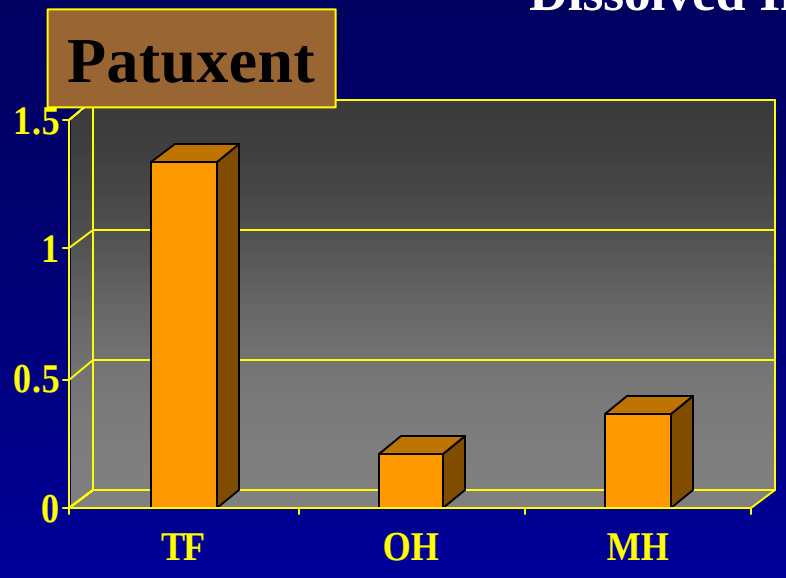
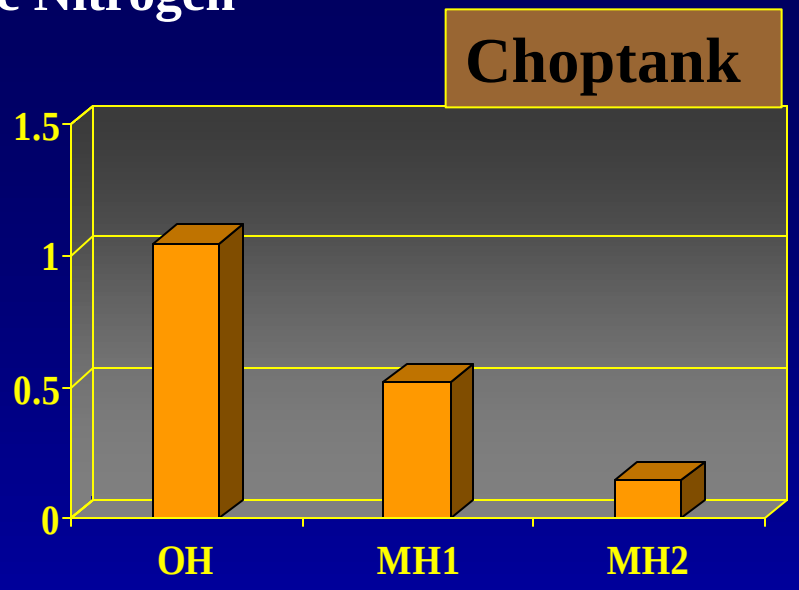
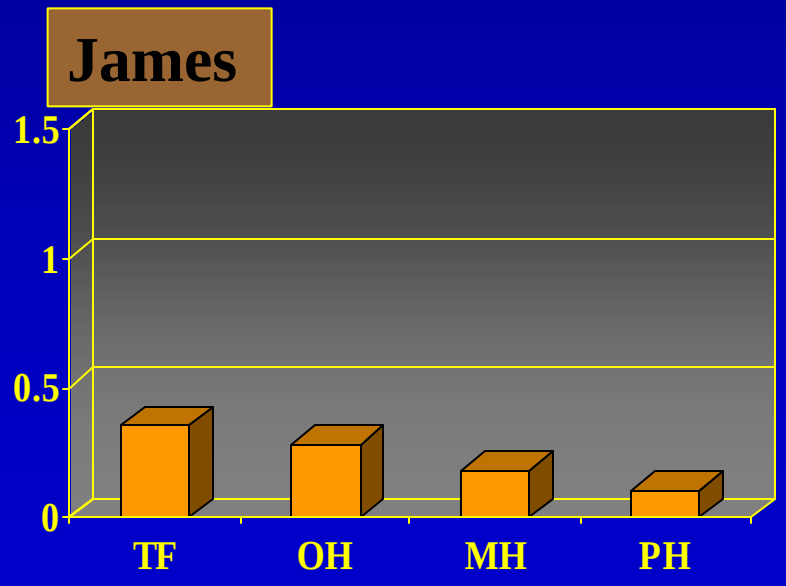
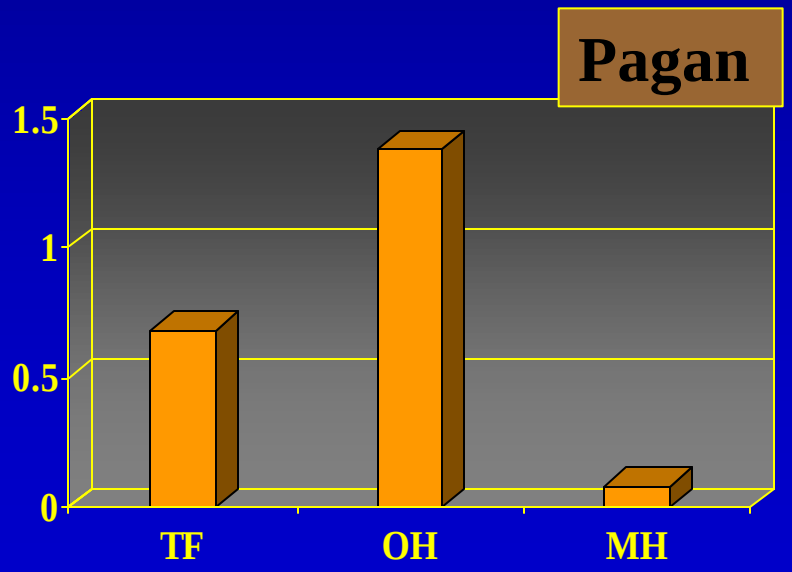
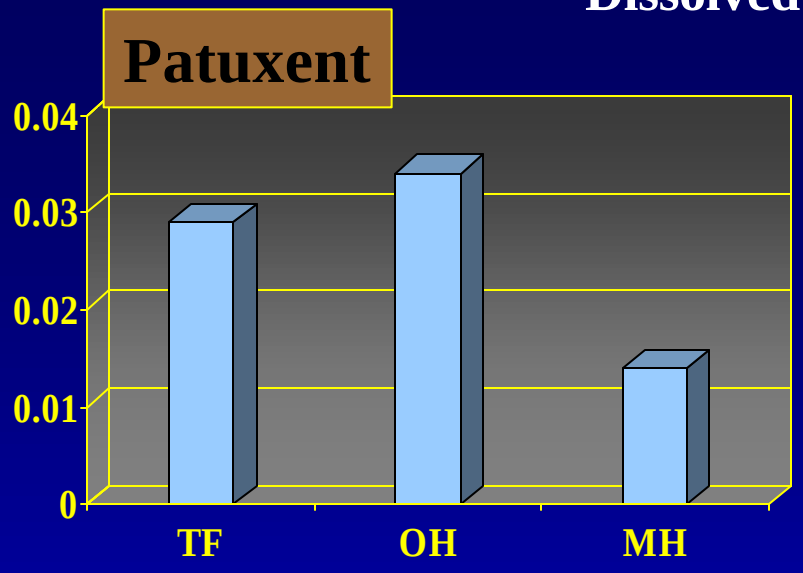


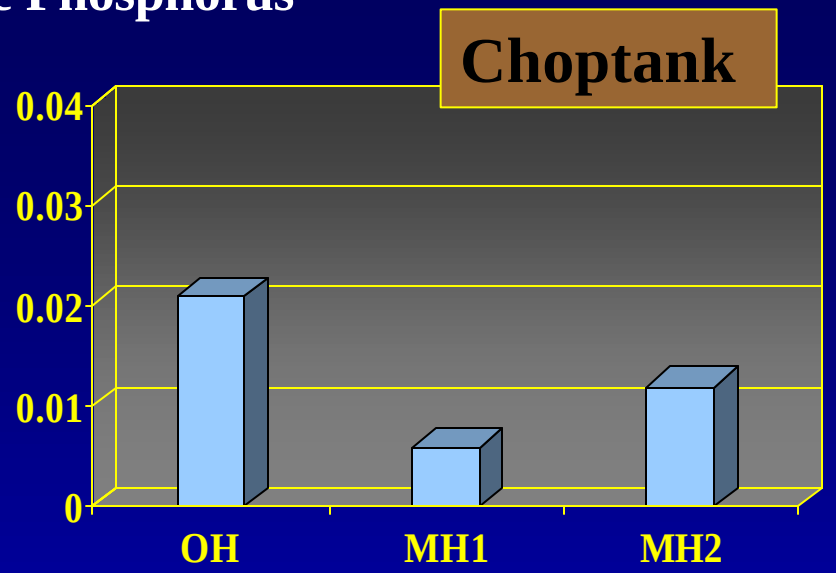


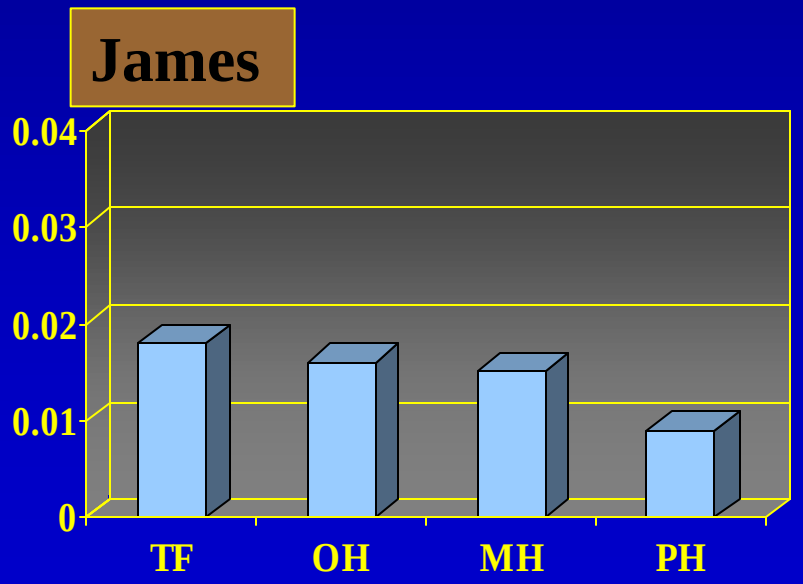


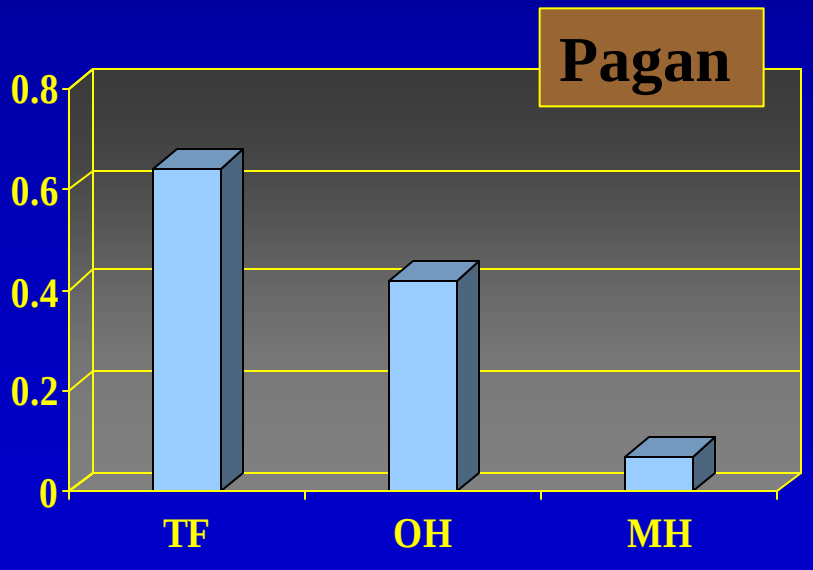


Dissolved Inorganic Phosphorus

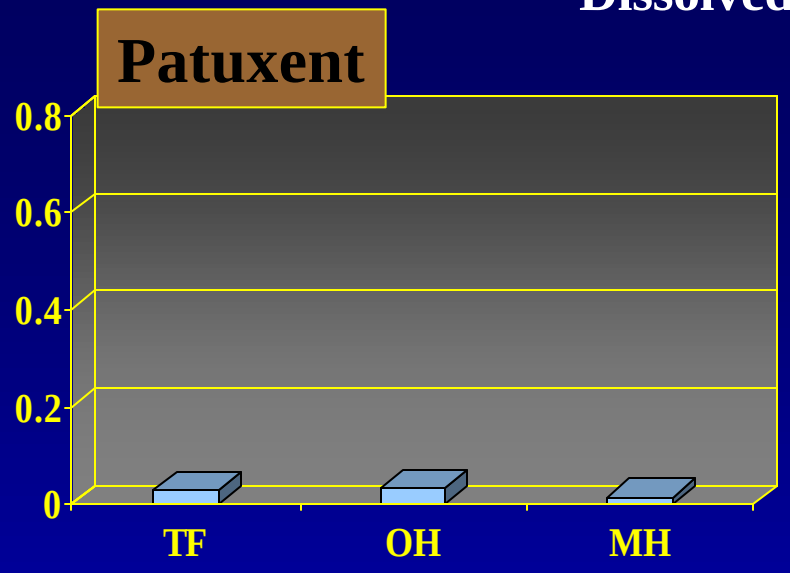


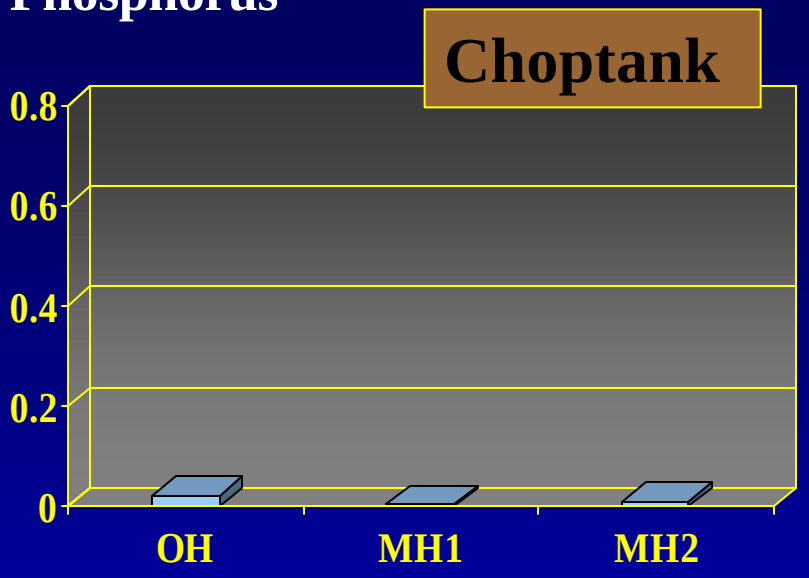


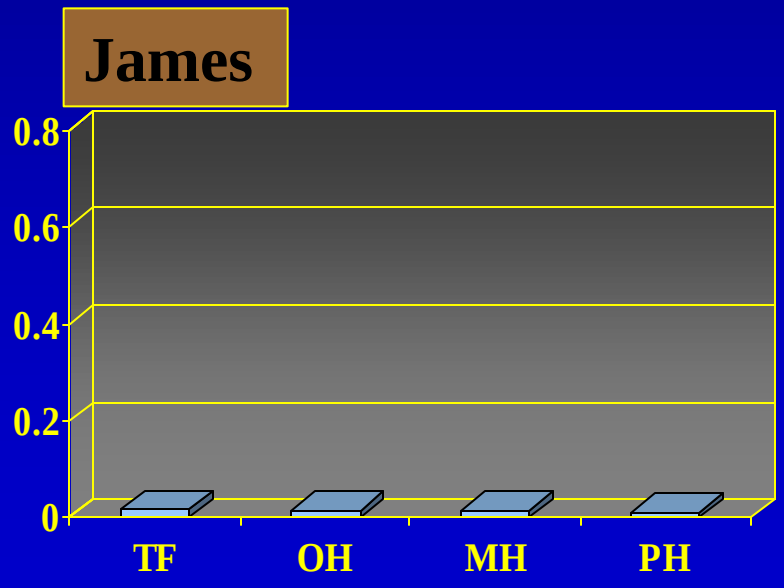


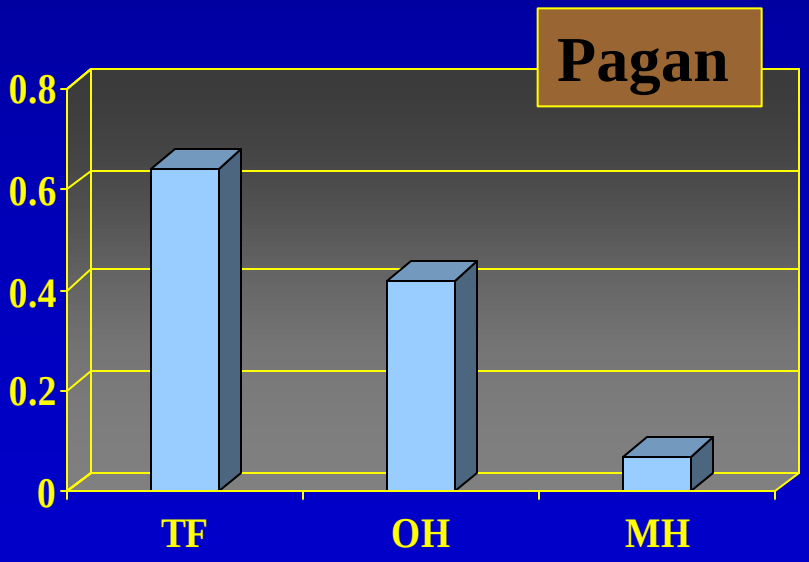


Dissolved Inorganic Phosphorus

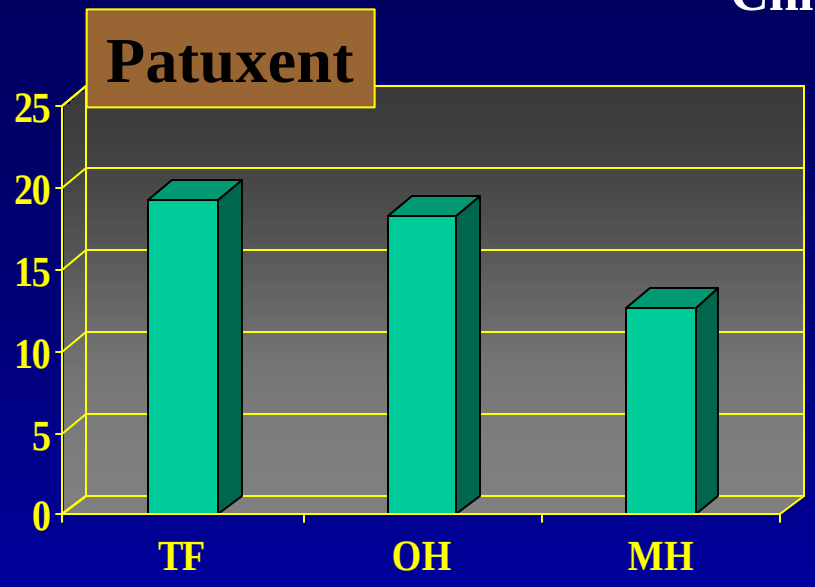


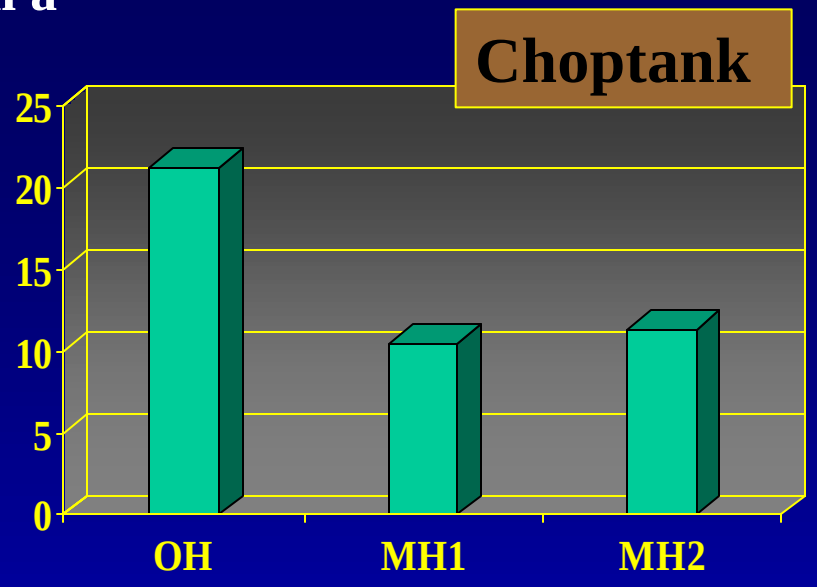


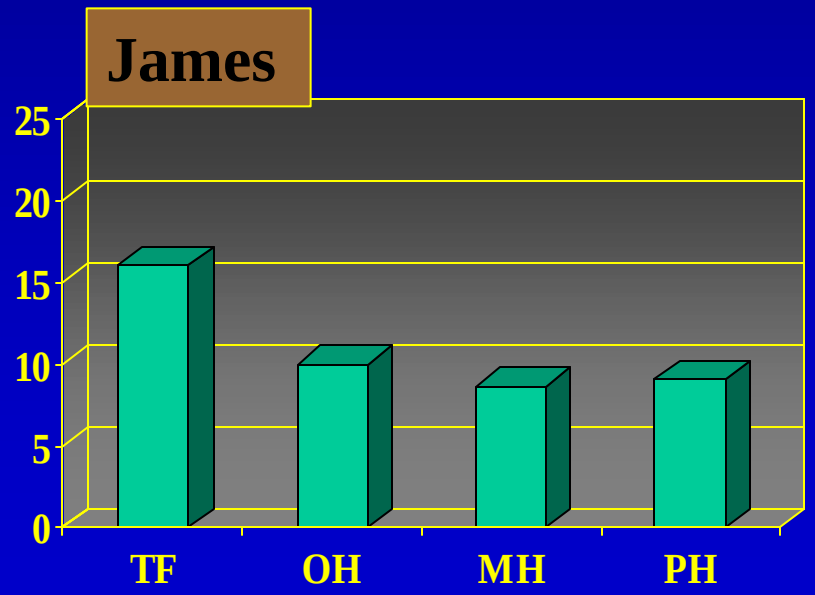


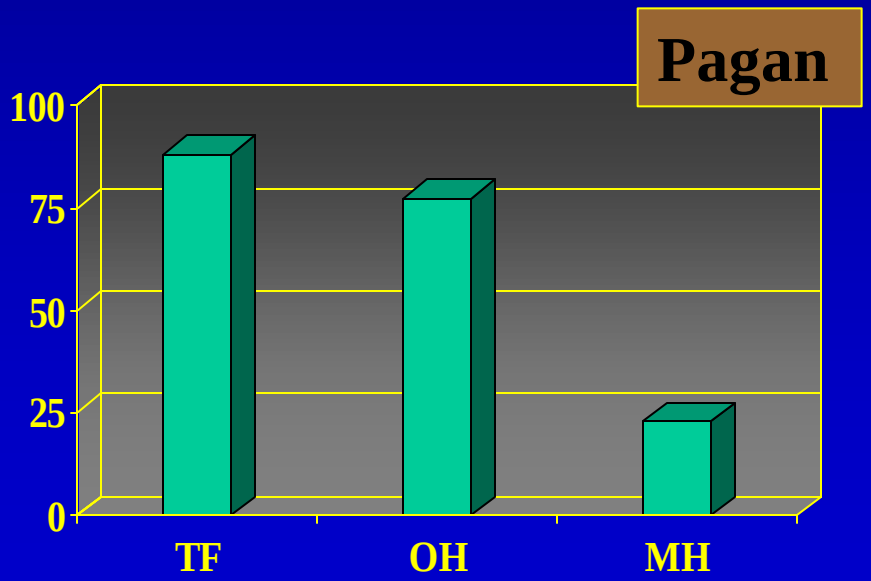


Chlorophyll a

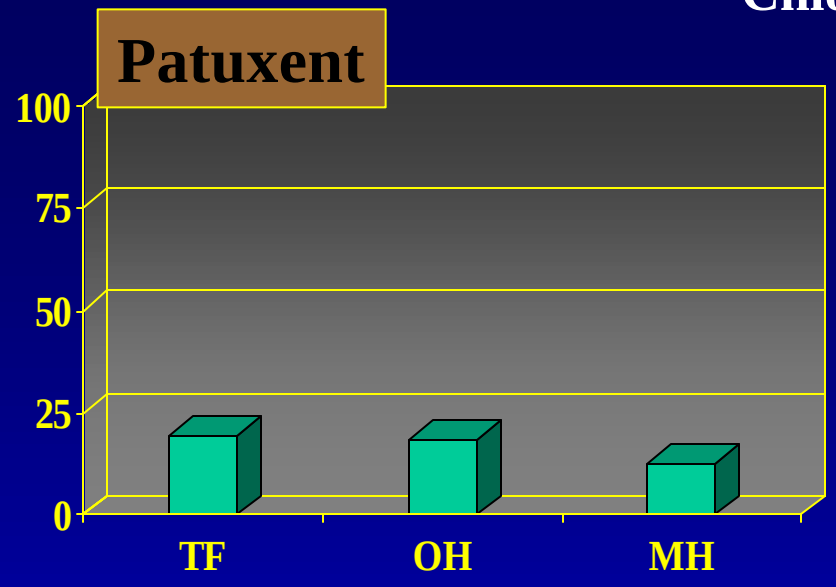


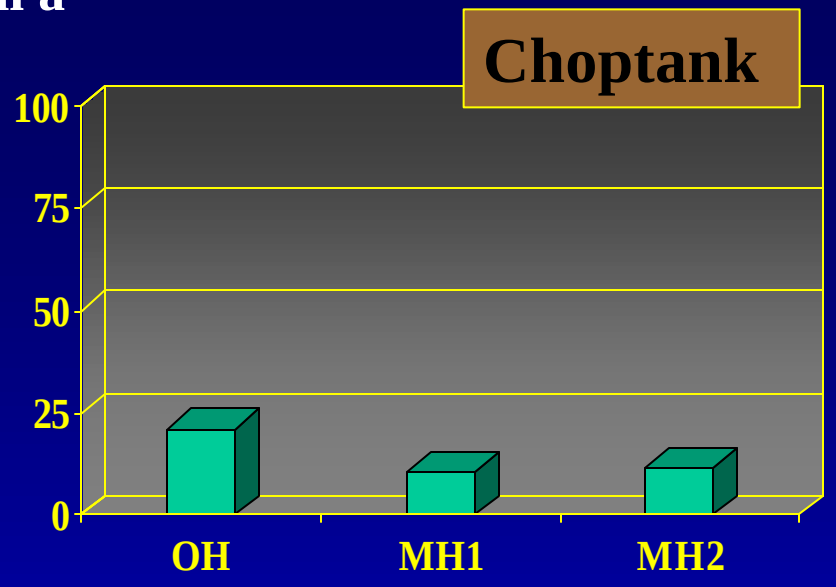


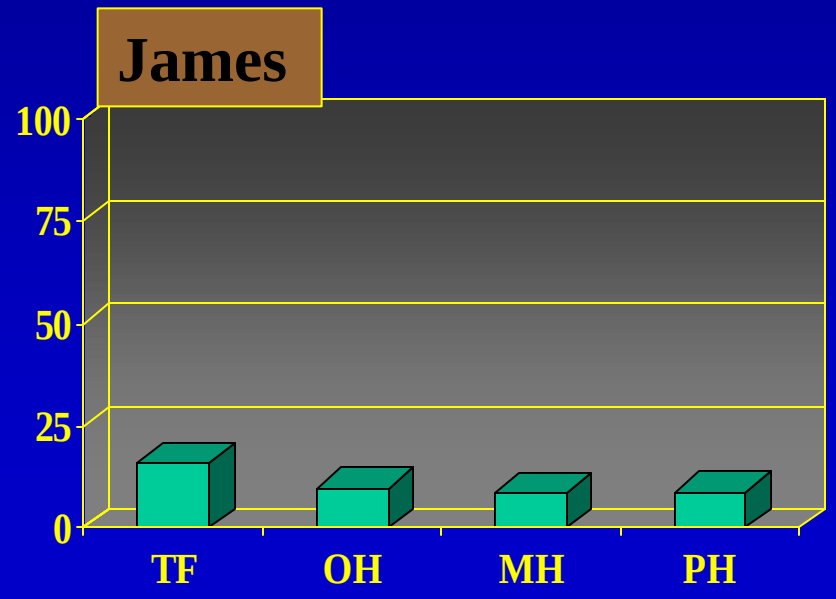


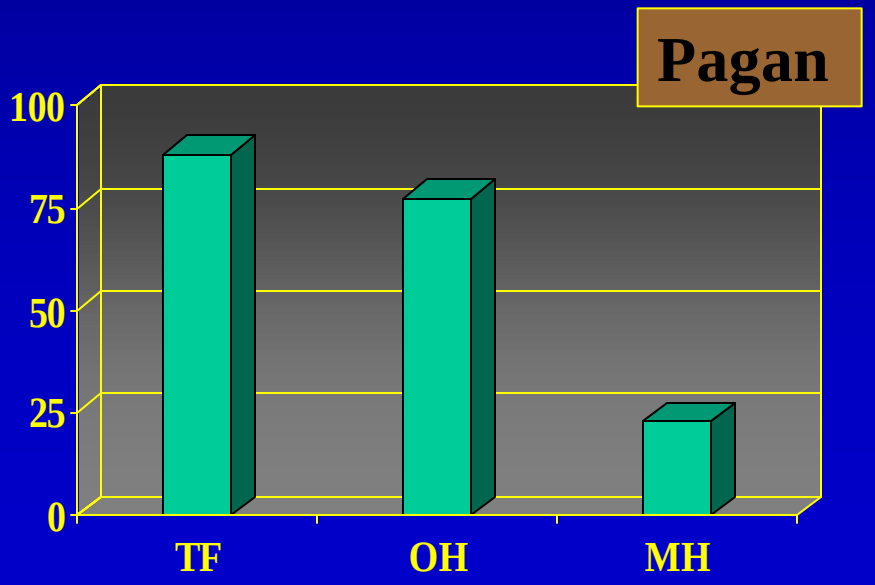


Chlorophyll a



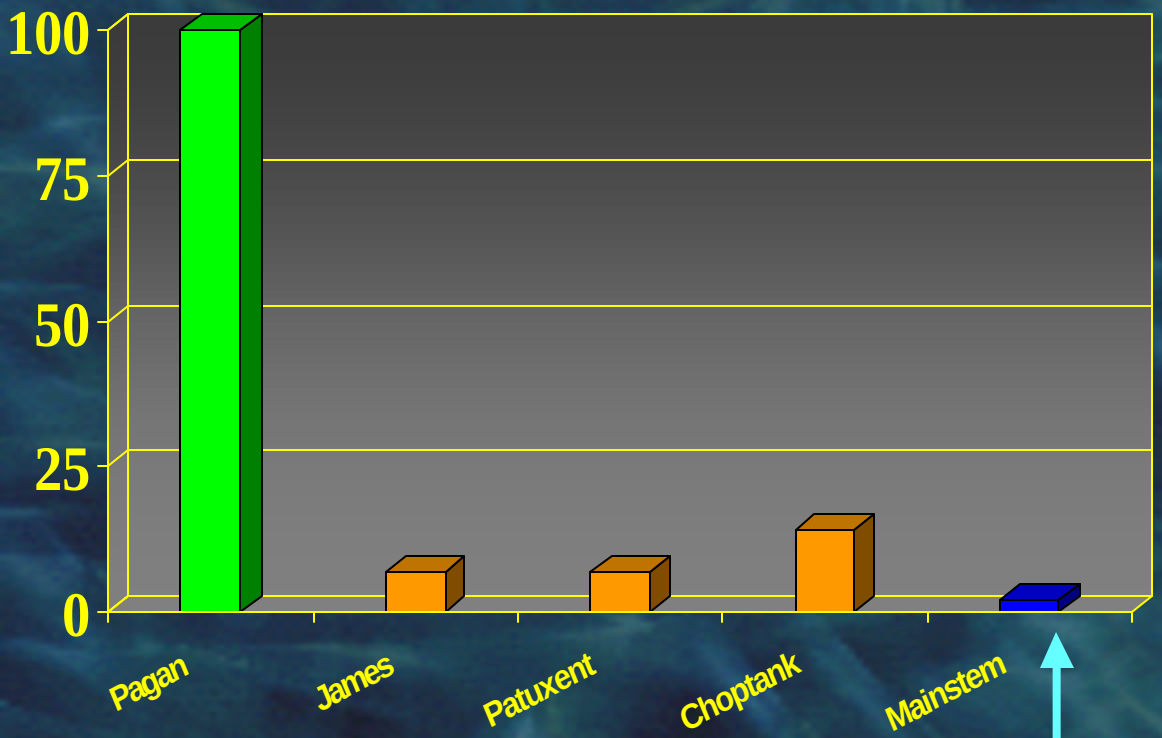






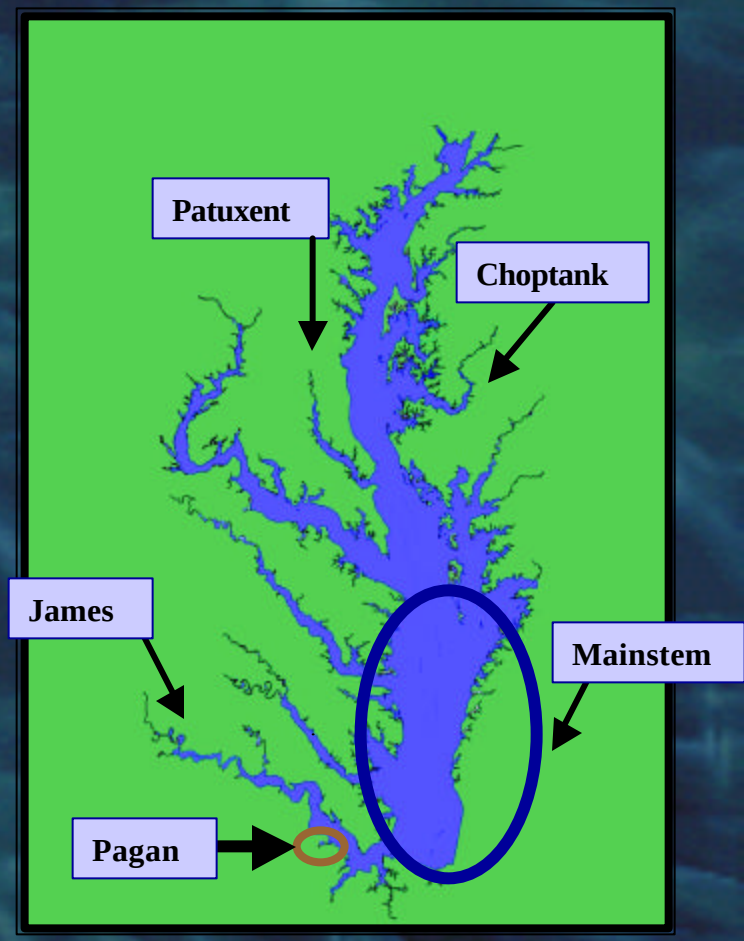
High nutrients and chlorophyll

Percentage of stratum with excessive abundance (organic enrichment)

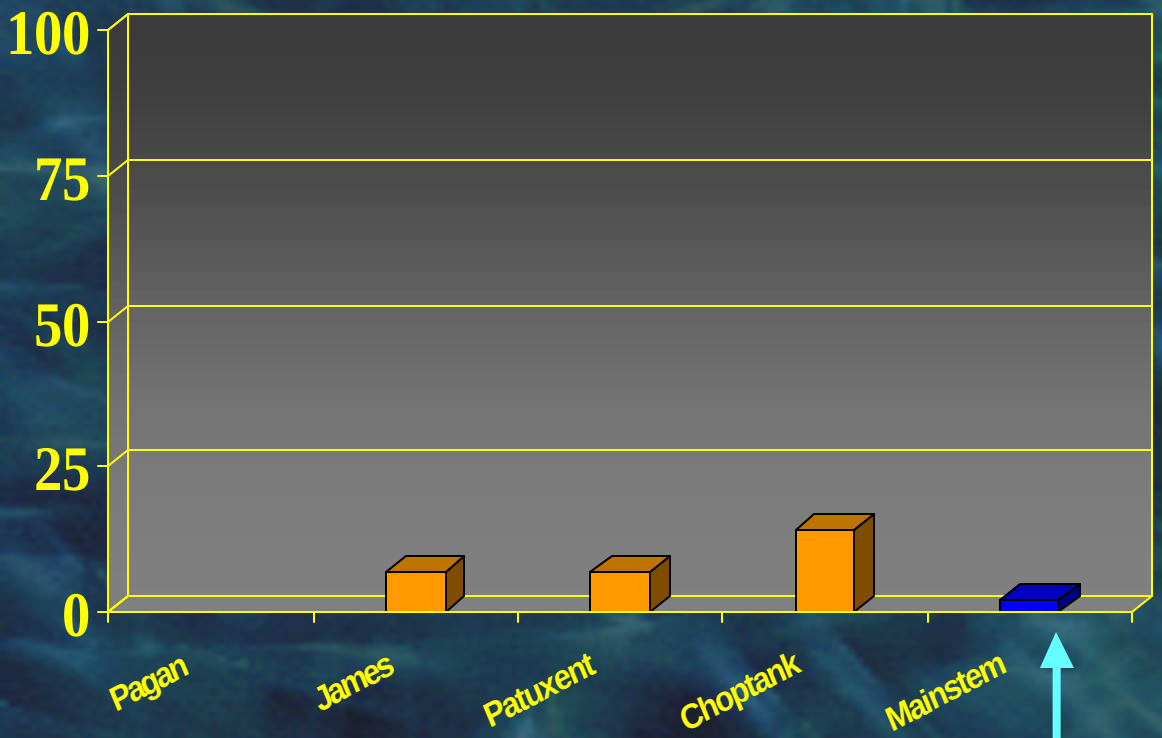


Tributaries

Low nutrients and chlorophyll

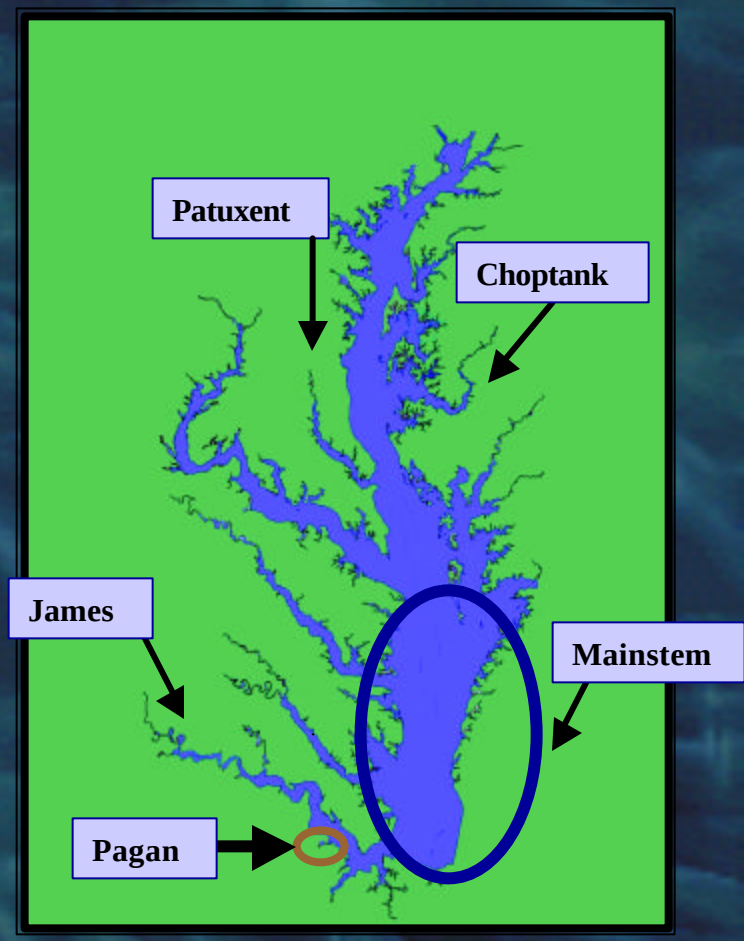


Percentage of stratum with excessive abundance (organic enrichment)

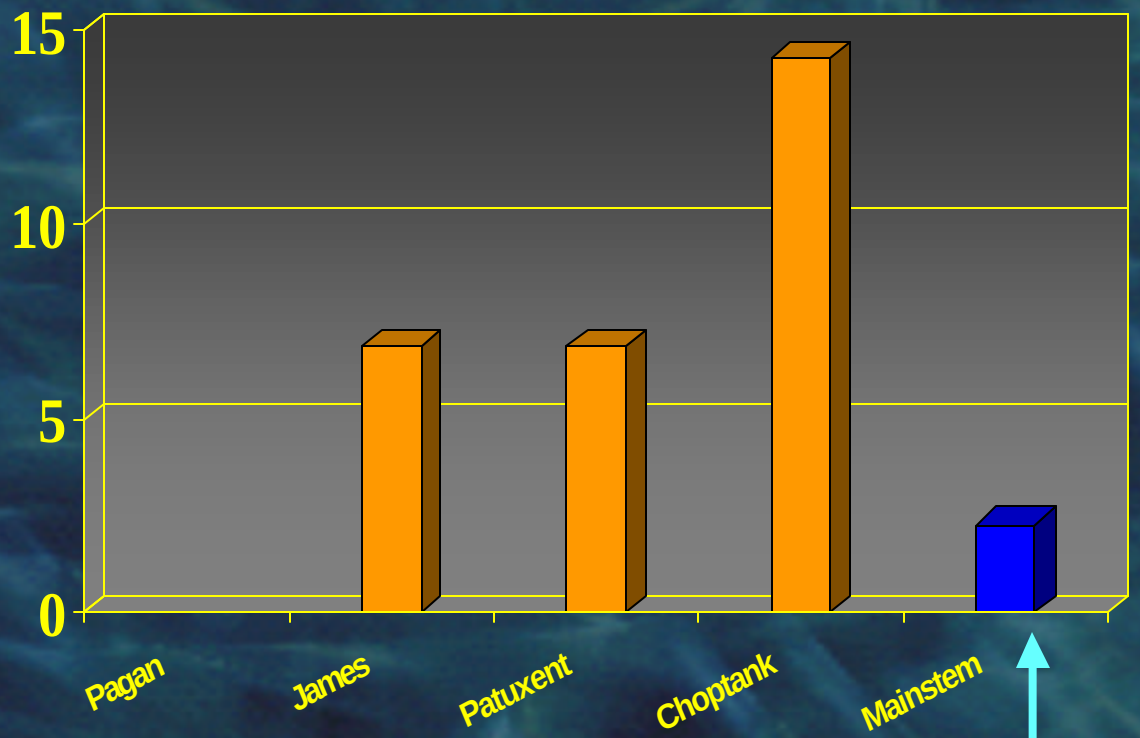


Tributaries

Low nutrients and chlorophyll

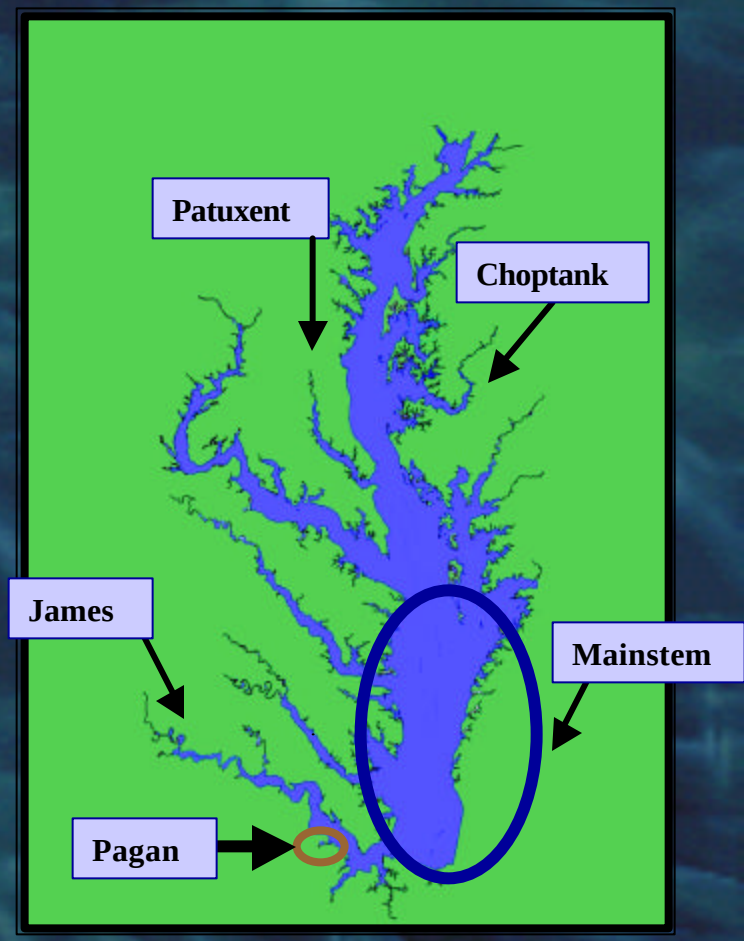


Percentage of stratum with excessive abundance (organic enrichment)



Tributaries

Low nutrients and chlorophyll



Insufficient abundance as an indicator of low dissolved oxygen

The Chesapeake Bay Benthic Experience

I. Program Accomplishments

II. Benthic Communities

III. Spatial patterns of degradation

A. By strata

B. At Bay scale

The Chesapeake Bay Benthic Experience

Spatial Patterns of degradation categories

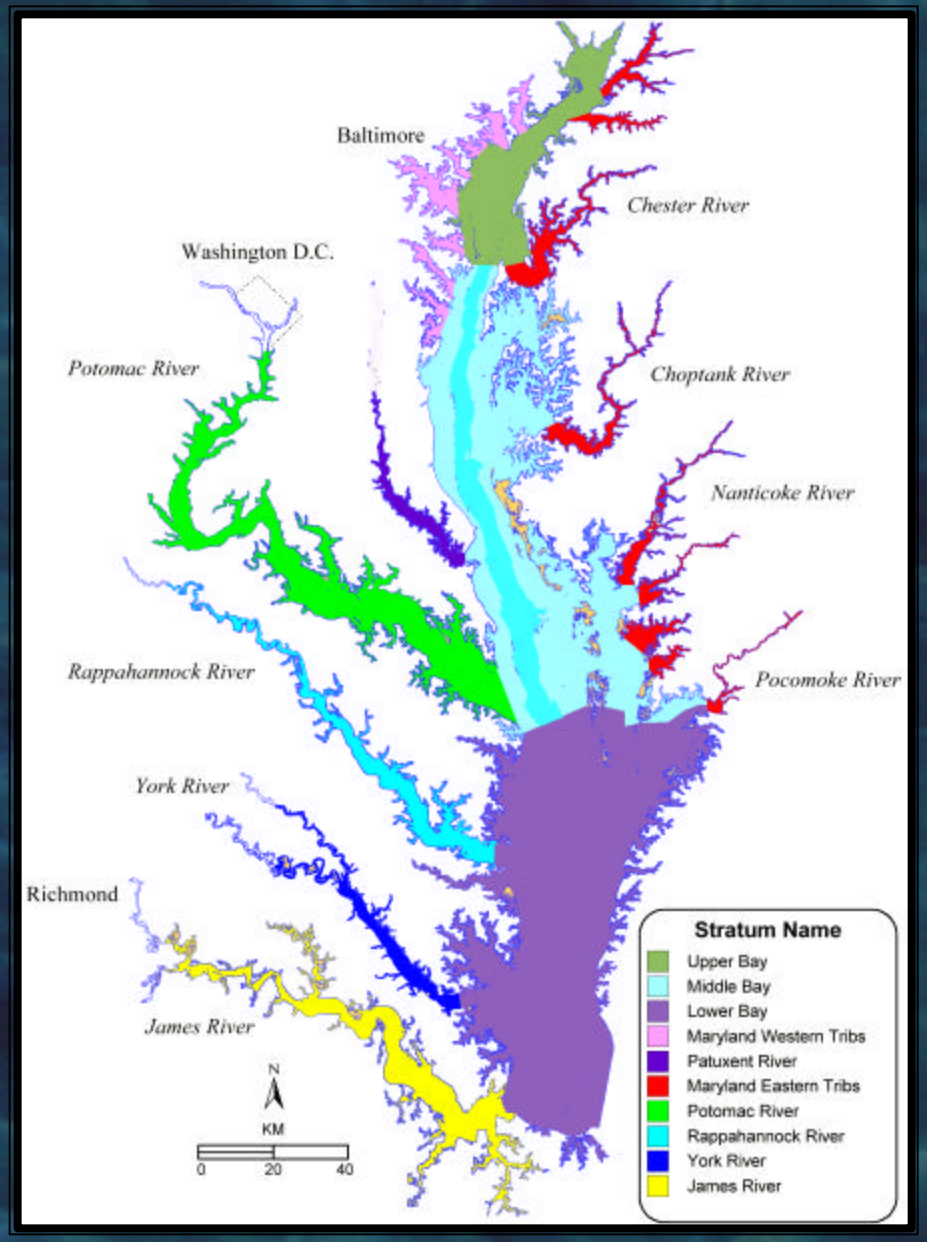
B-IBI designations of degradation

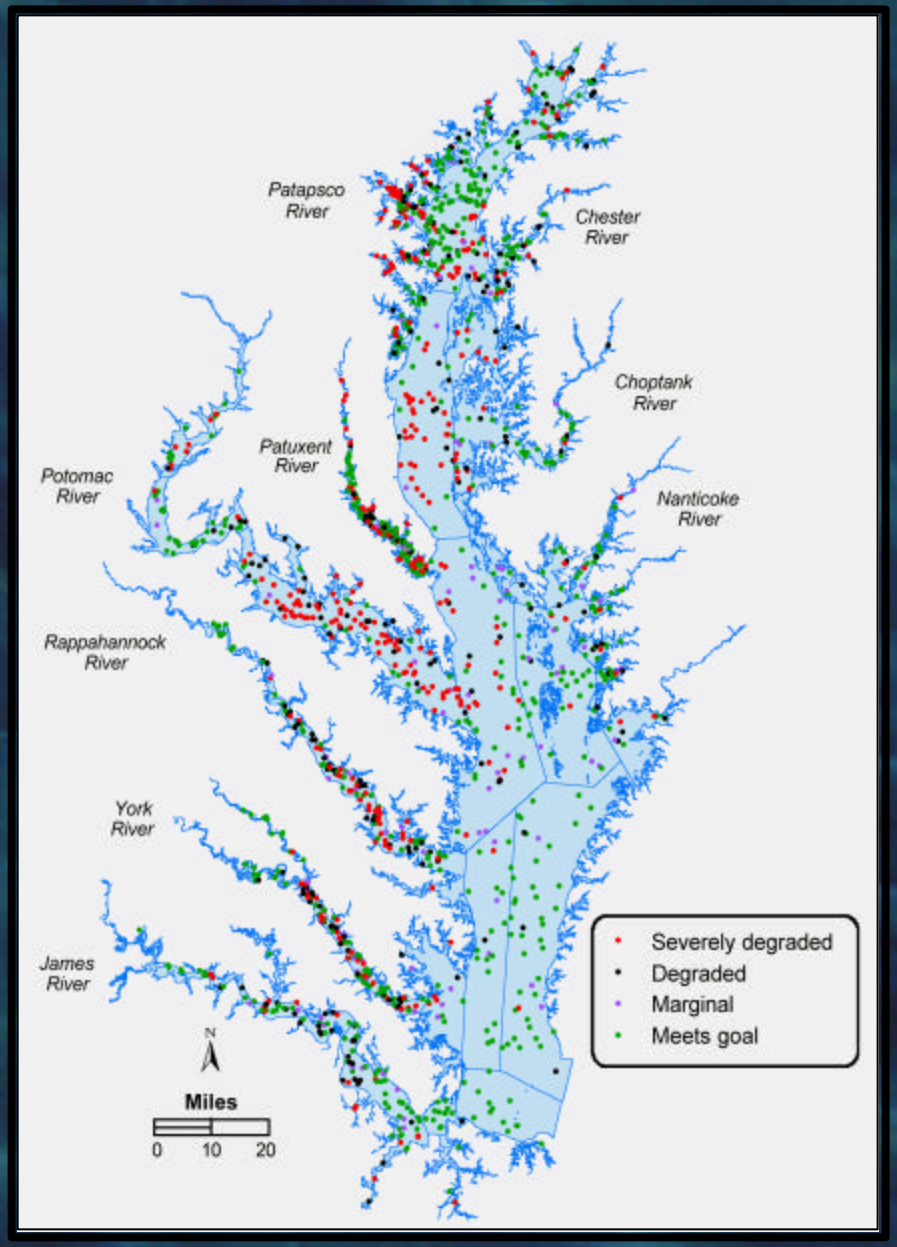
Random sampling

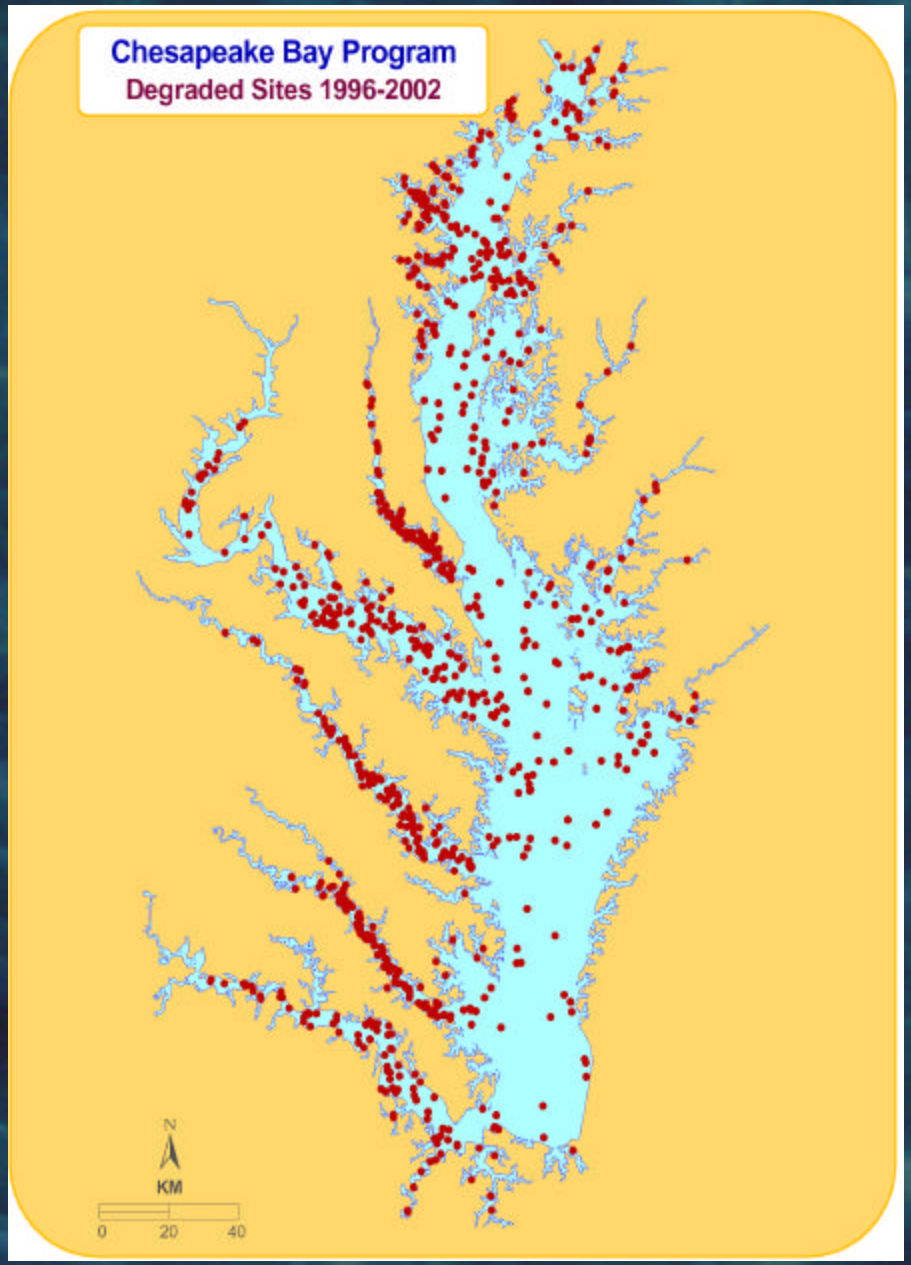
Contaminant DA approach

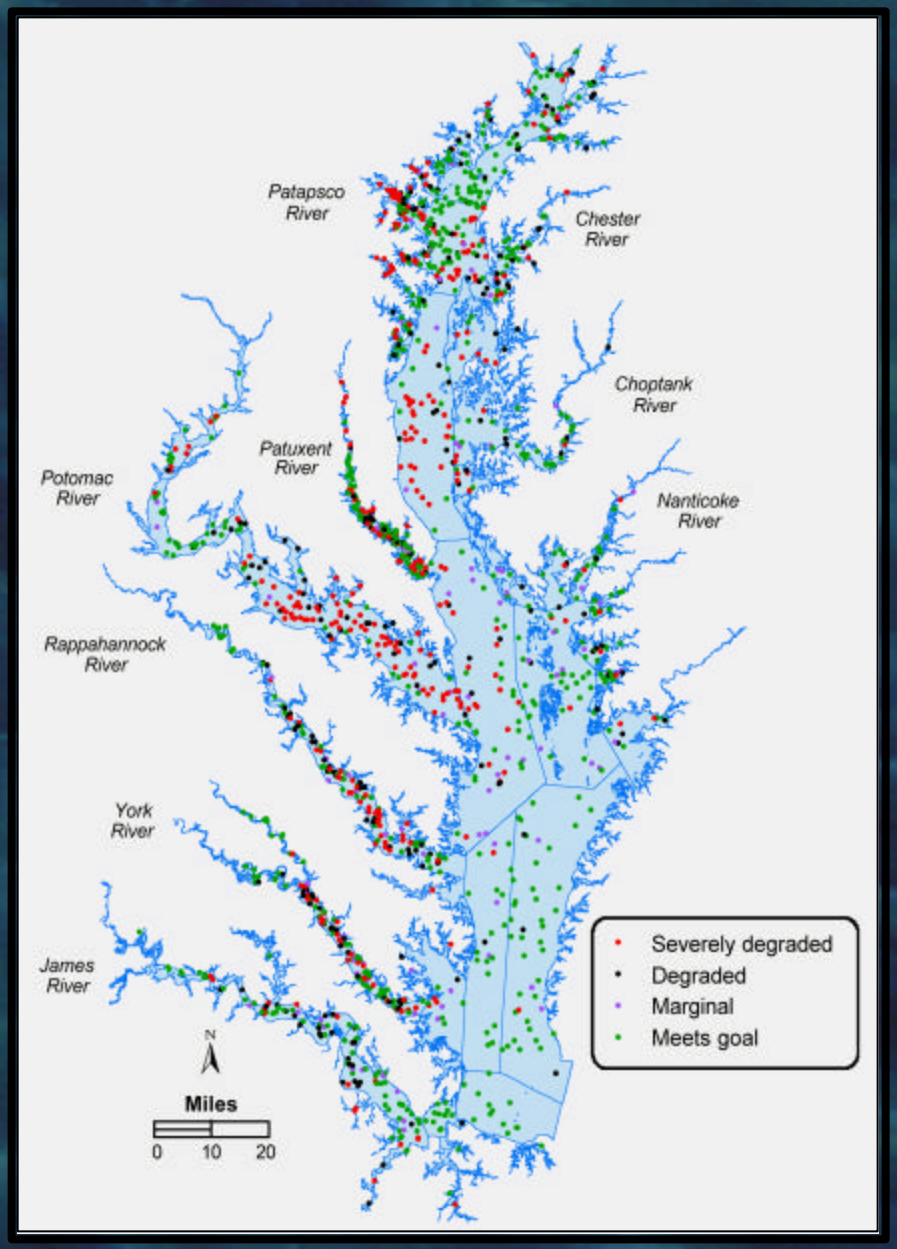
Excessive Abundance

Insufficient Abundance


Baltimore
Chester River
Washington D.C.
Potomac River
Choptank River
Nanticoke River
Rappahannock River
Pocomoke River
York River
Richmond
James River
N
KM
0
20
40
Stratum Name
Upper Bay
Middle Bay
Lower Bay
Maryland Western Tribs
Patuxent River
Maryland Eastern Tribs
Potomac River
Rappahannock River
York River
James River

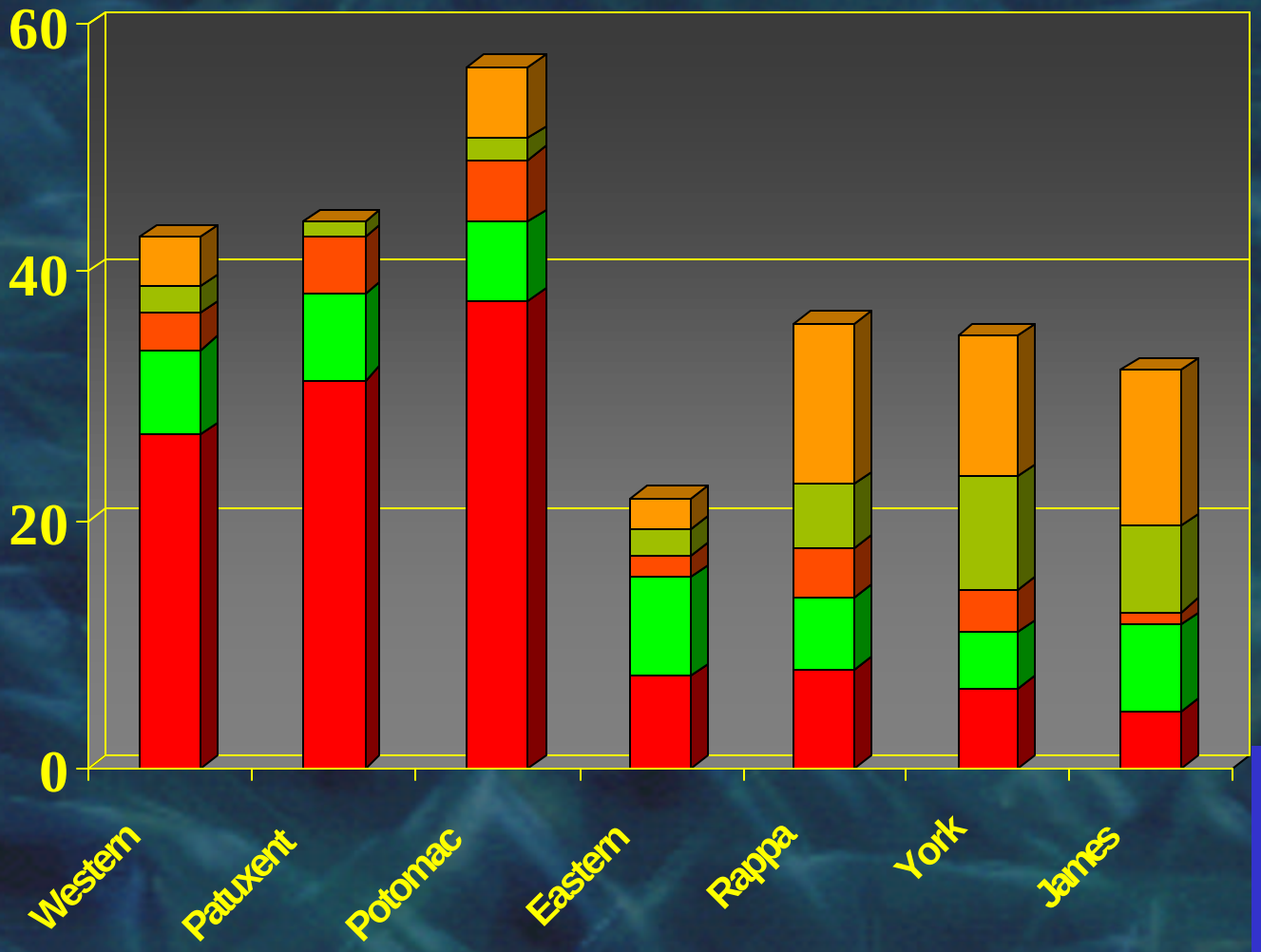

Patapsco River
Chester River
Choptank River
Patuxent River
Potomac River
Nanticoke River
Rappahannock River
York River
James River
N
Miles
0
10
20
Severely degraded
Degraded
Marginal
Meets goal

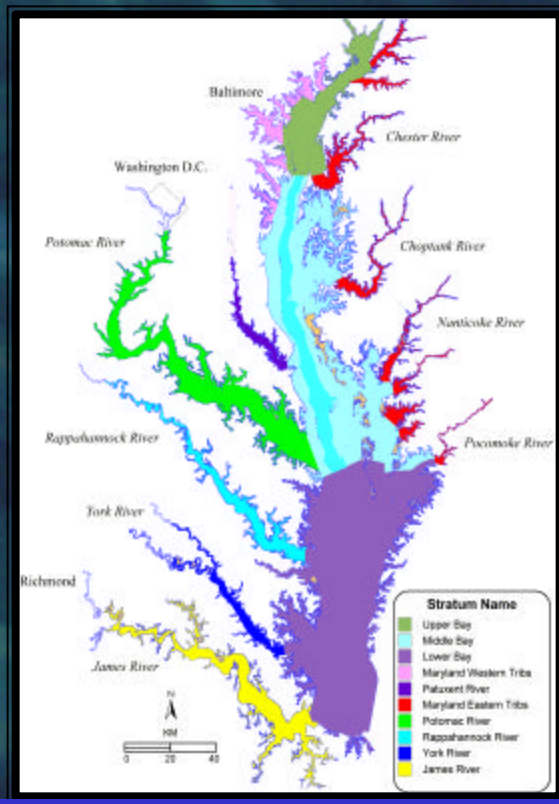

Chesapeake Bay Program
Degraded Sites 1996-2002
N
KM
0
20
40


Patapsco River
Chester River
Choptank River
Patuxent River
Potomac River
Nanticoke River
Rappahannock River
York River
James River
Severely degraded
Degraded
Marginal
Meets goal
N
Miles
0
10
20

Degradation Categories

All degradation categories in samples with a BIBI < 3.0

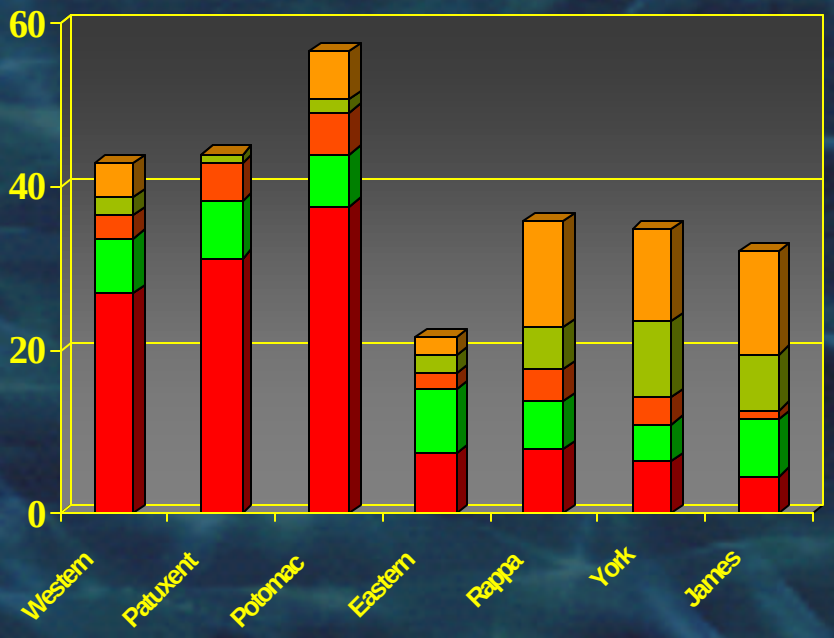




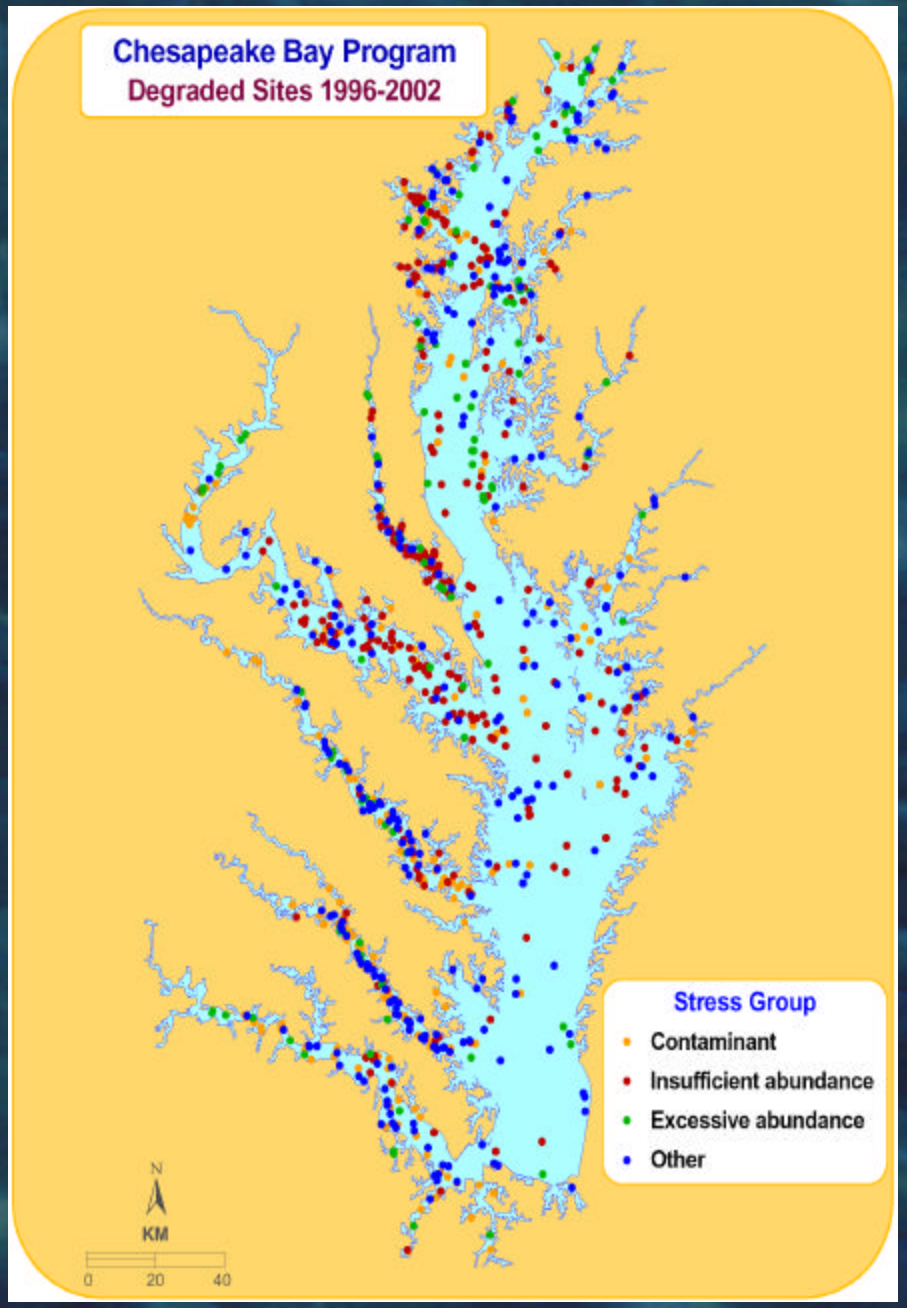
- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

Tributary strata

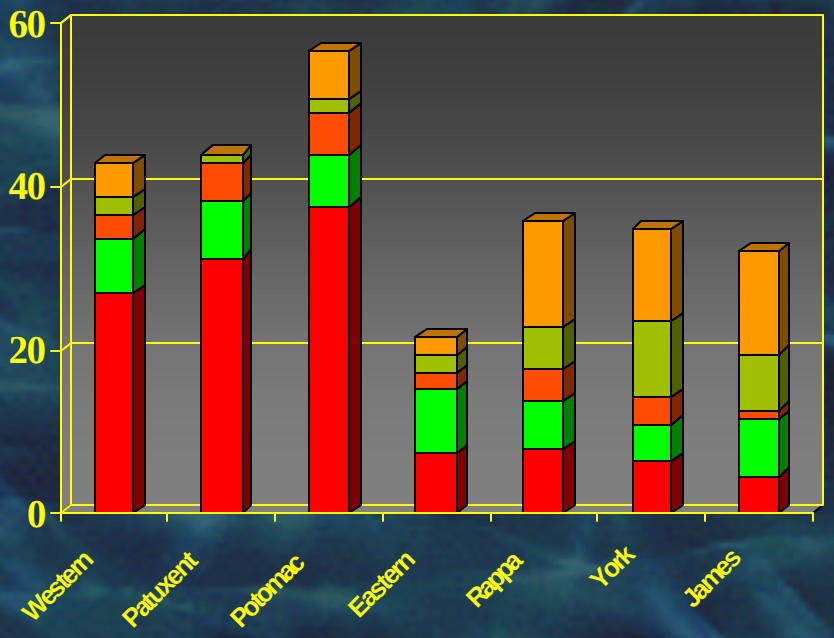
All degradation categories



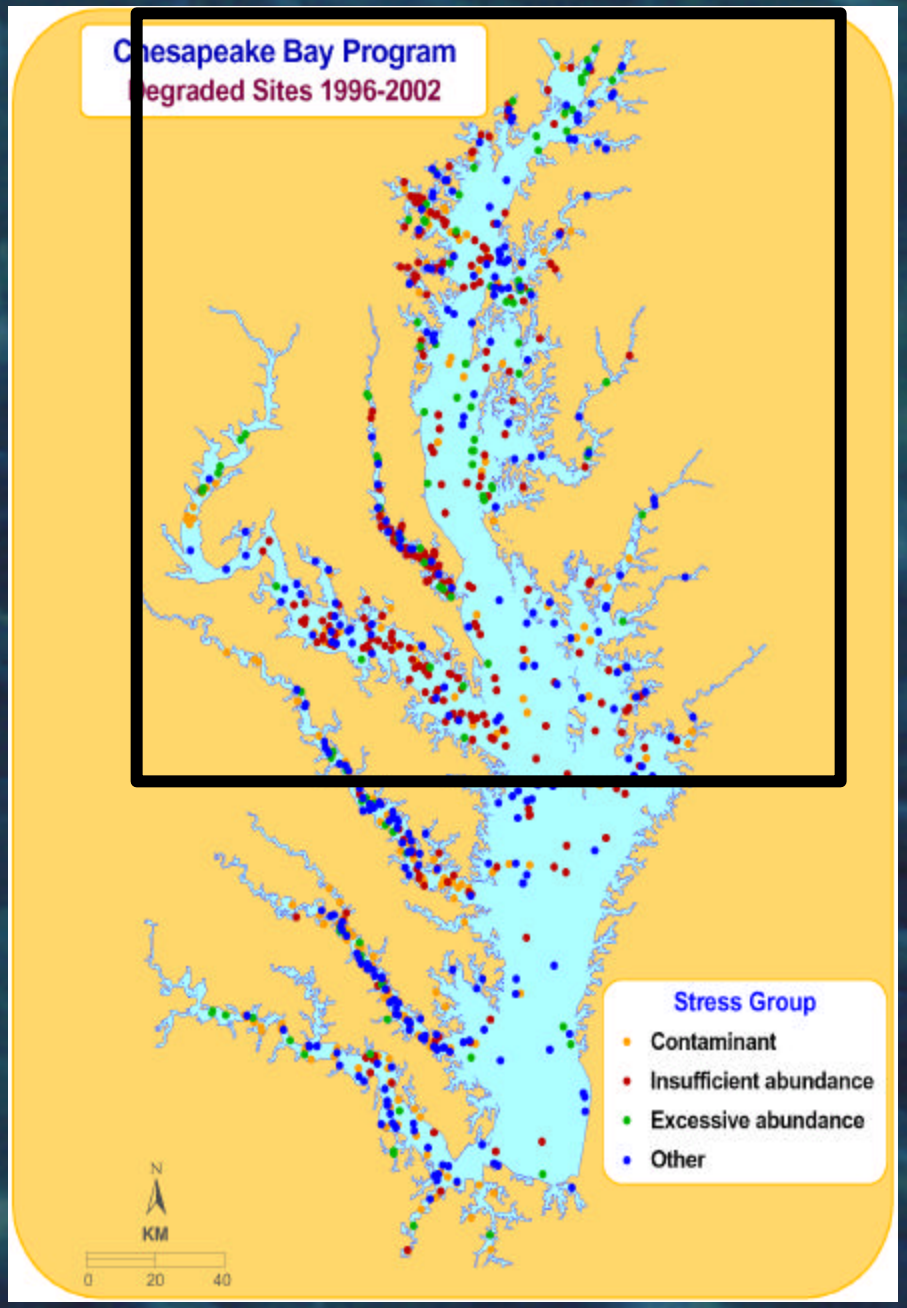
- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance



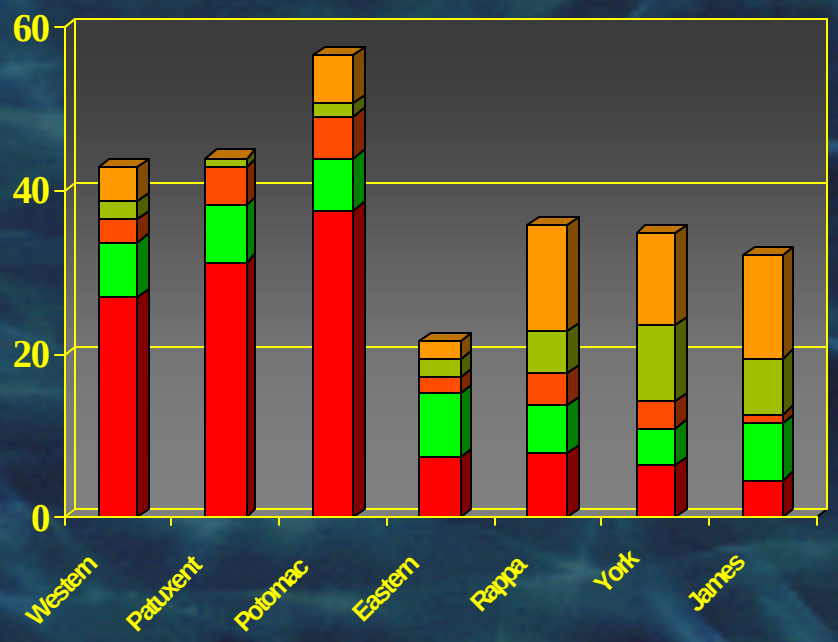
All degradation categories



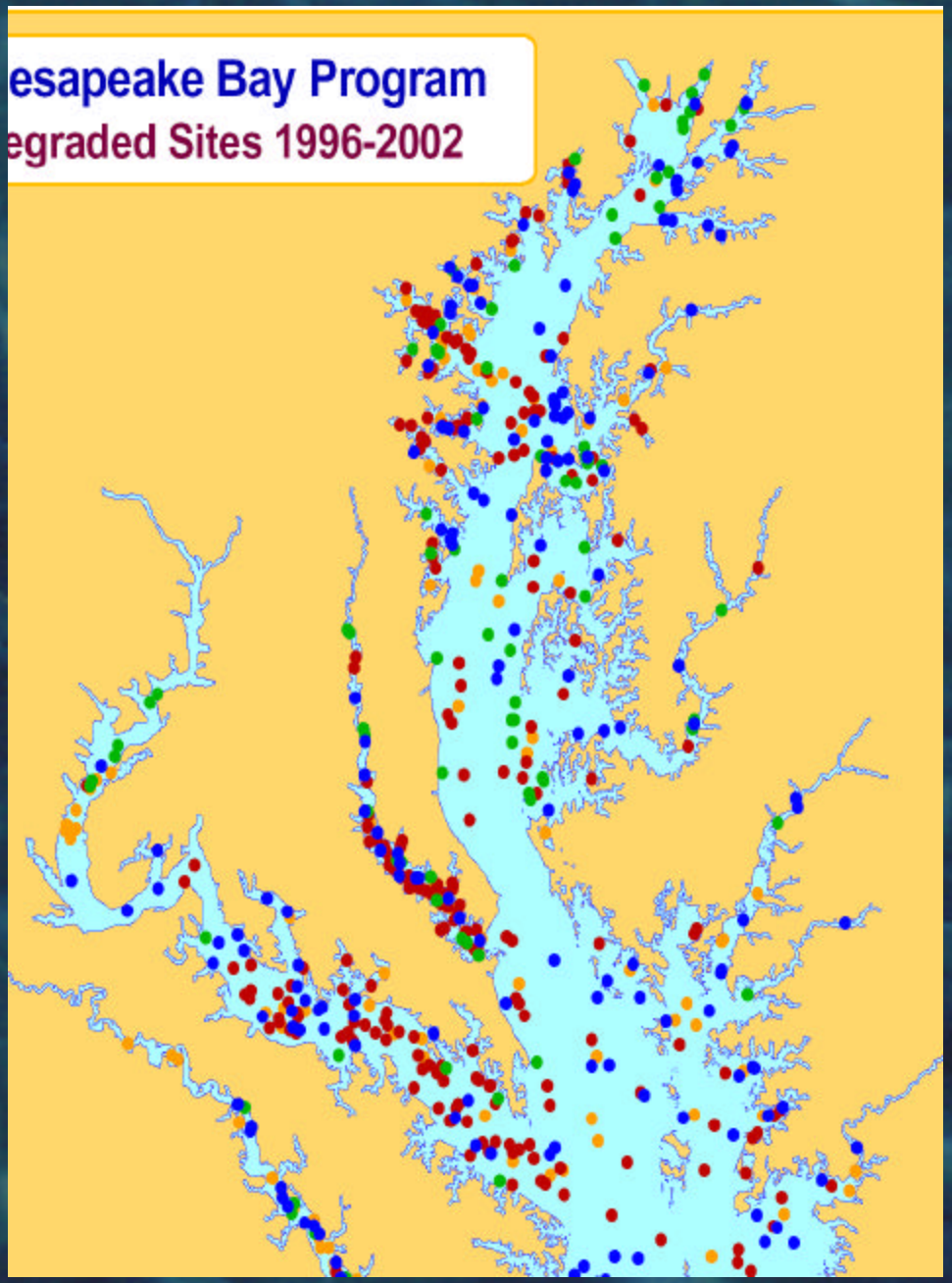
- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance



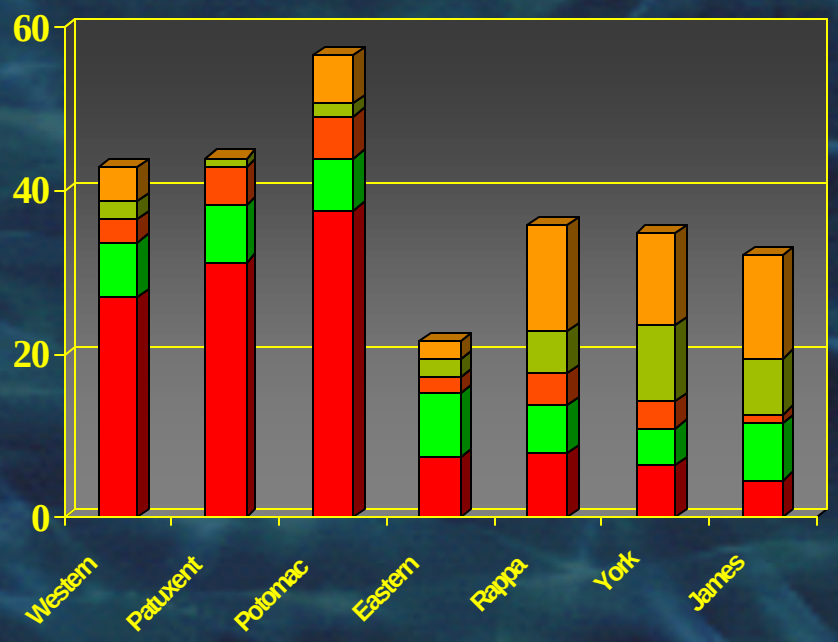
All degradation categories



- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance



All degradation categories



- Contaminant (Cont)
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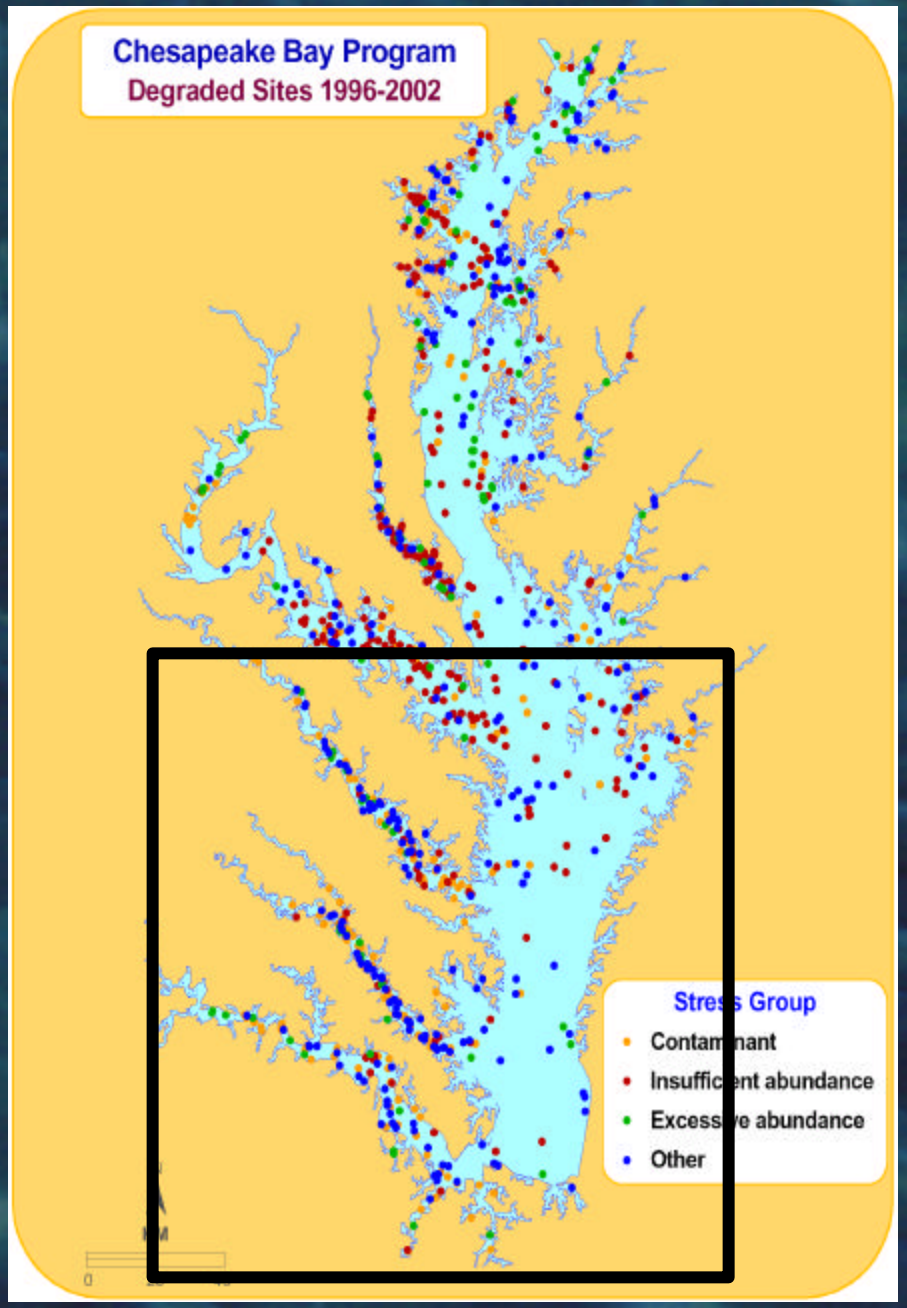
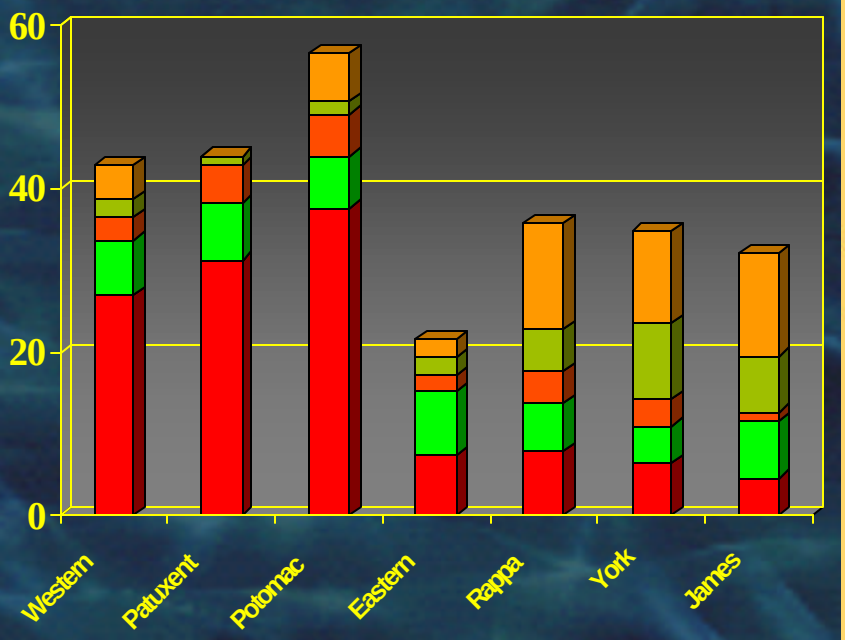
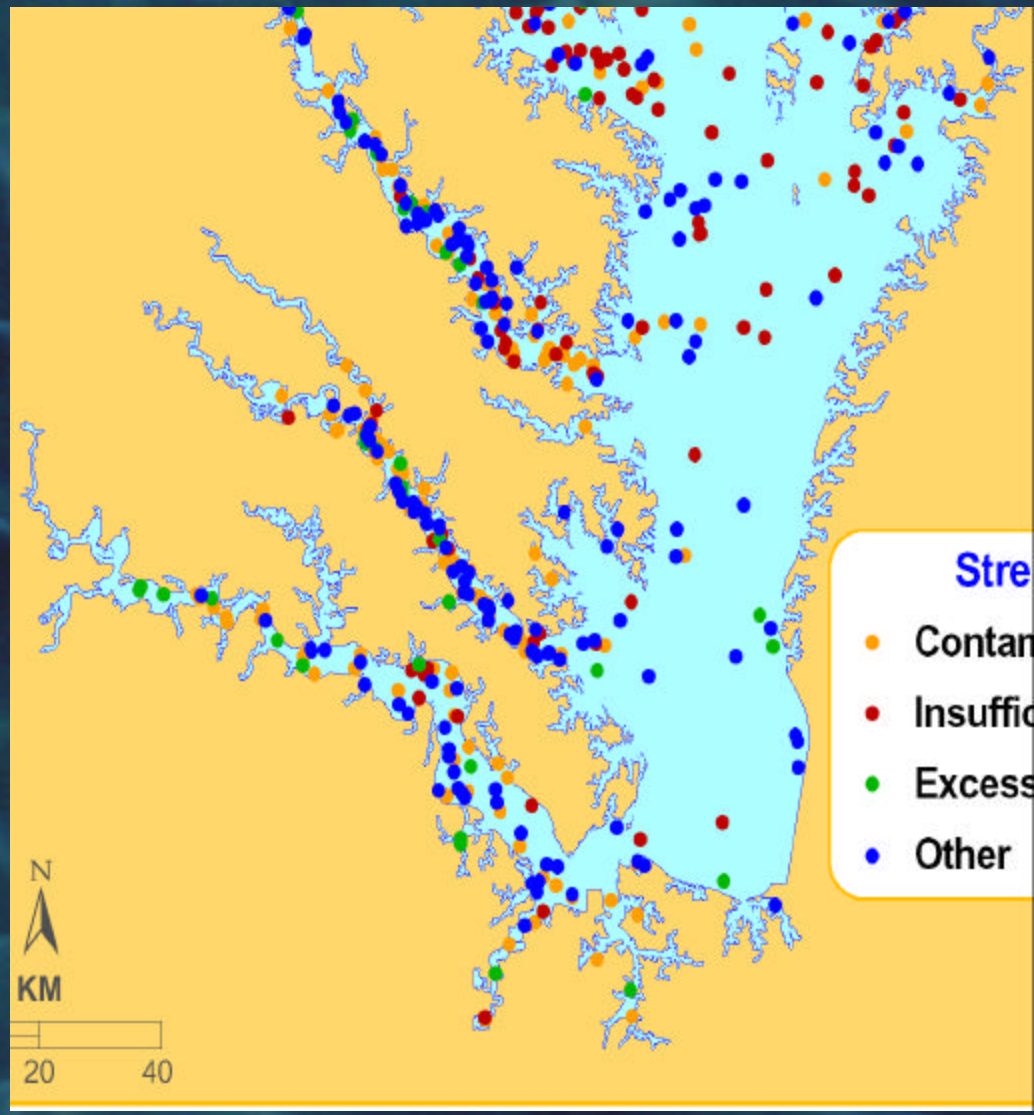
- Excessive Abundance
- Insufficient Abundance



All degradation categories

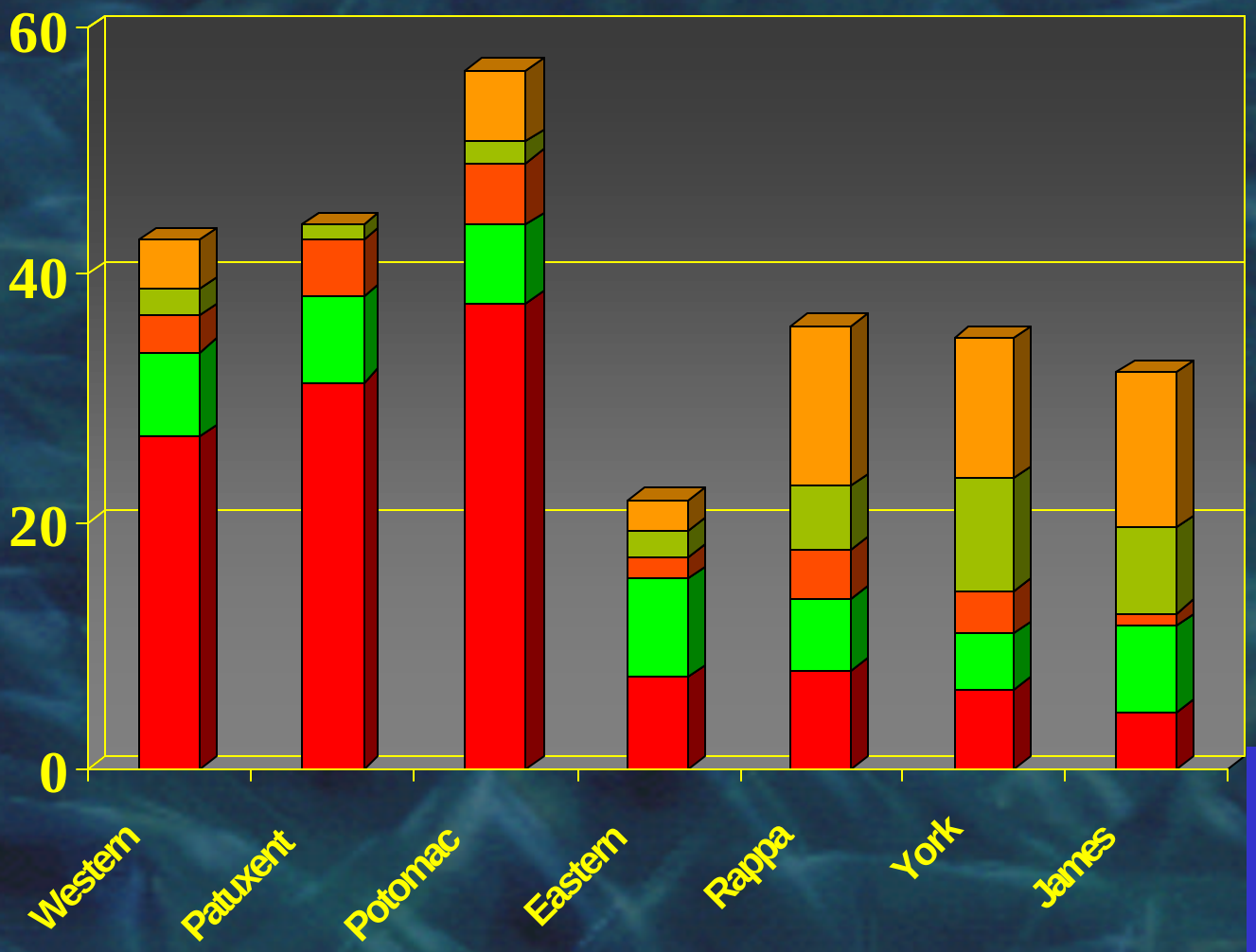


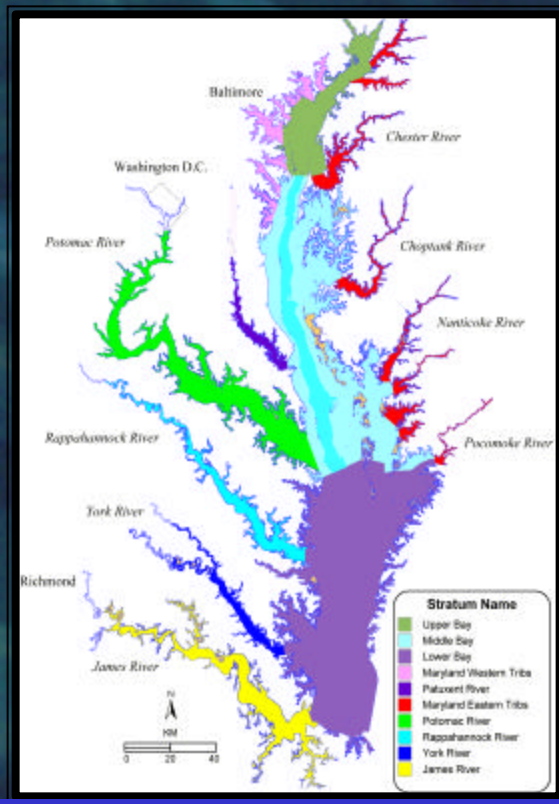
- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance



Degradation Categories

Contaminant effect (p > 0.9) in samples with a BIBI < 3.0



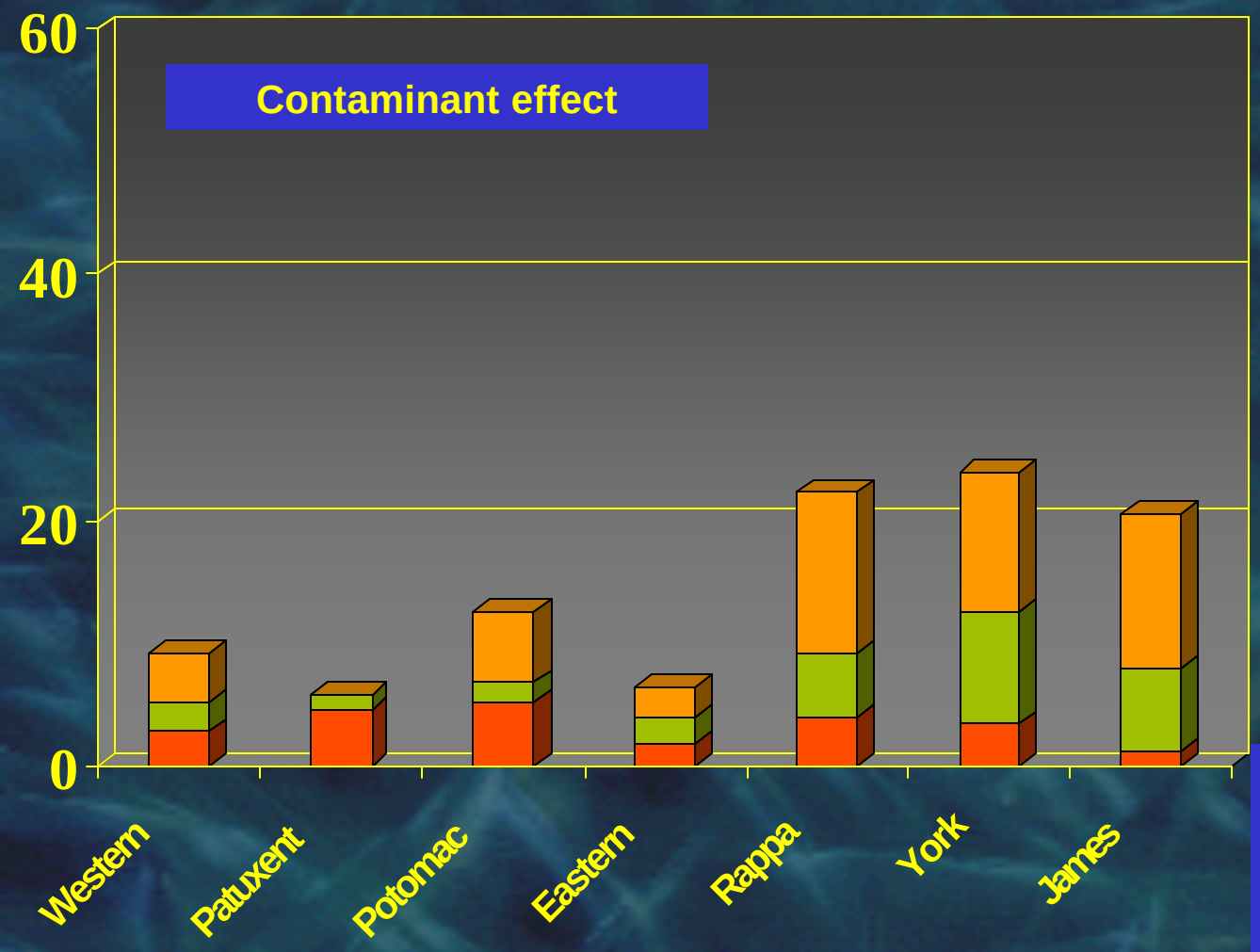


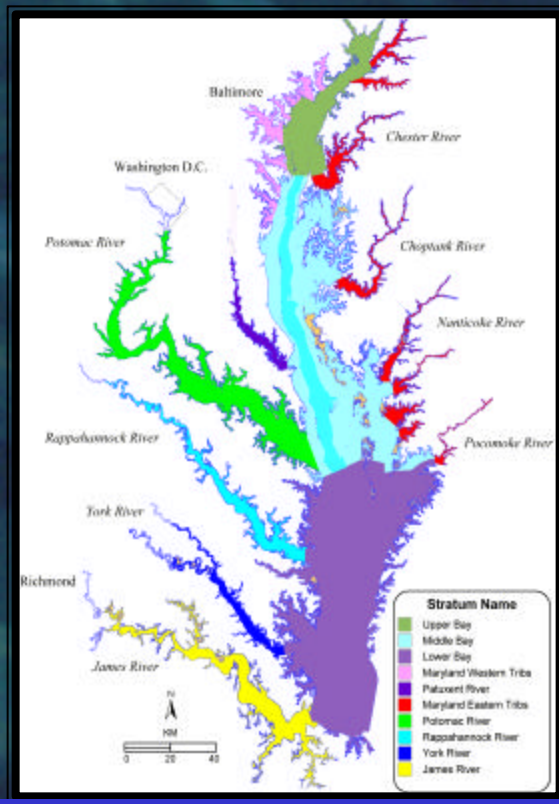
- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

Tributary strata

Degradation Categories

Contaminant effect ($p > 0.9$) in samples with a BIBI < 3.0





- Contaminant (Cont)
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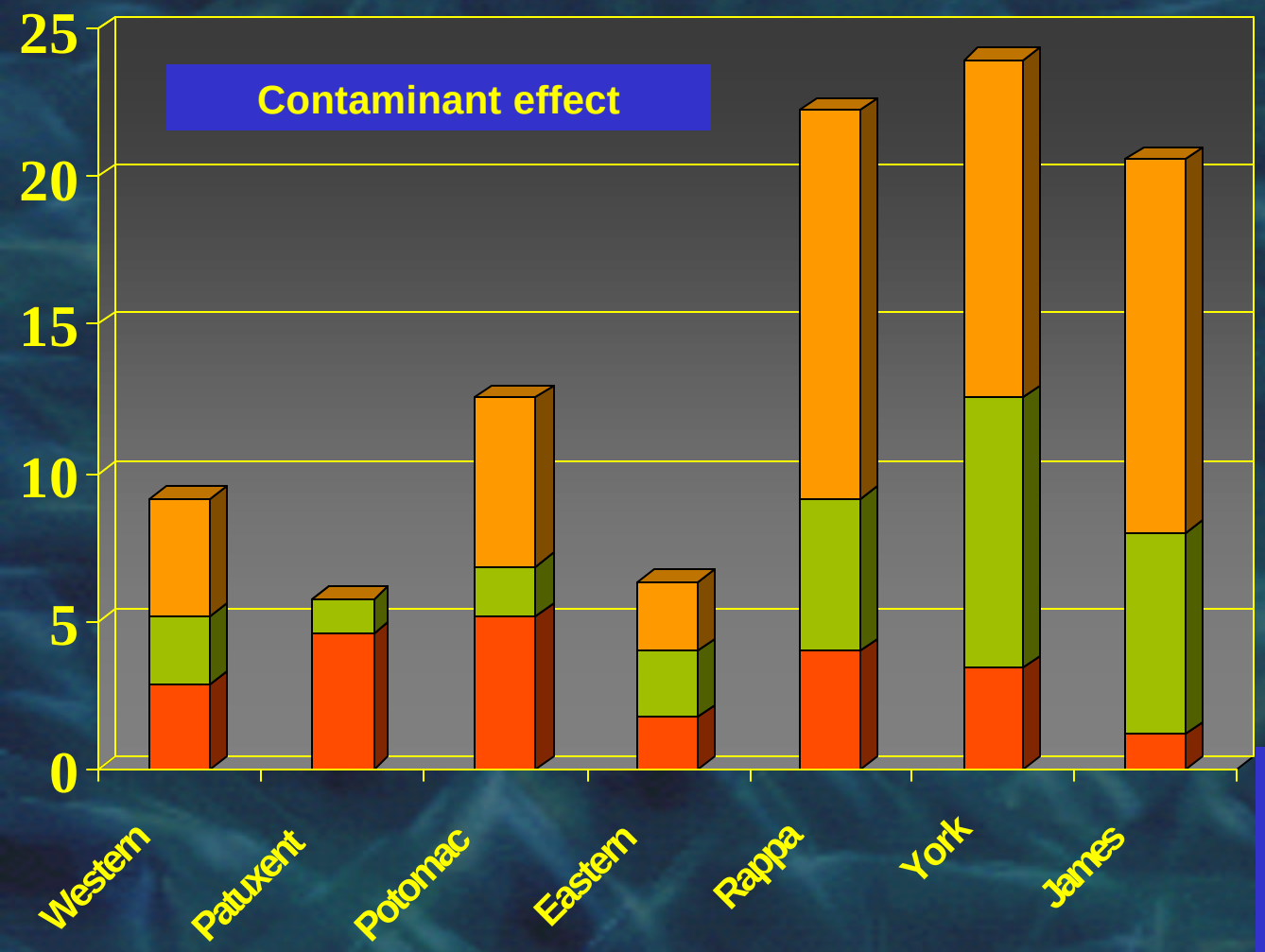
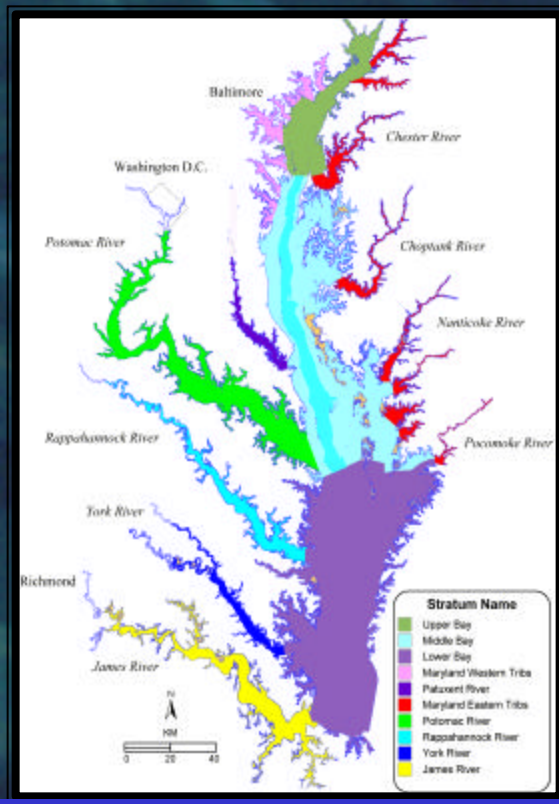
- Excessive Abundance
- Insufficient Abundance

Tributary strata

Degradation Categories

Contaminant effect ($p > 0.9$) in samples with a BIBI < 3.0





- Contaminant (Cont)
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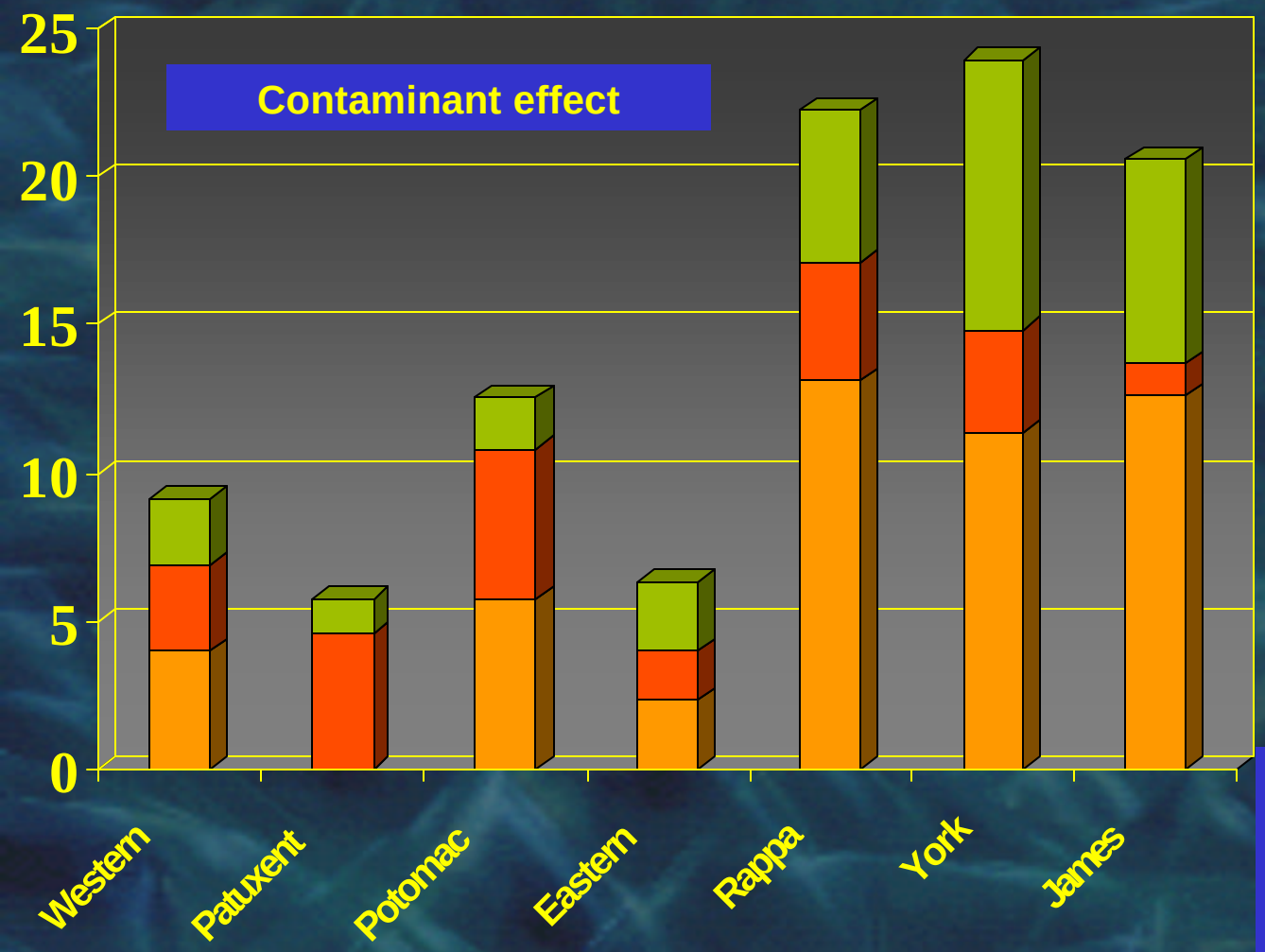
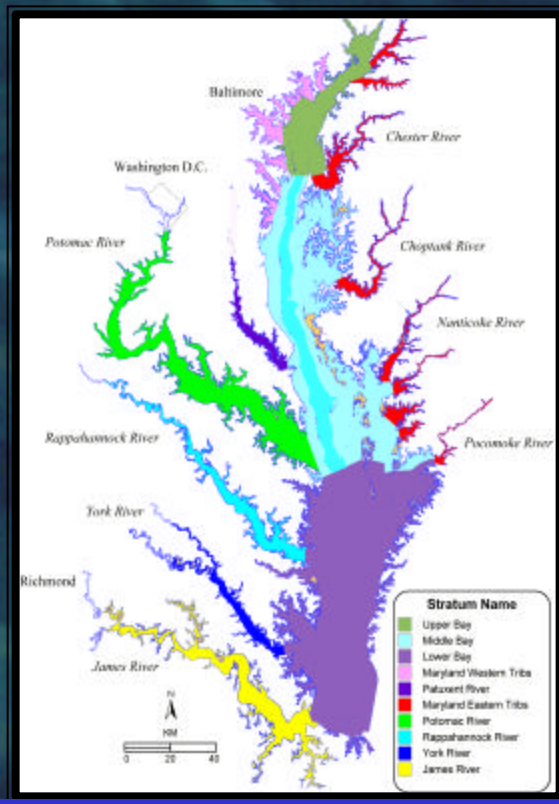
- Excessive Abundance
- Insufficient Abundance

Tributary strata

Degradation Categories

Contaminant effect ($p > 0.9$) in samples with a BIBI < 3.0





- Contaminant (Cont)
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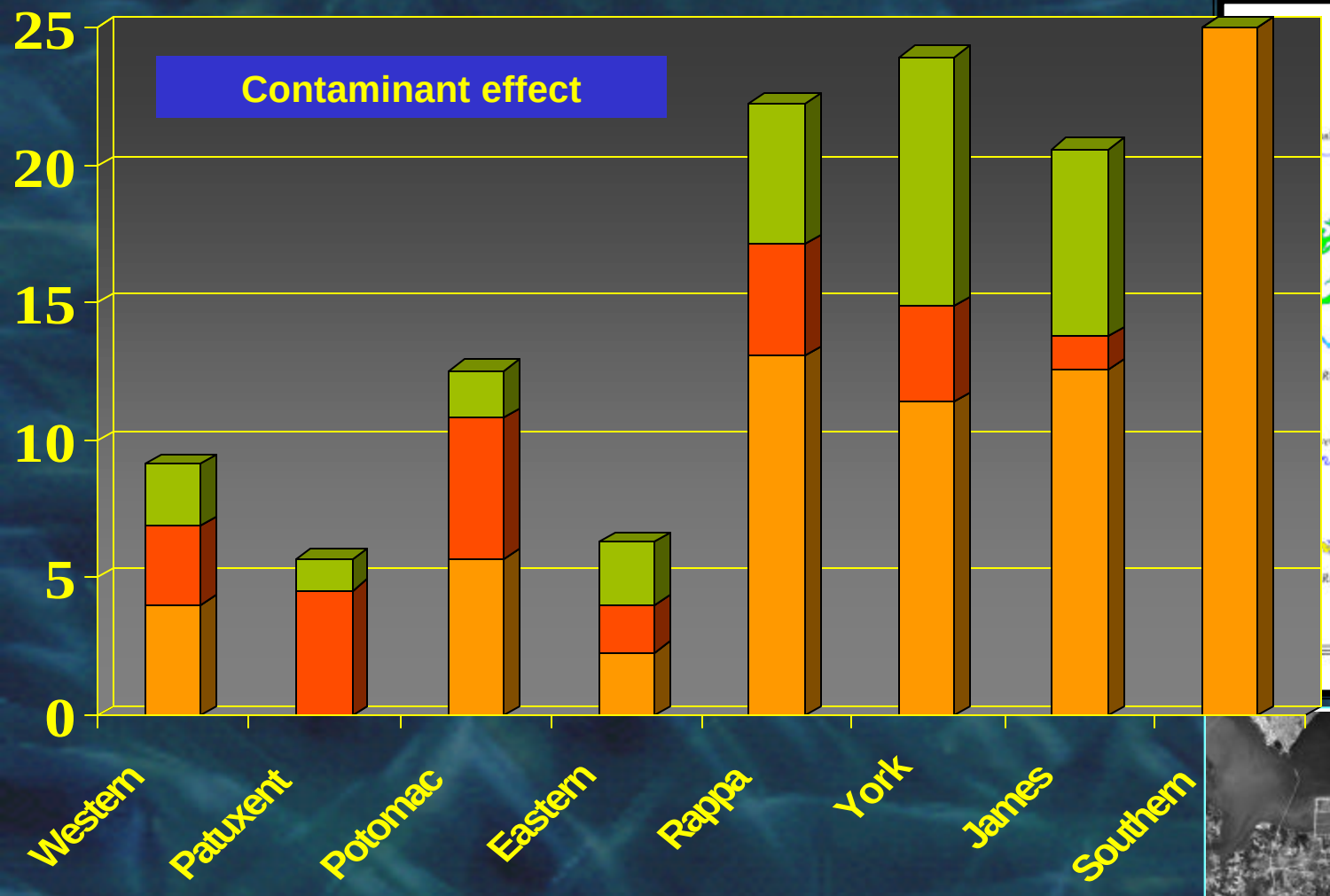
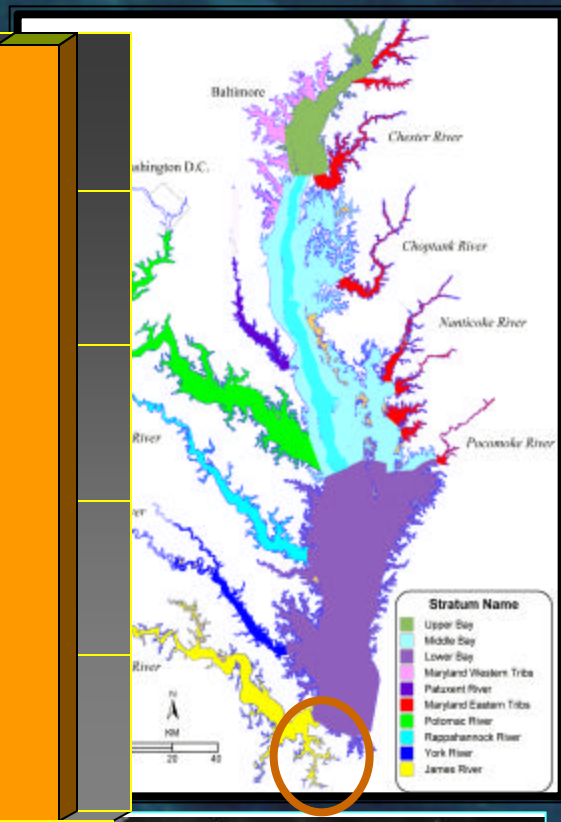
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

Tributary strata

Degradation Categories

Contaminant effect (p > 0.9) in samples with a BIBI < 3.0



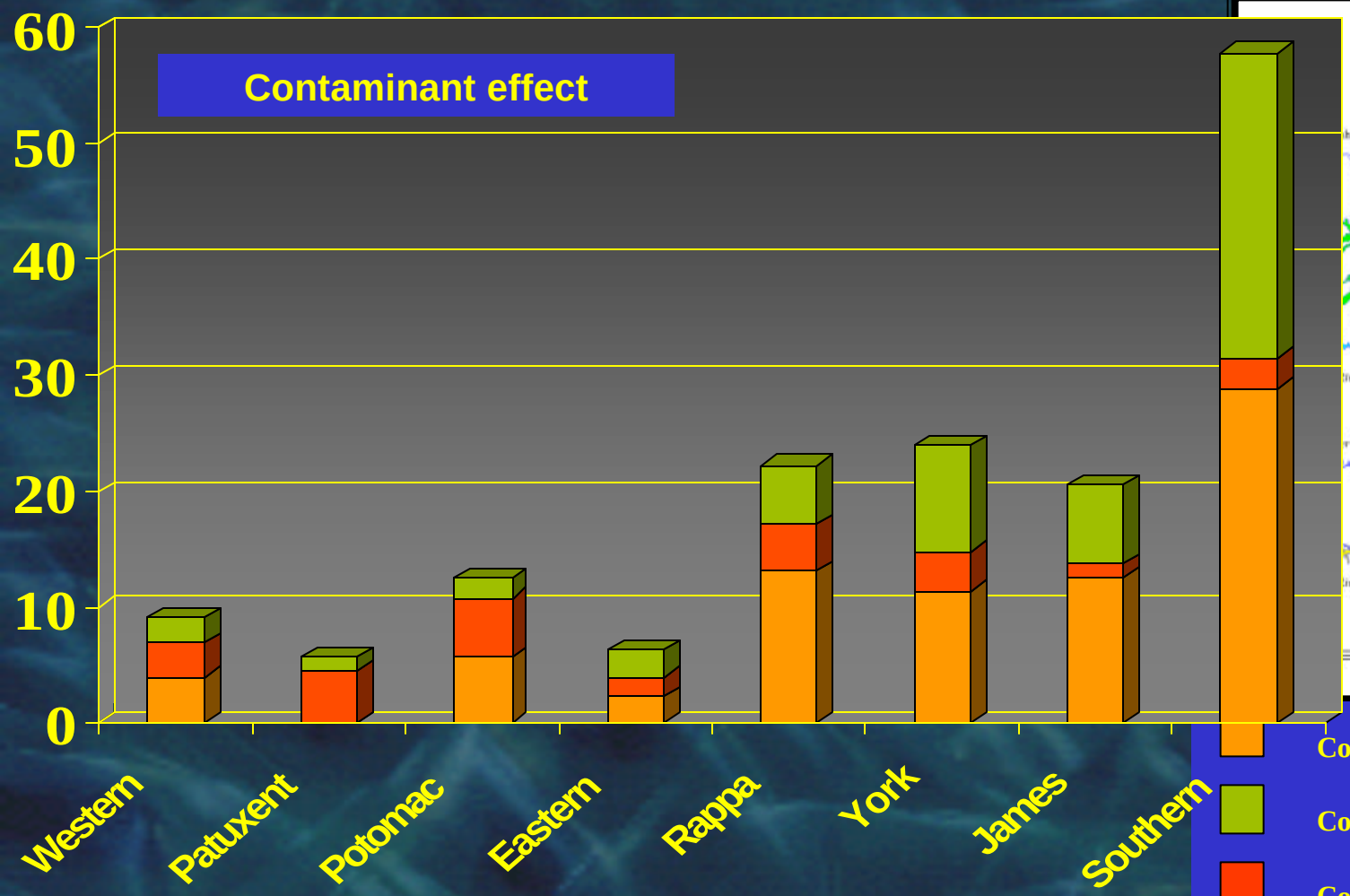


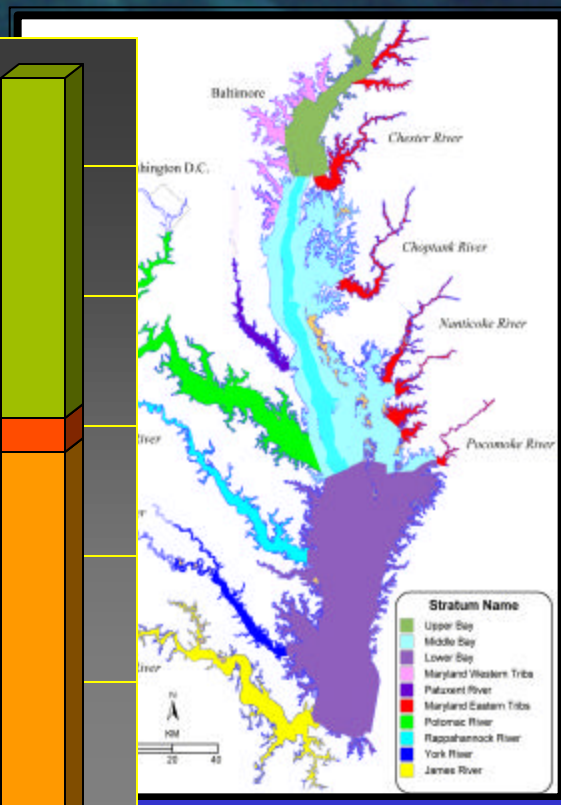
Elizabeth River watershed

Tributary strata

Degradation Categories

Contaminant effect (p > 0.9) in samples with a BIBI < 3.0

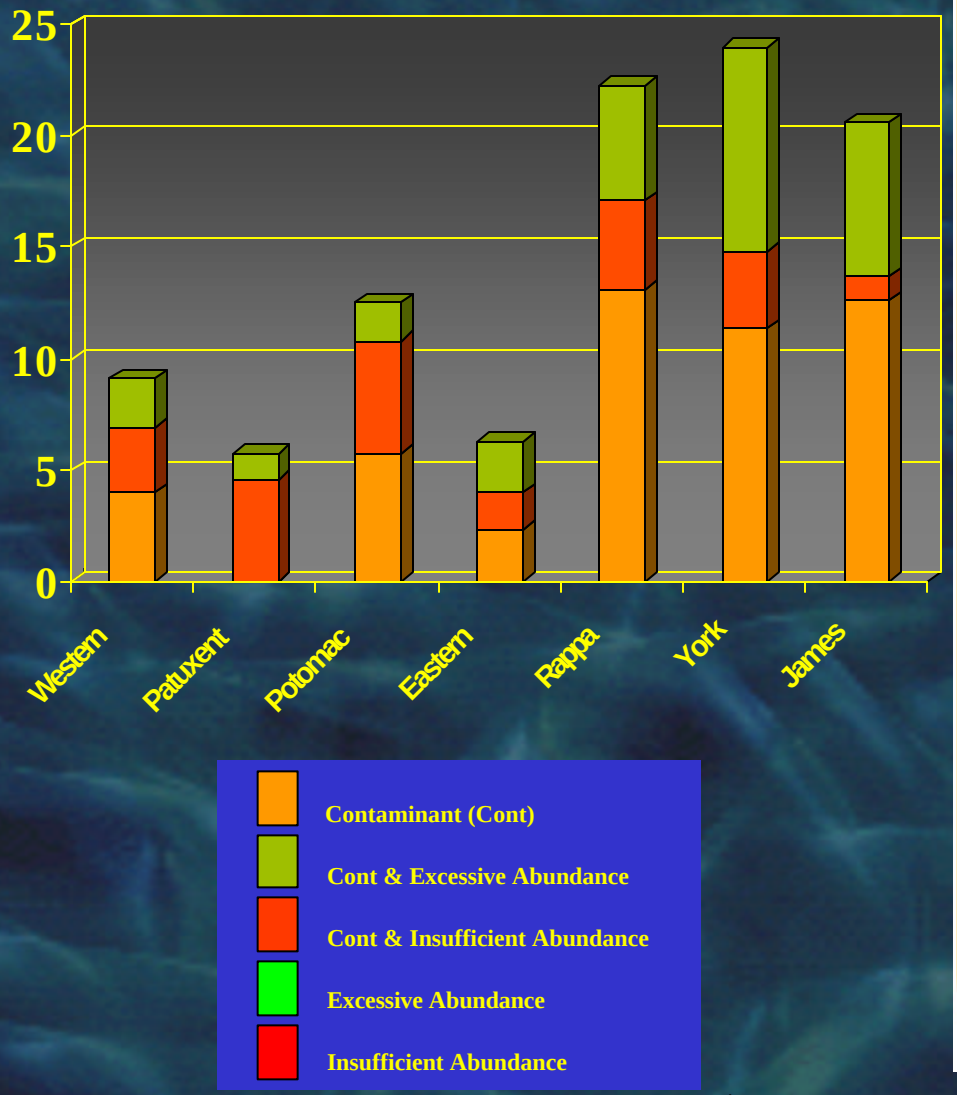


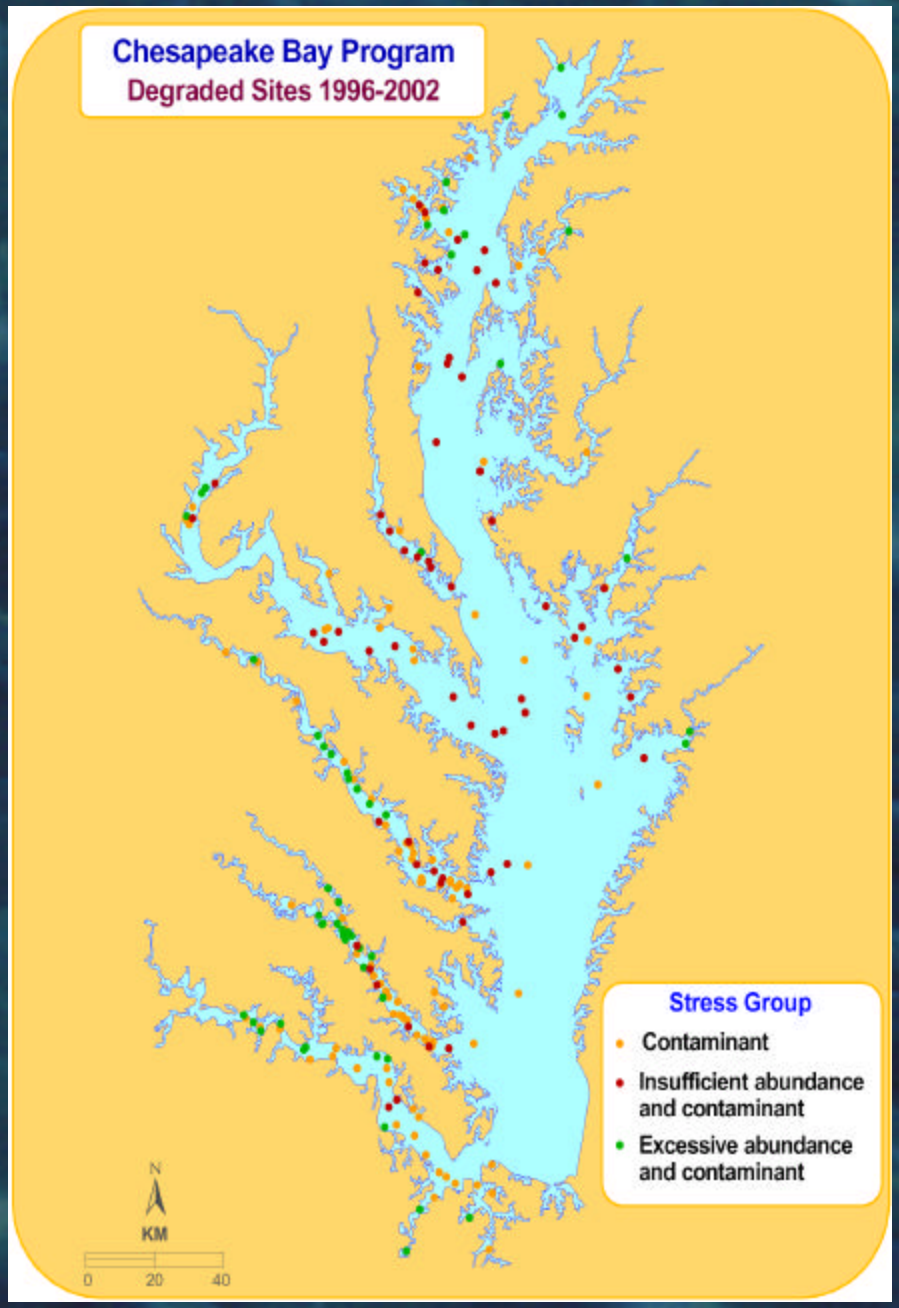


- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

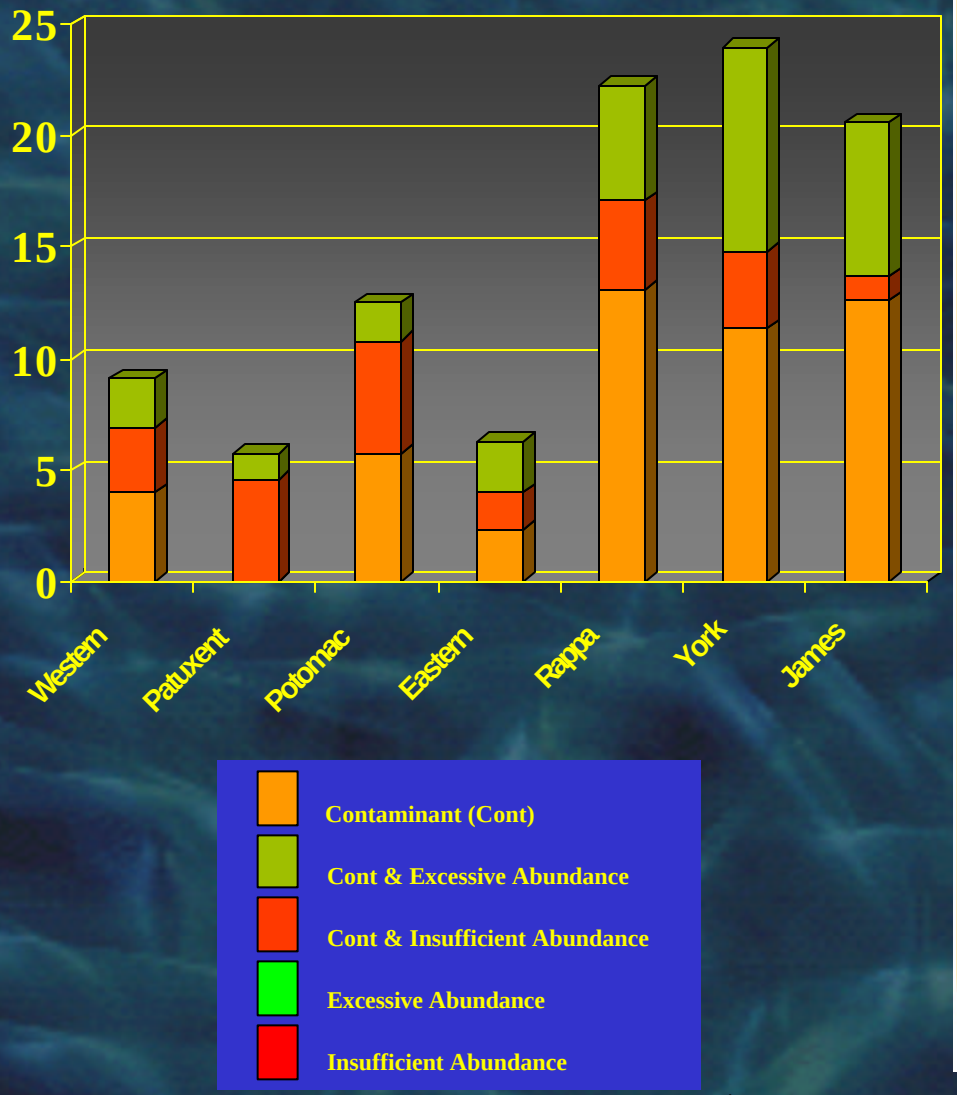
Tributary strata

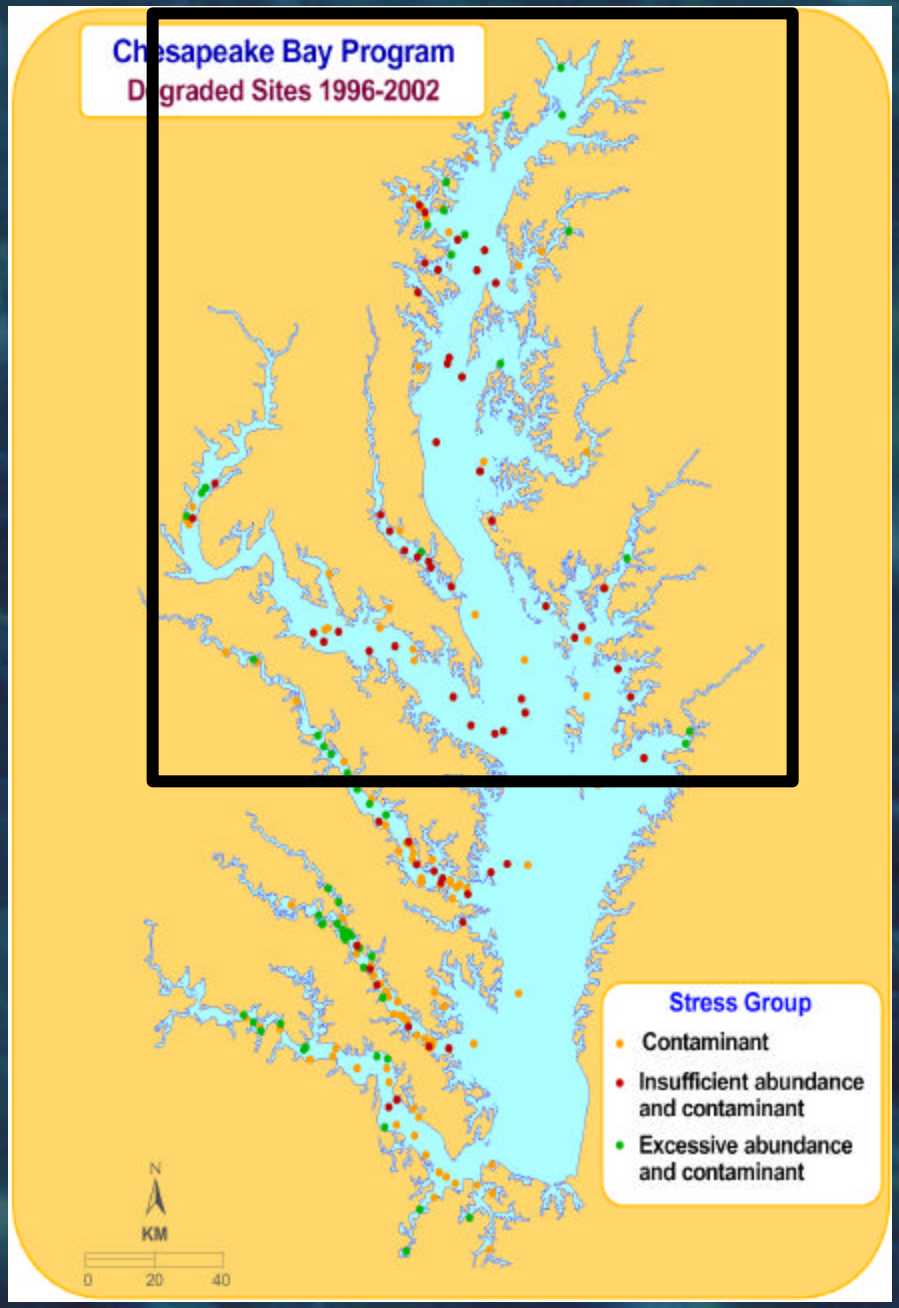
Contaminant Sites



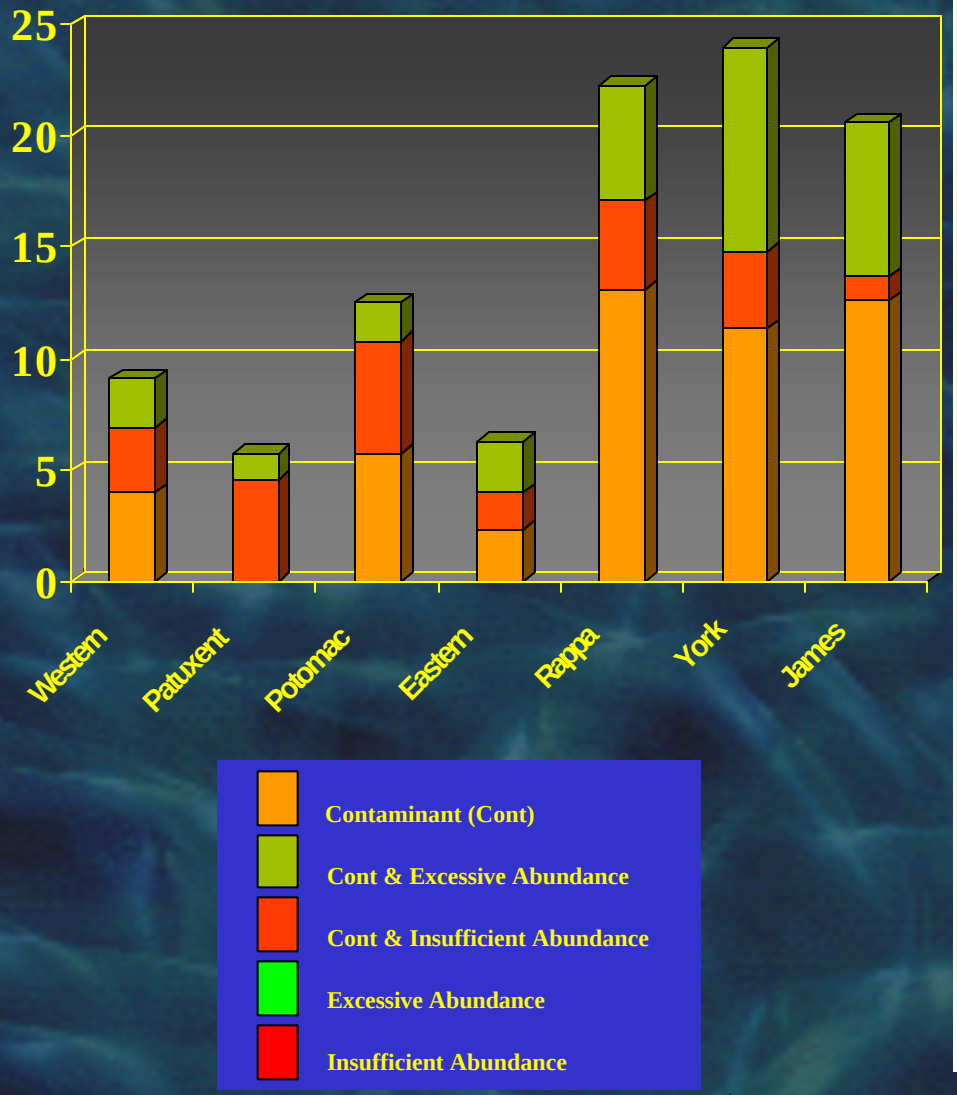


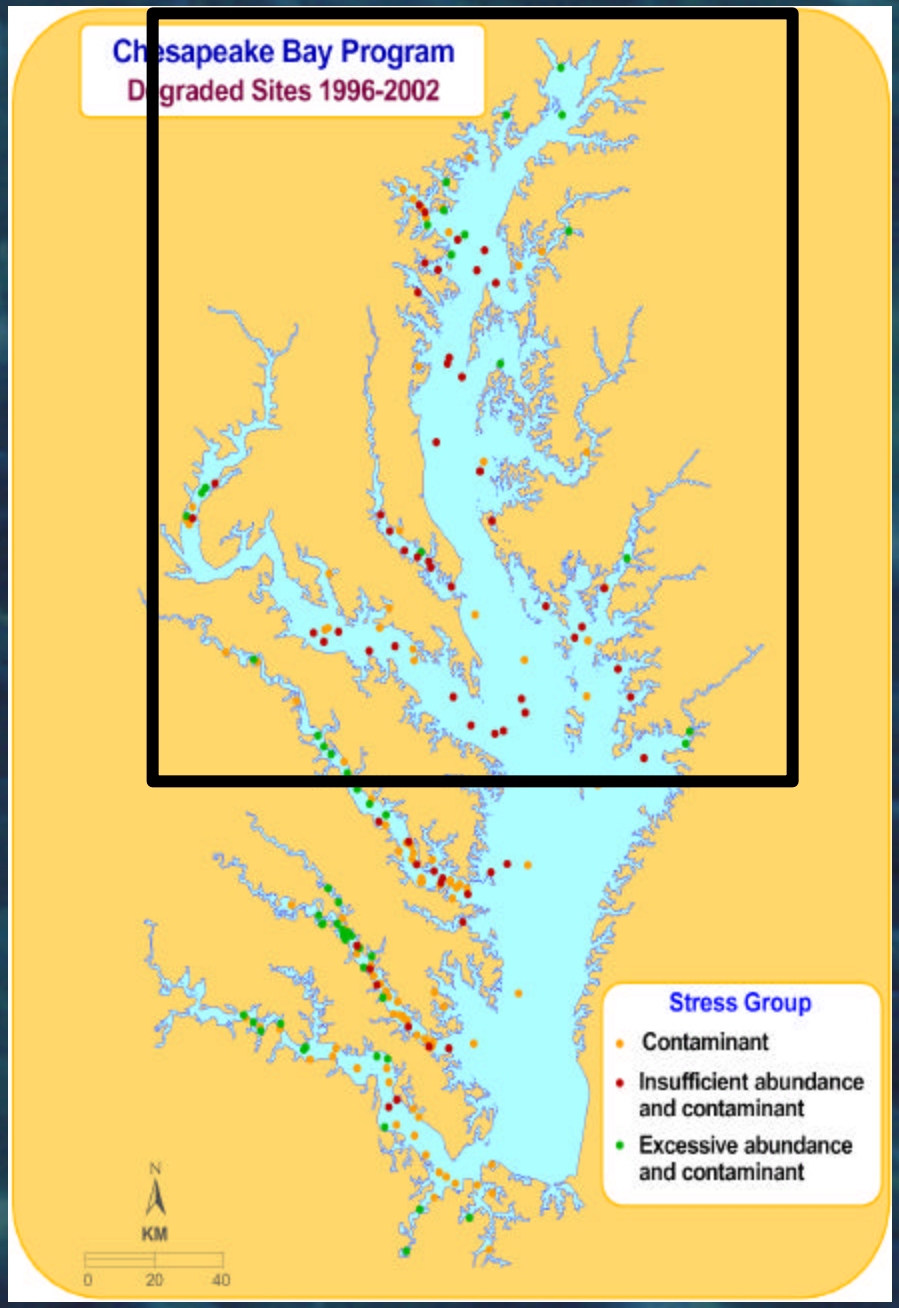
Contaminant Sites



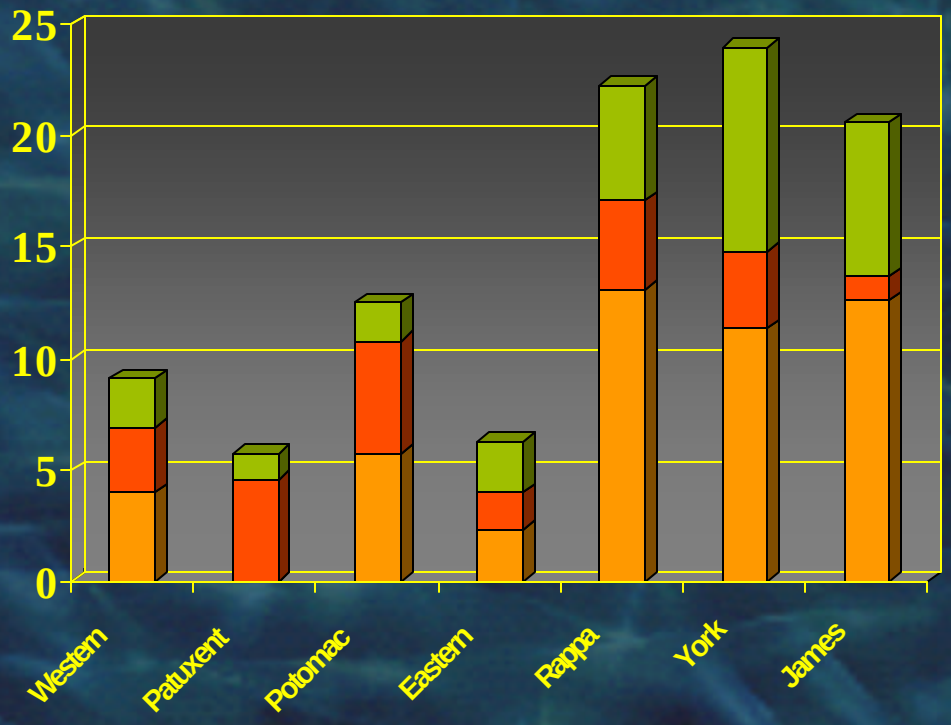


Contaminant Sites

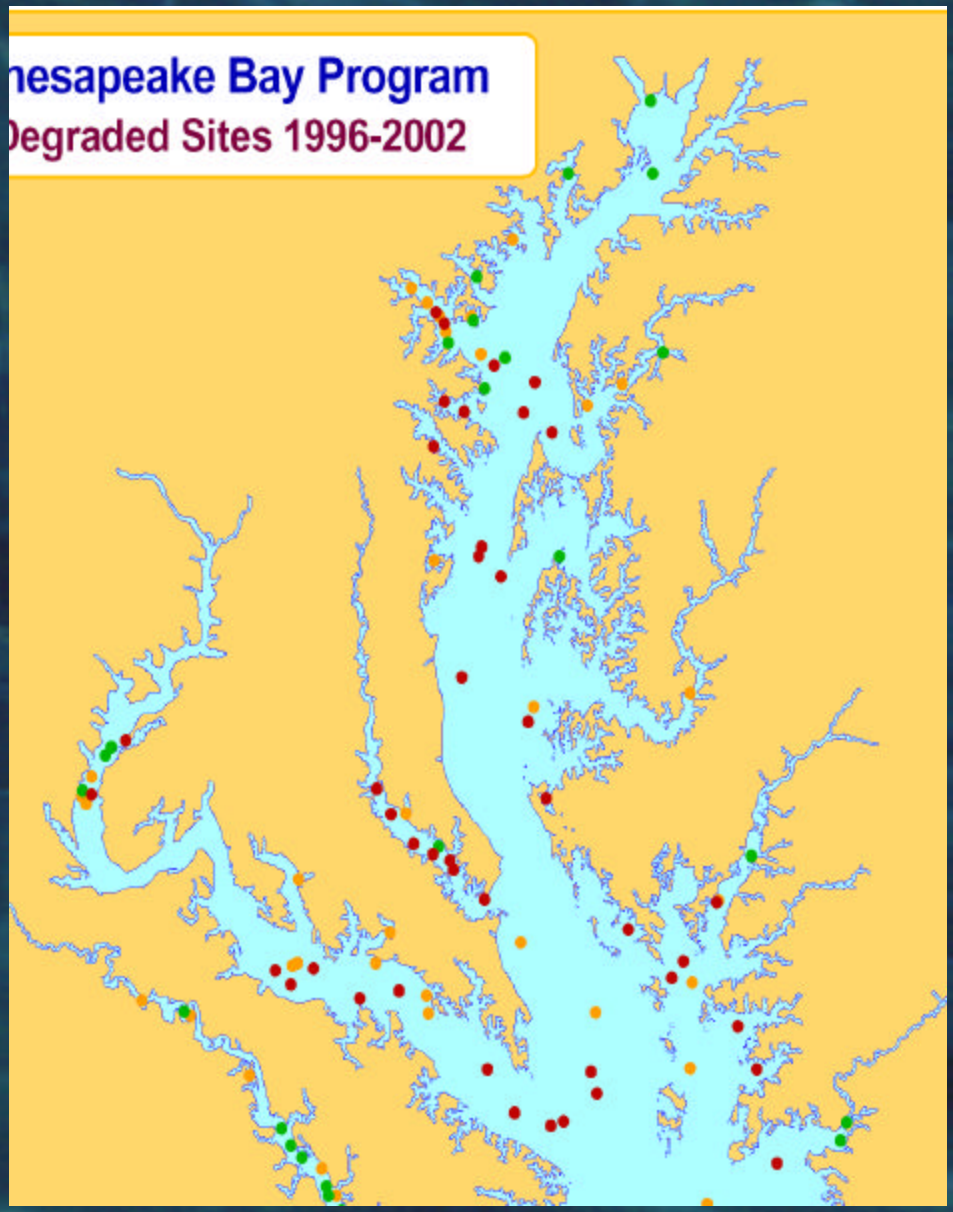




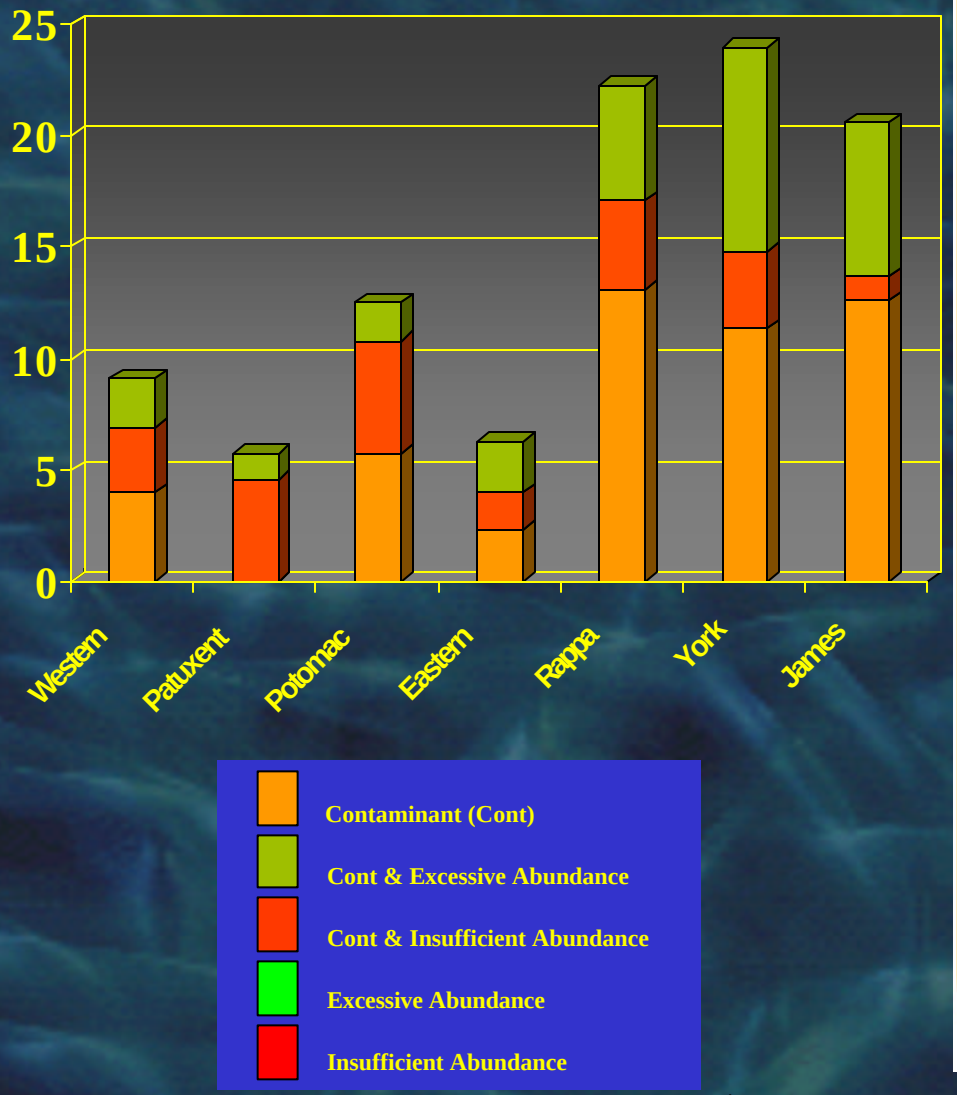
Contaminant Sites

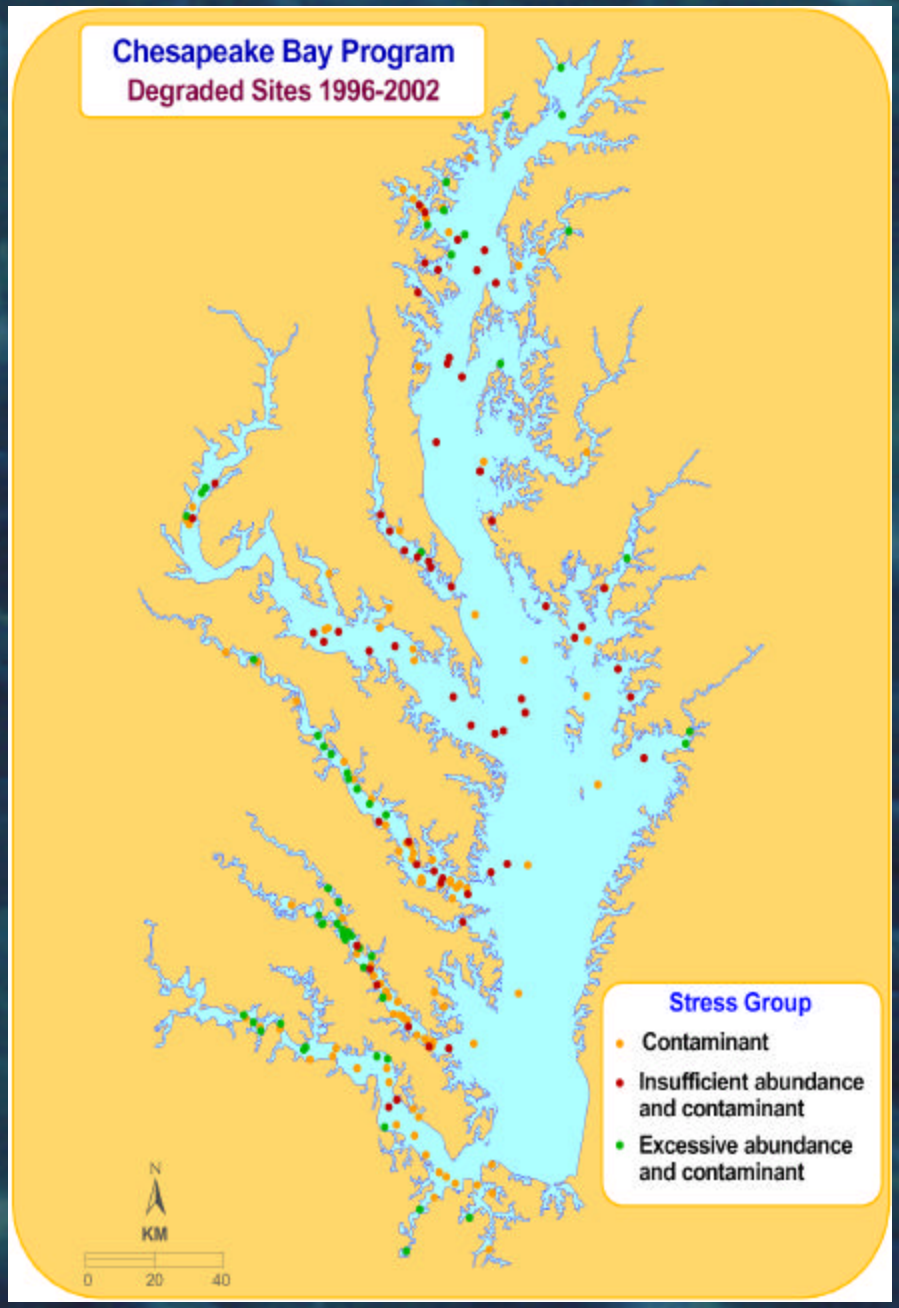


- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

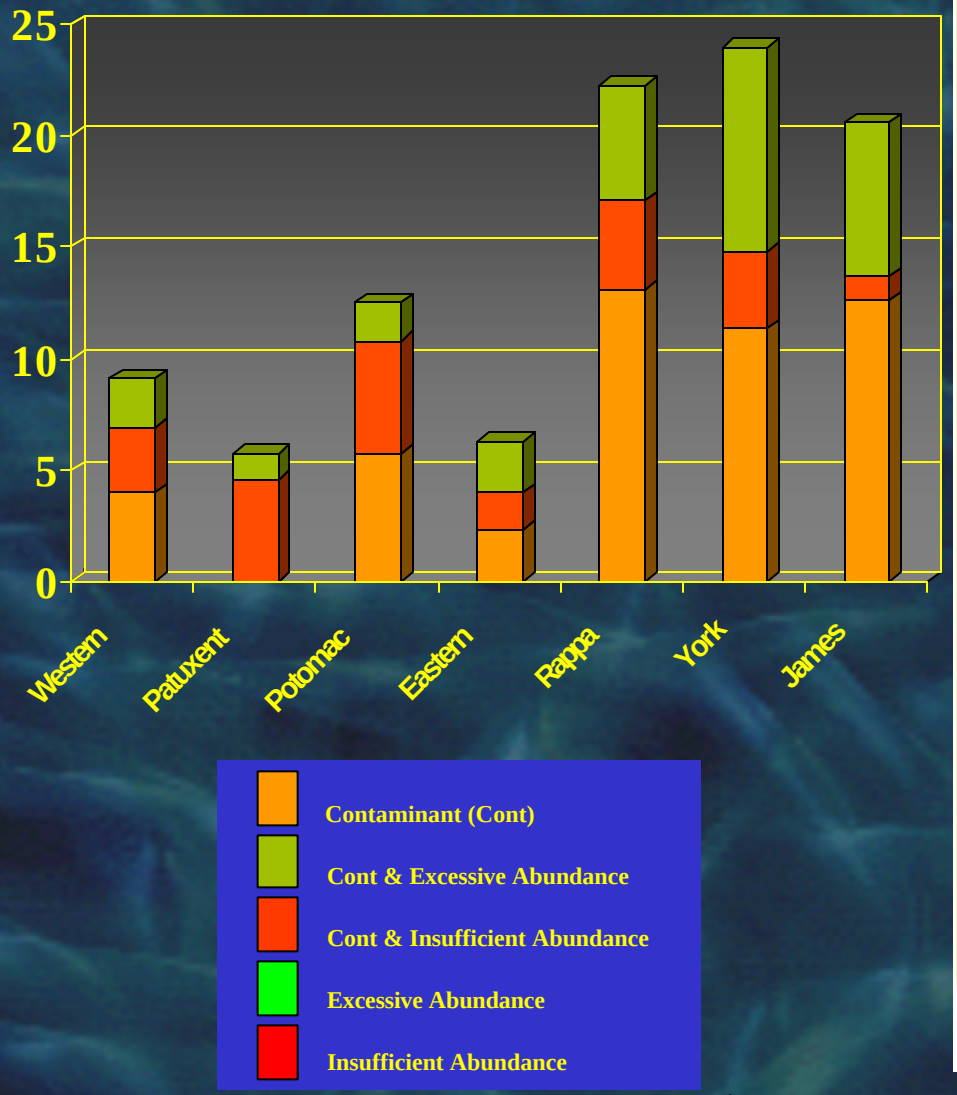


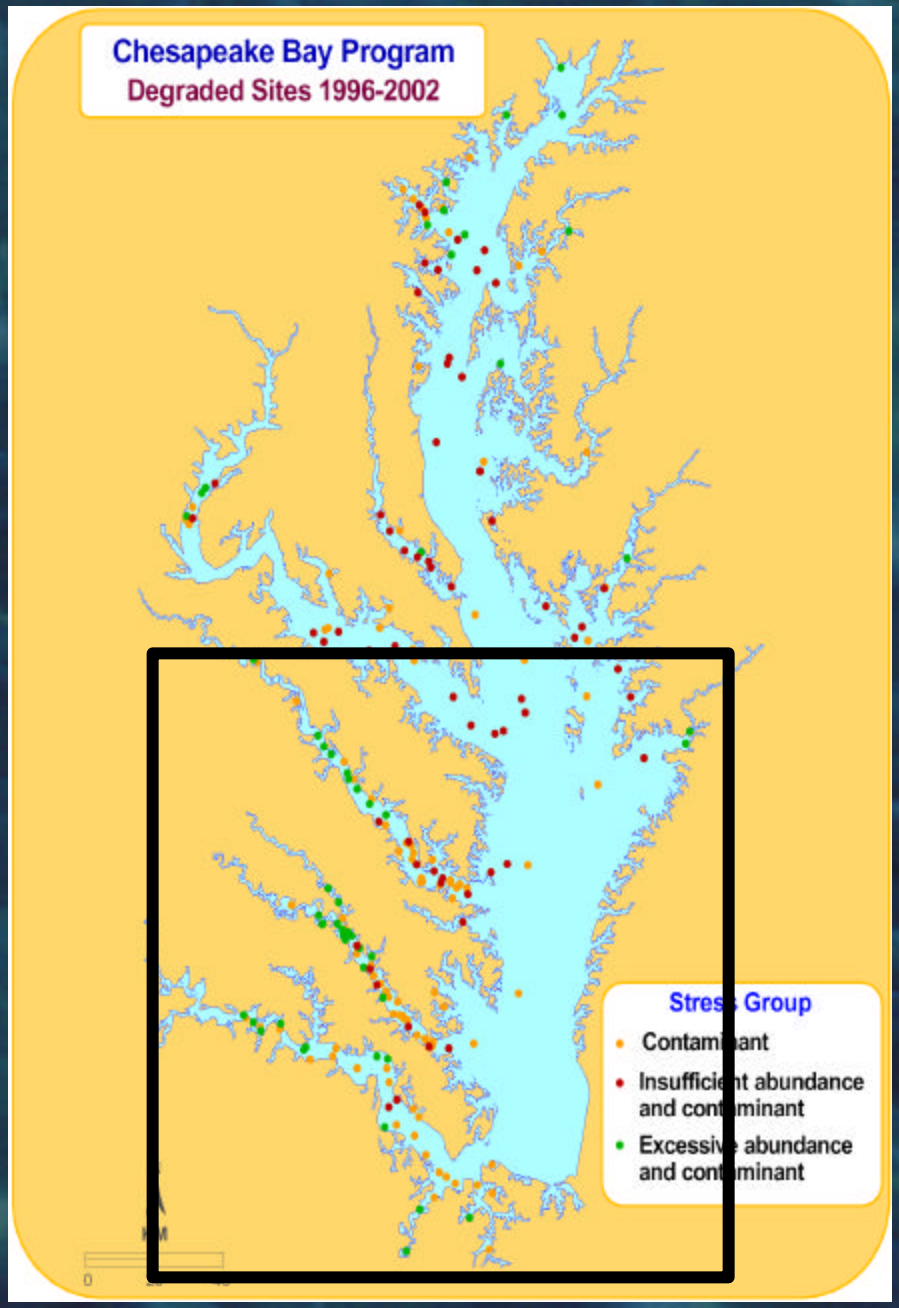
Contaminant Sites



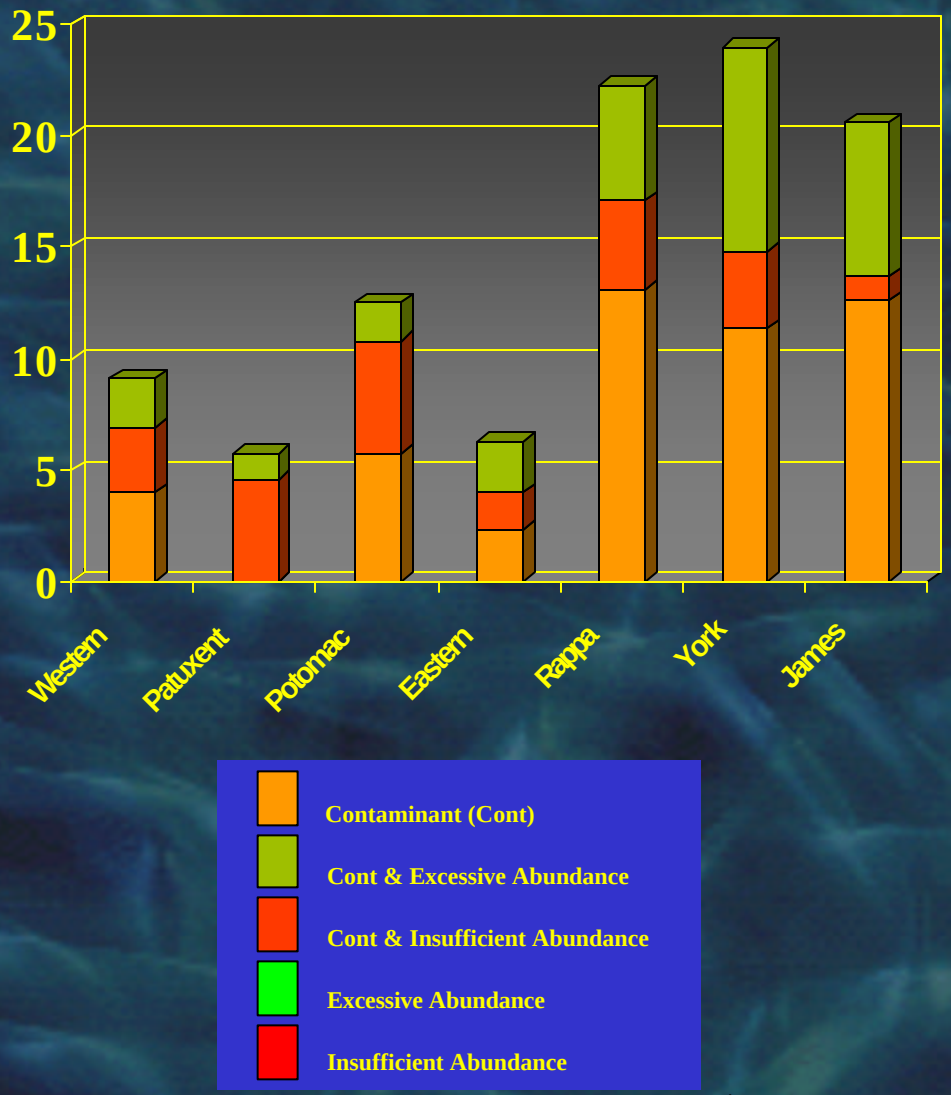


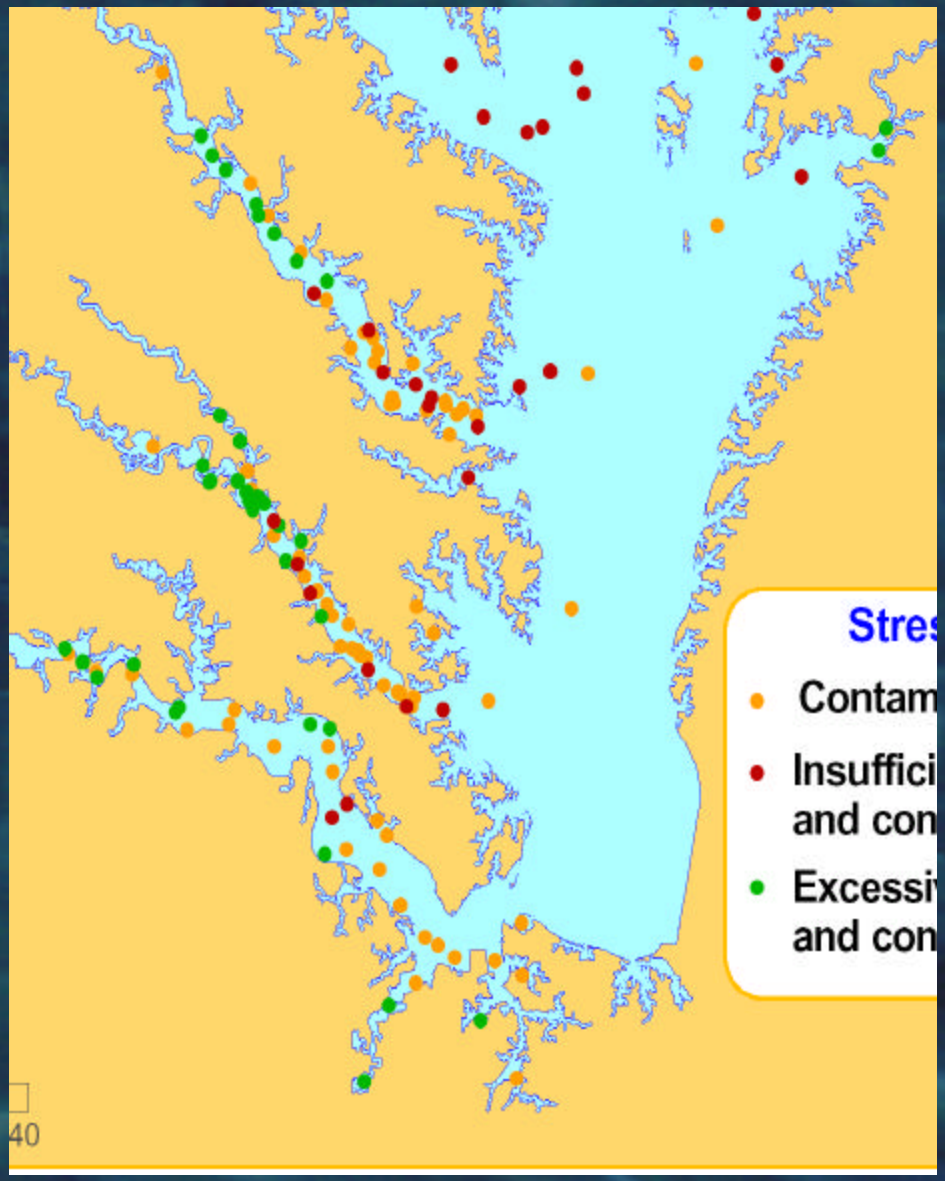
Contaminant Sites





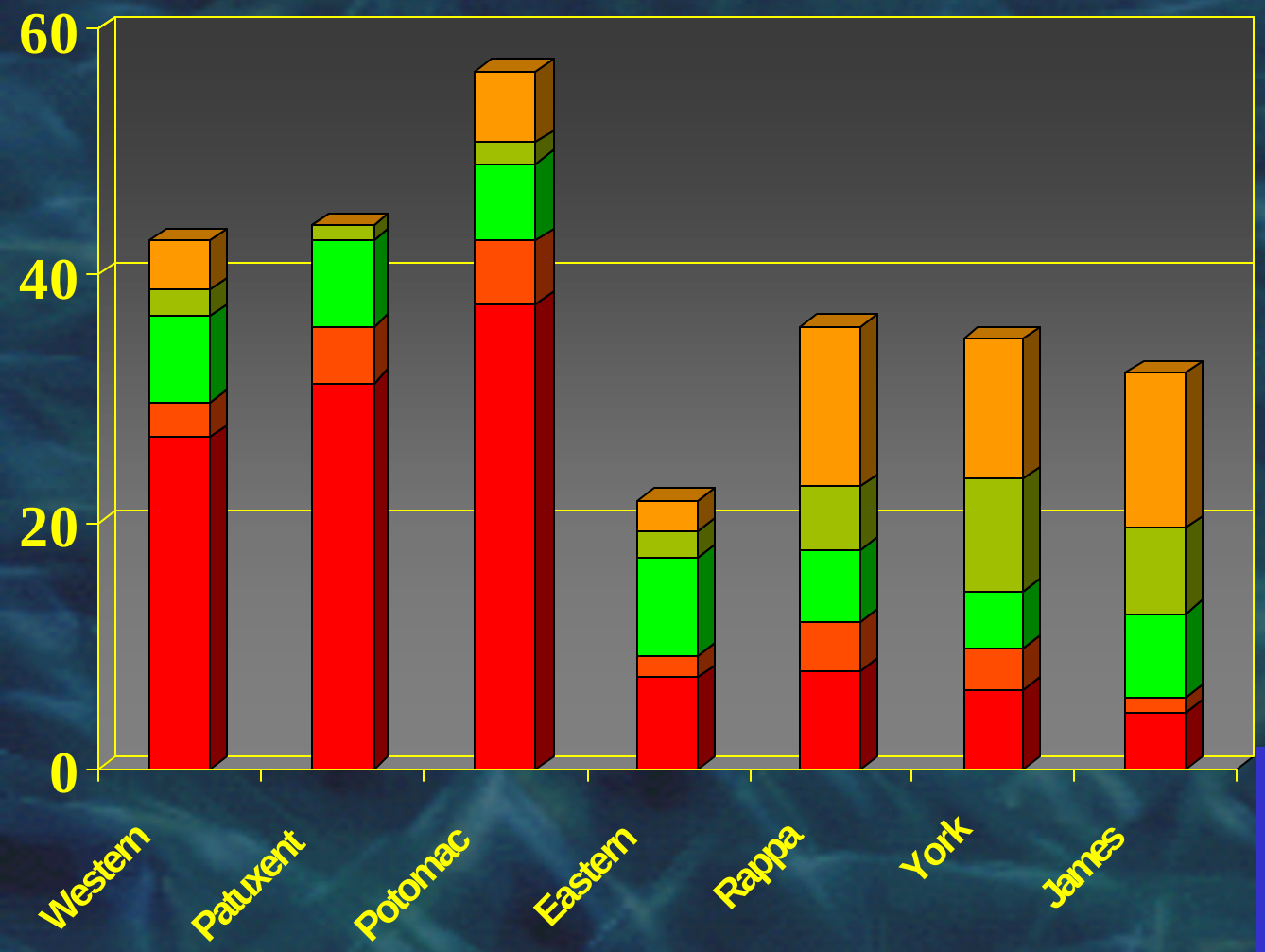
Contaminant Sites

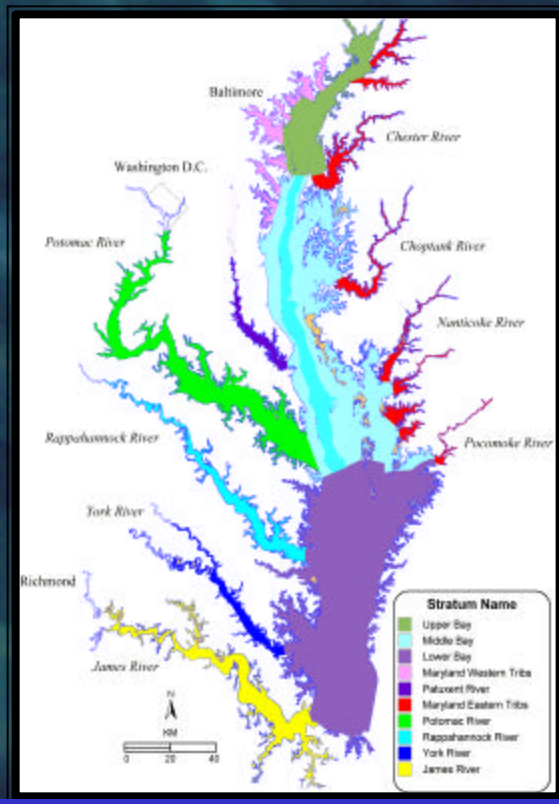




Degradation Categories

Insufficient abundance in samples with a BIBI < 3.0



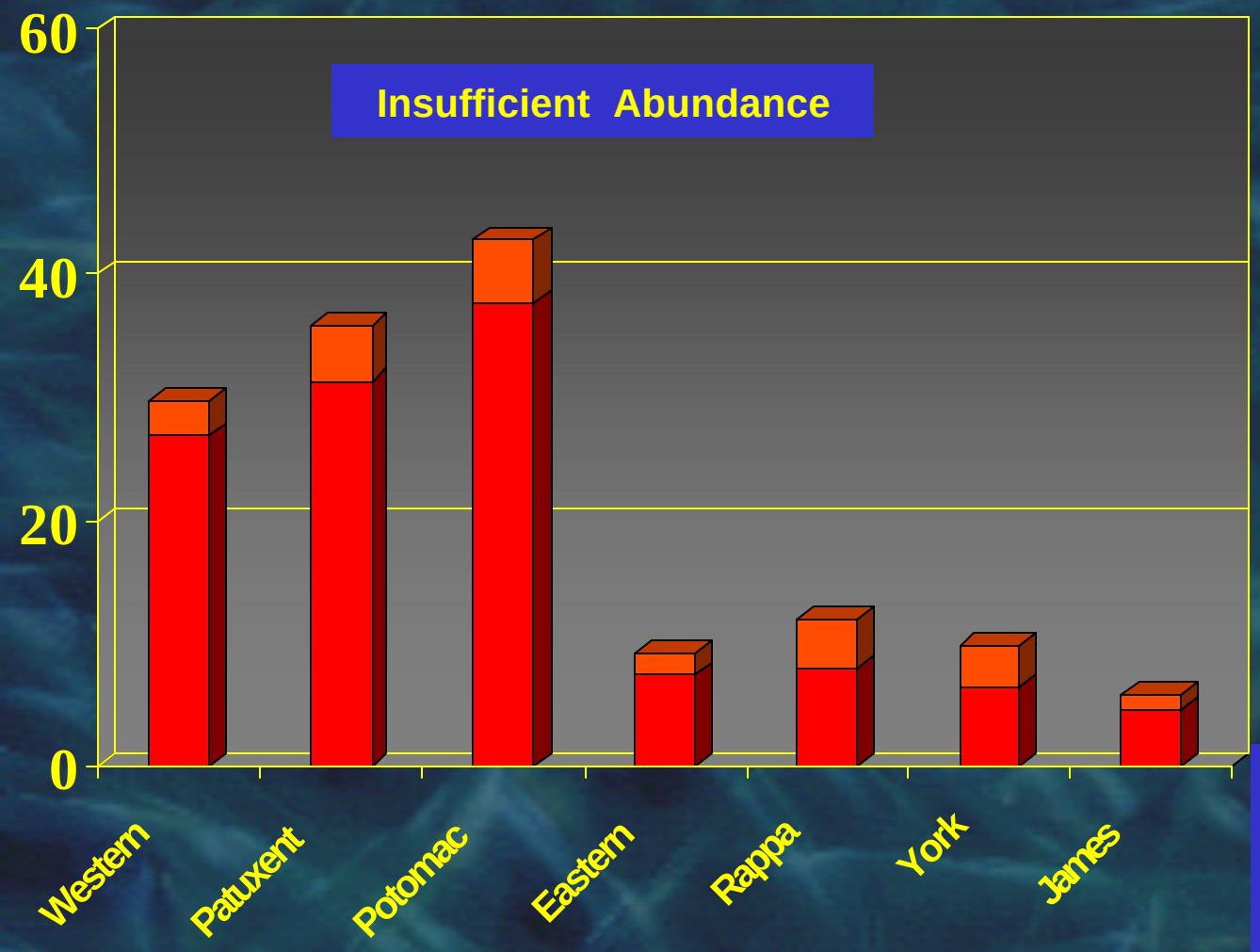


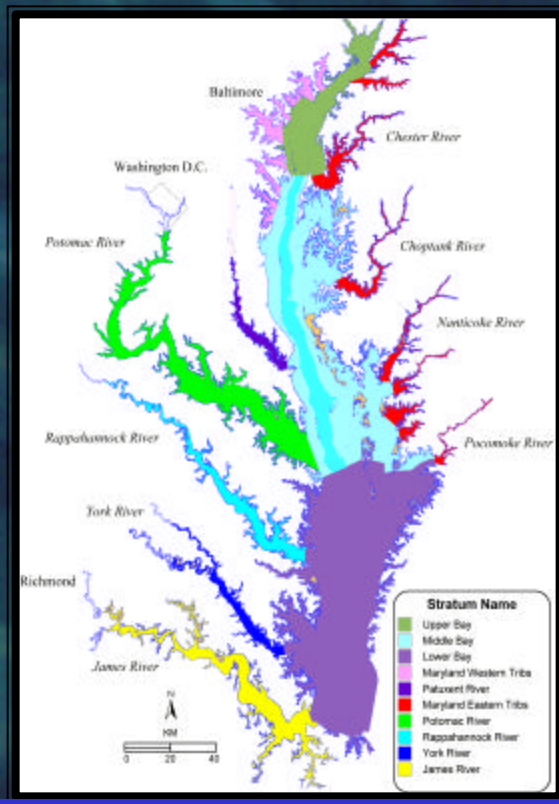
- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

Tributary strata

Degradation Categories

Insufficient abundance in samples with a BIBI < 3.0





- Contaminant (Cont)
- Cont & Excessive Abundance
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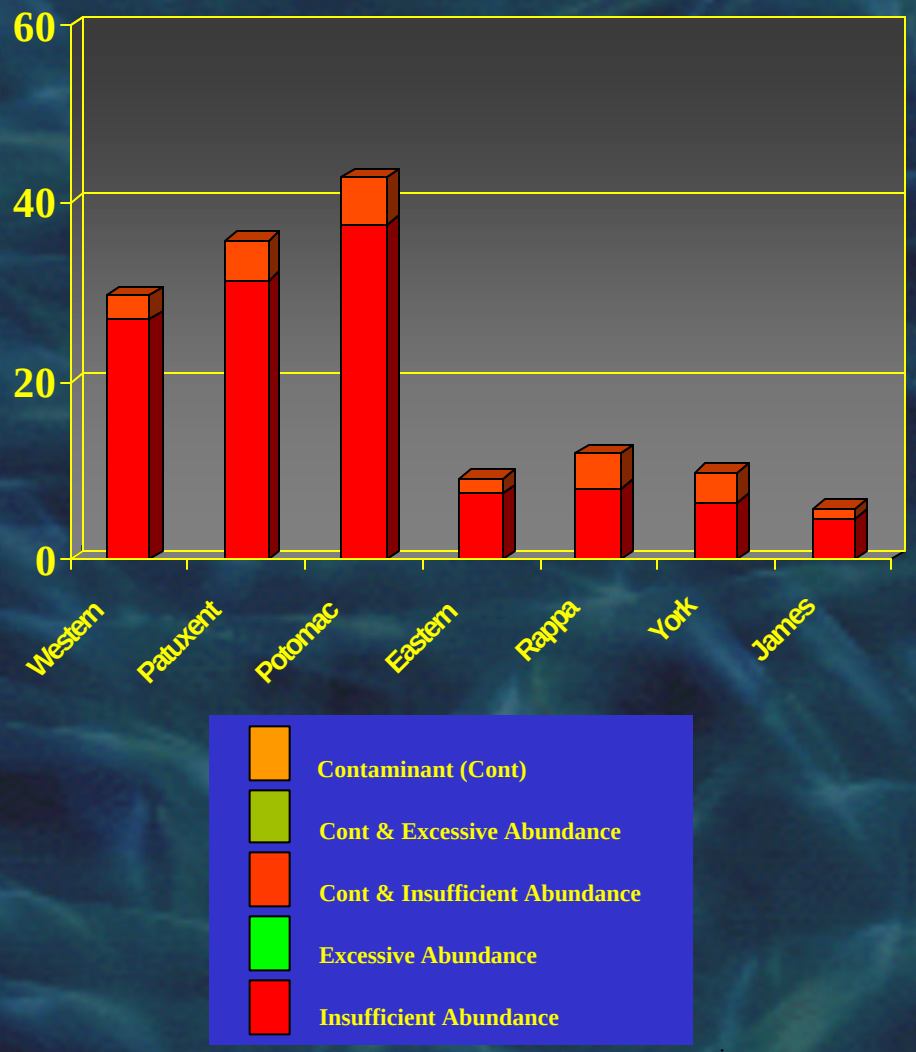
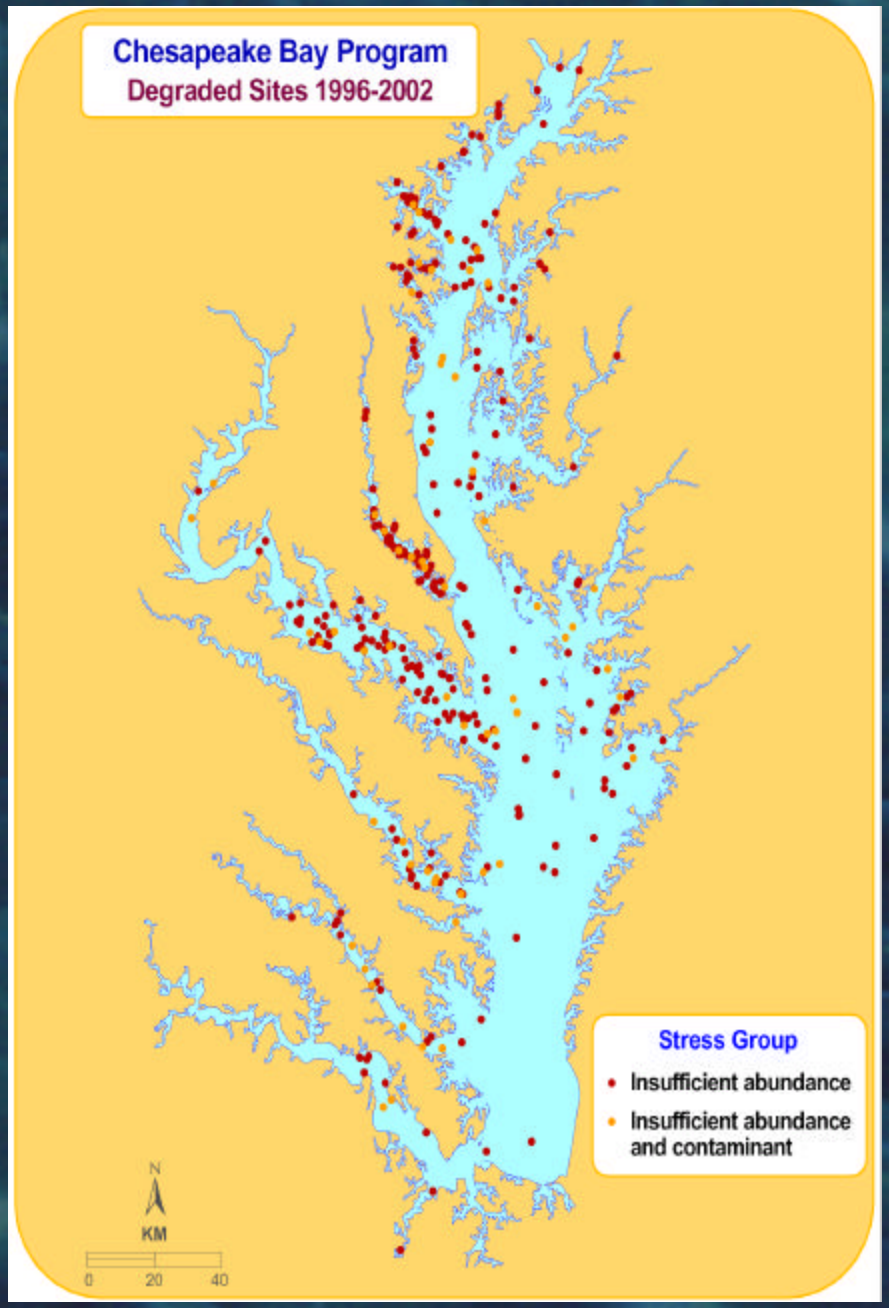
- Insufficient Abundance

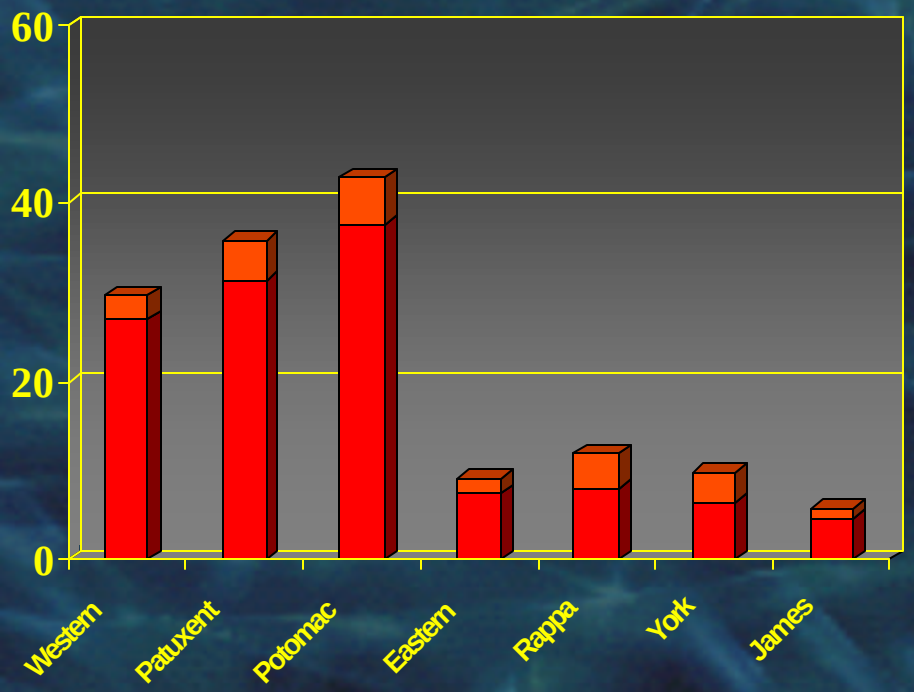
Tributary strata

Low Dissolved Oxygen





Low Dissolved Oxygen



- Contaminant (Cont)
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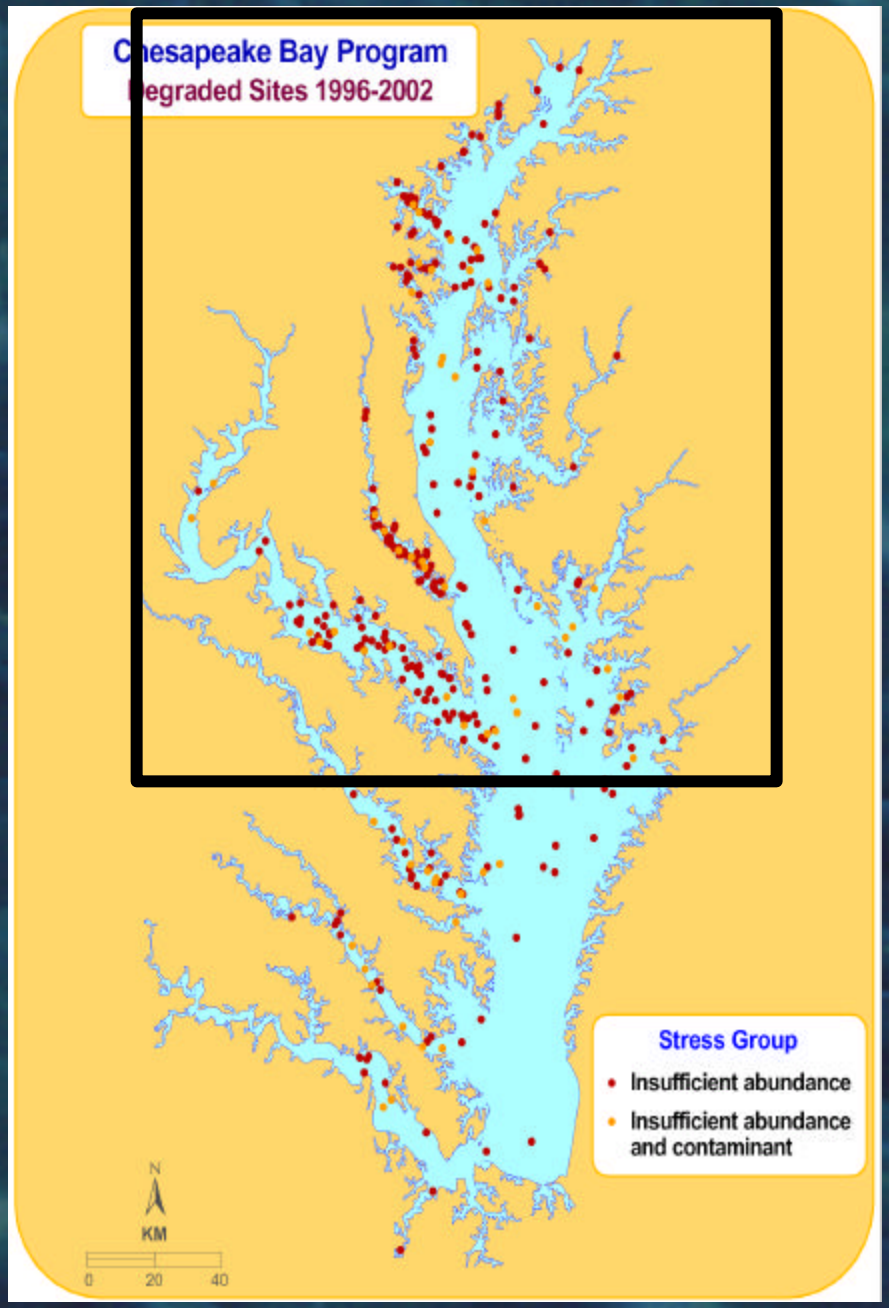
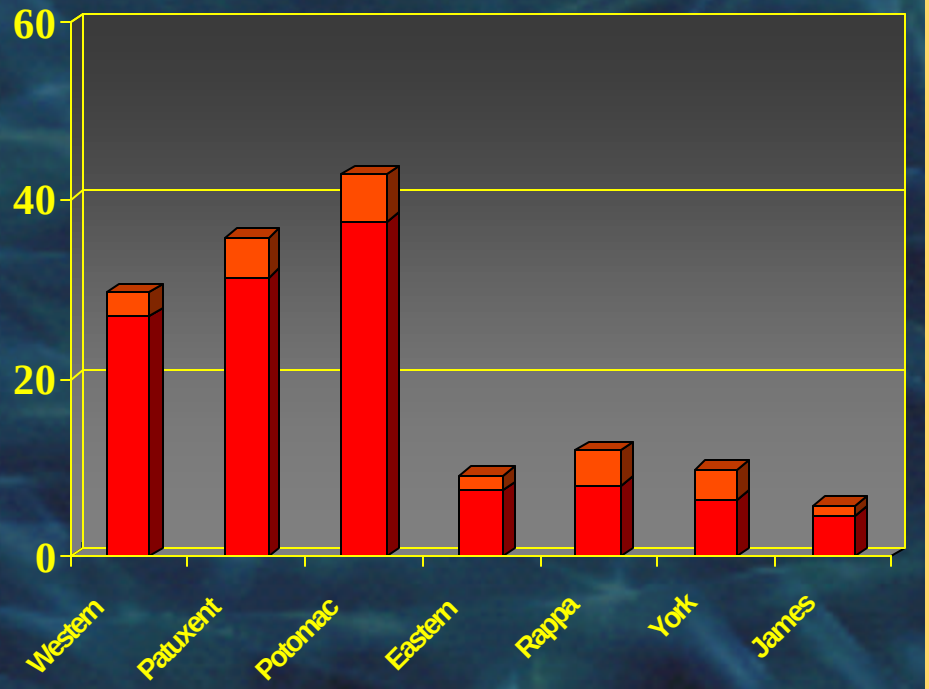
- Excessive Abundance
- Insufficient Abundance



Low Dissolved Oxygen



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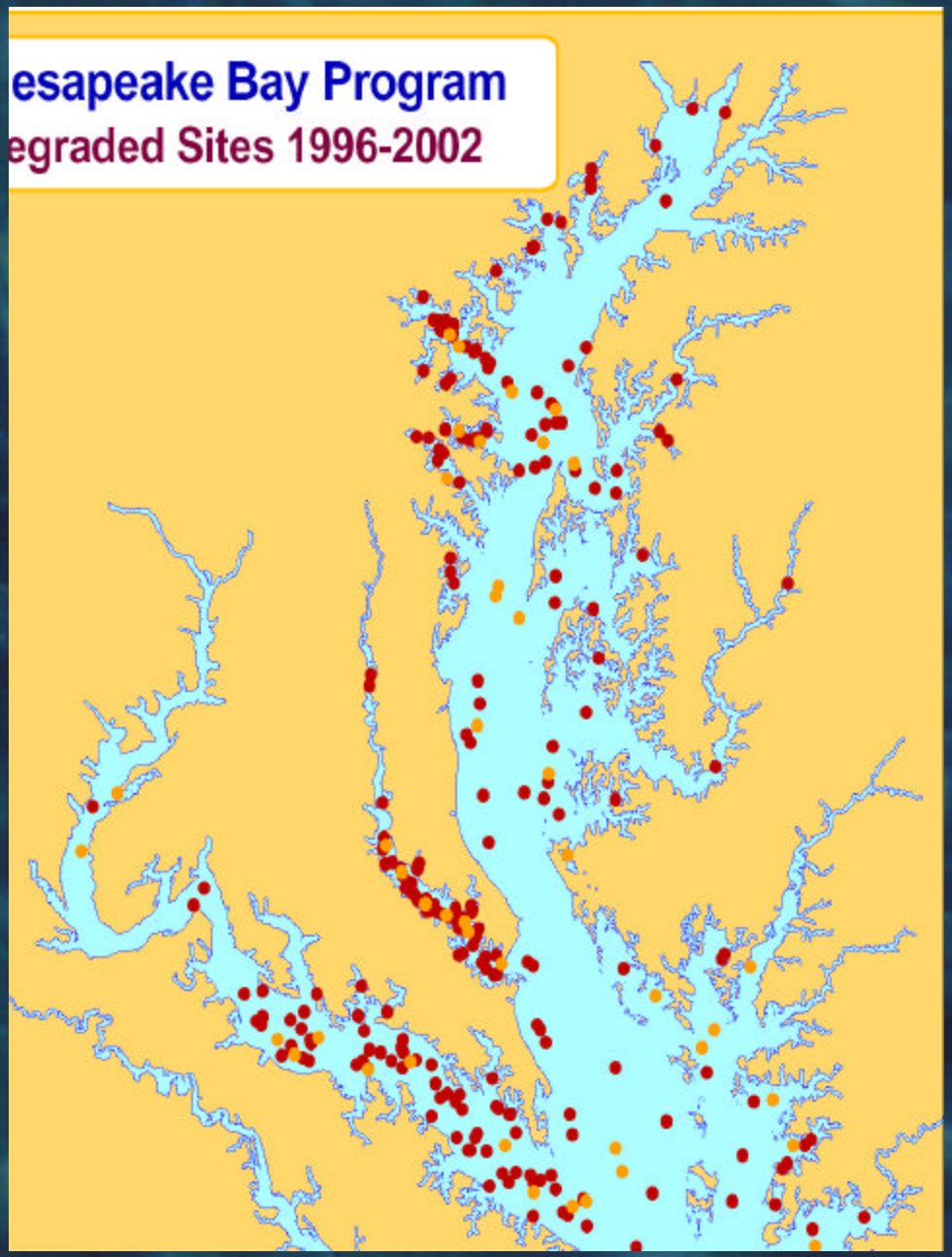
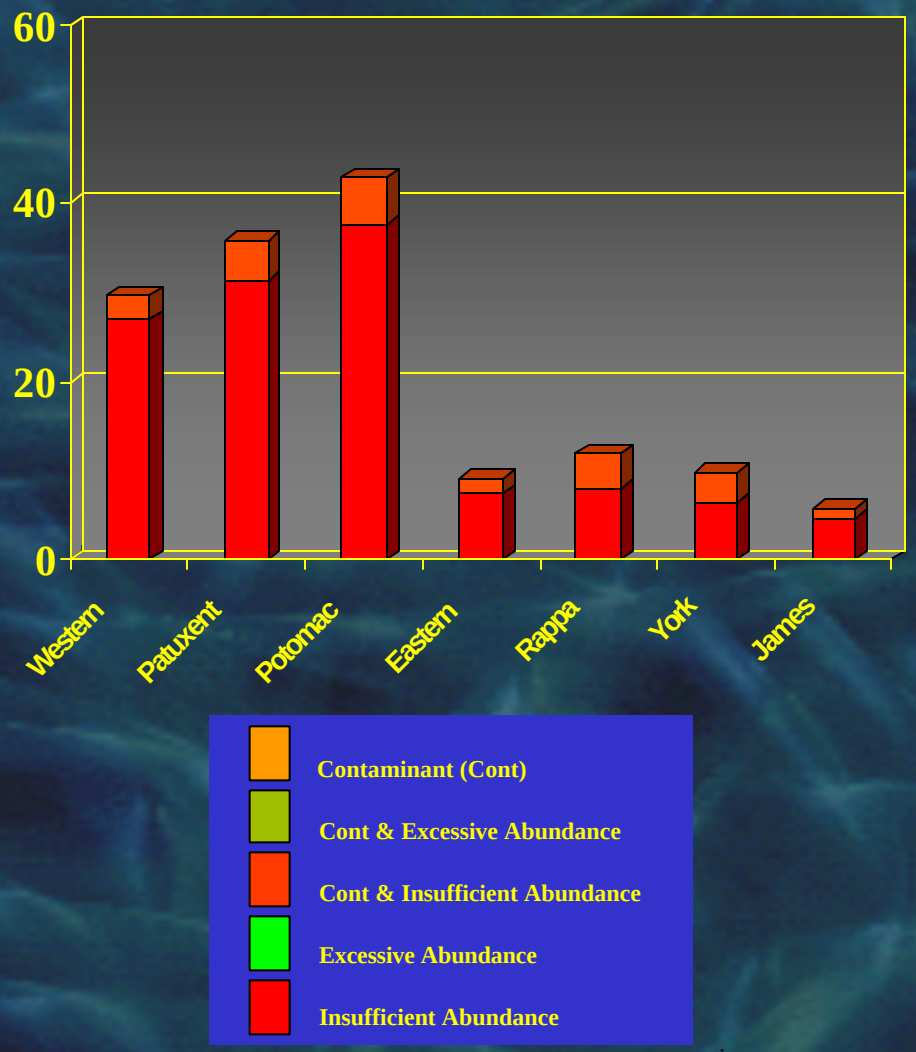
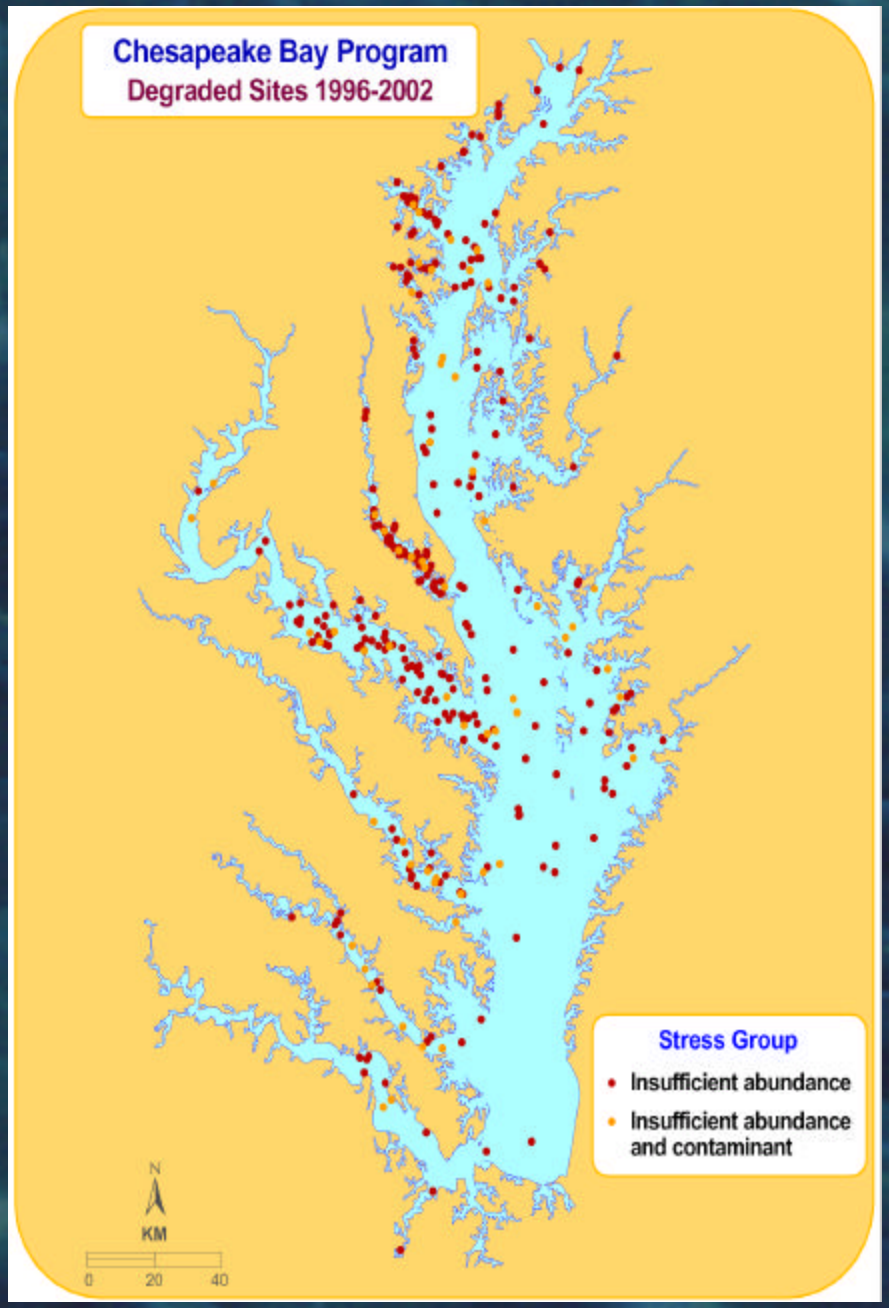
- Excessive Abundance
- Insufficient Abundance



Low Dissolved Oxygen





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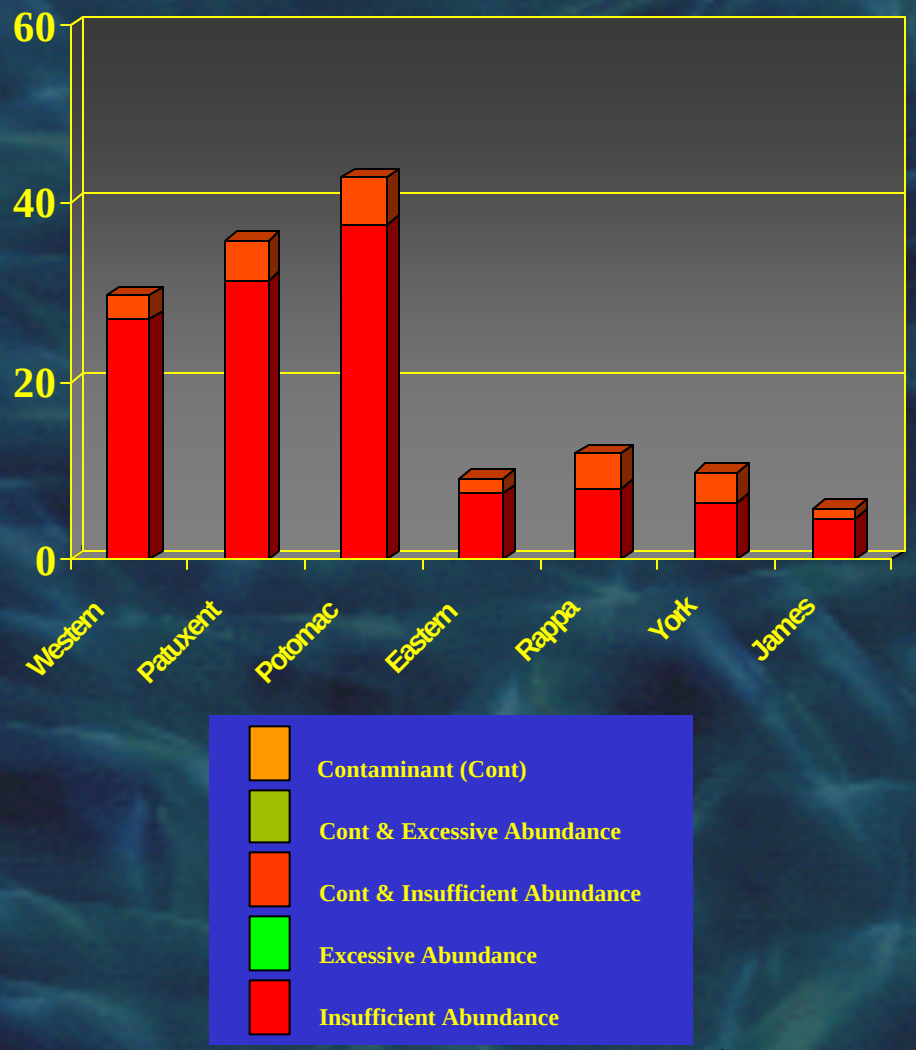
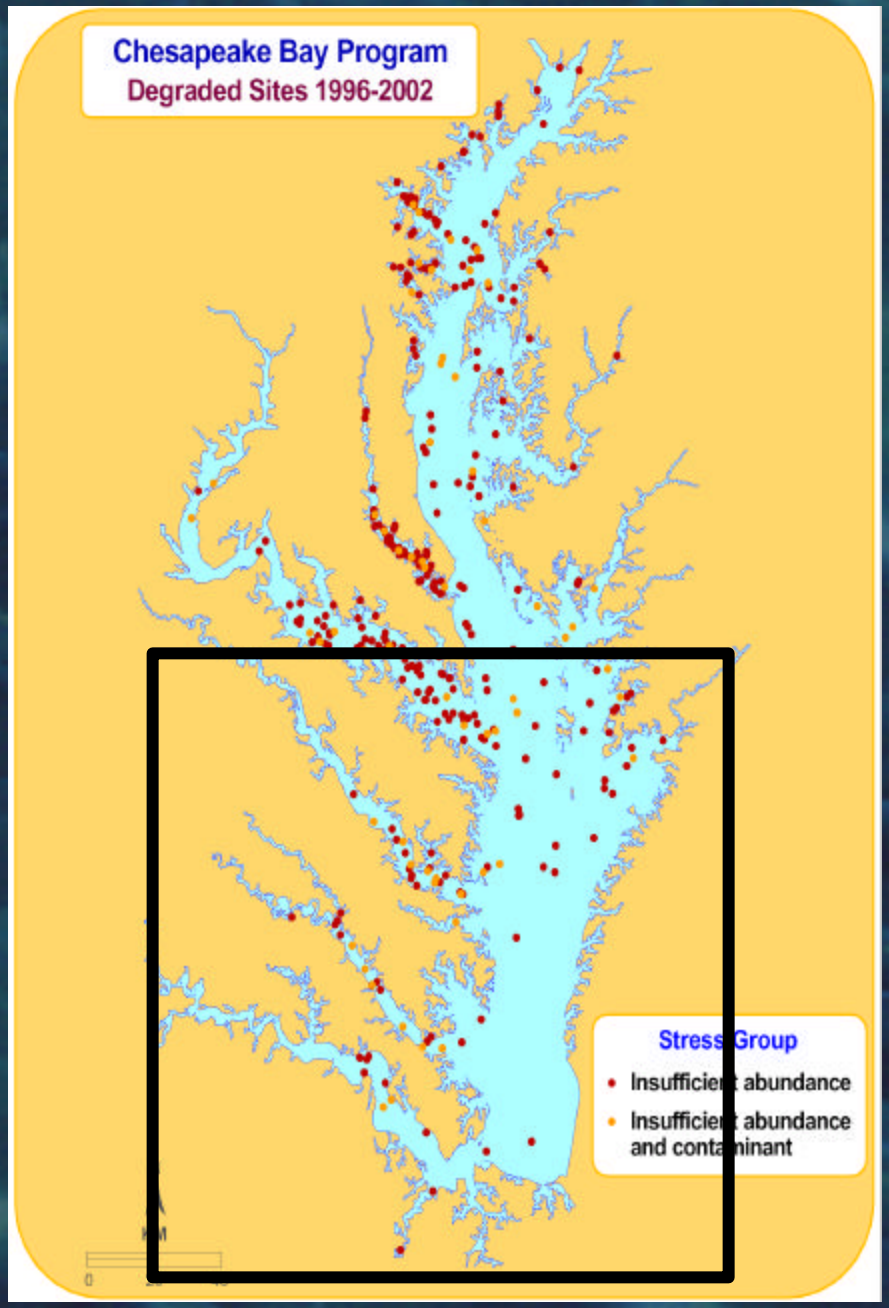
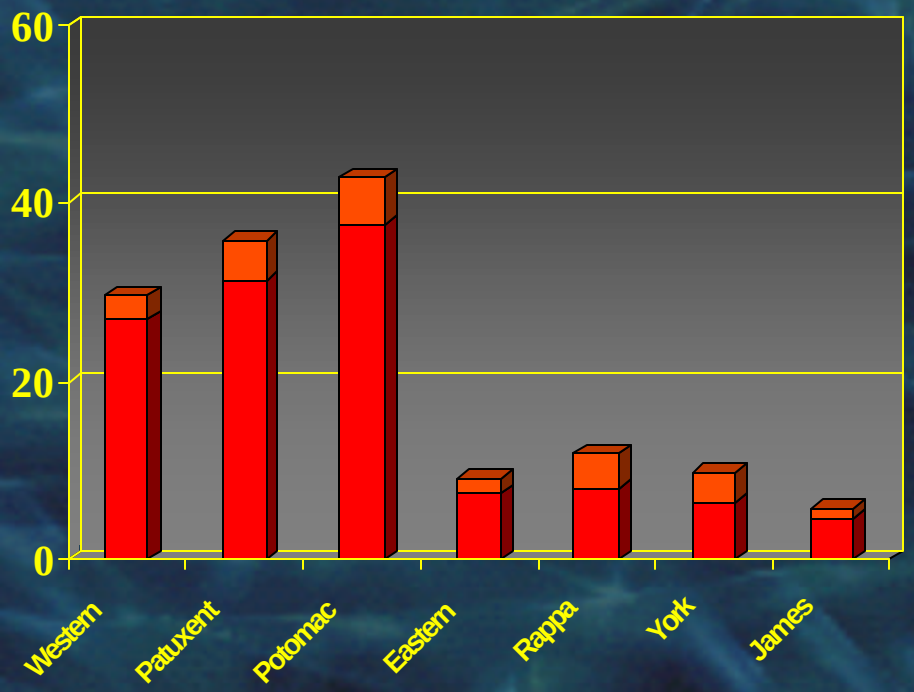




Low Dissolved Oxygen



- Contaminant (Cont)
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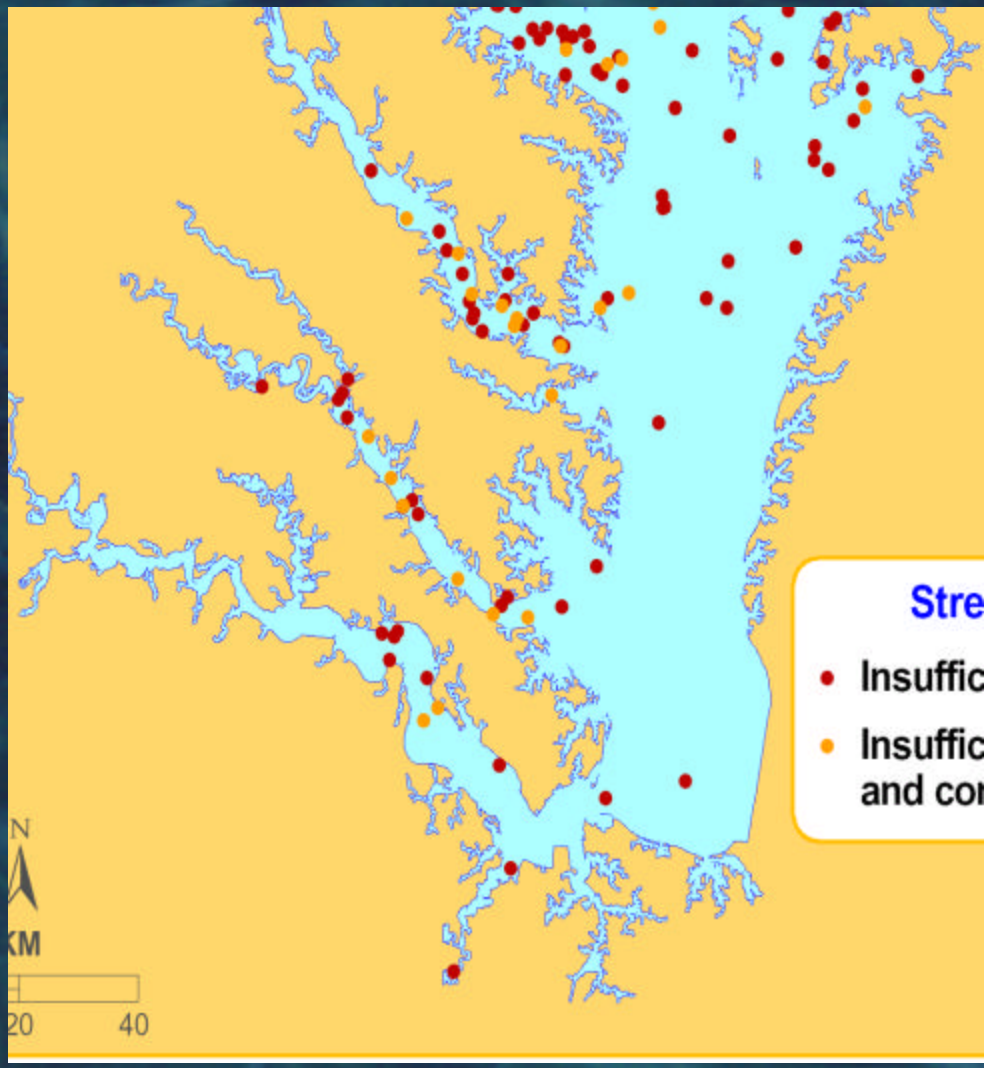
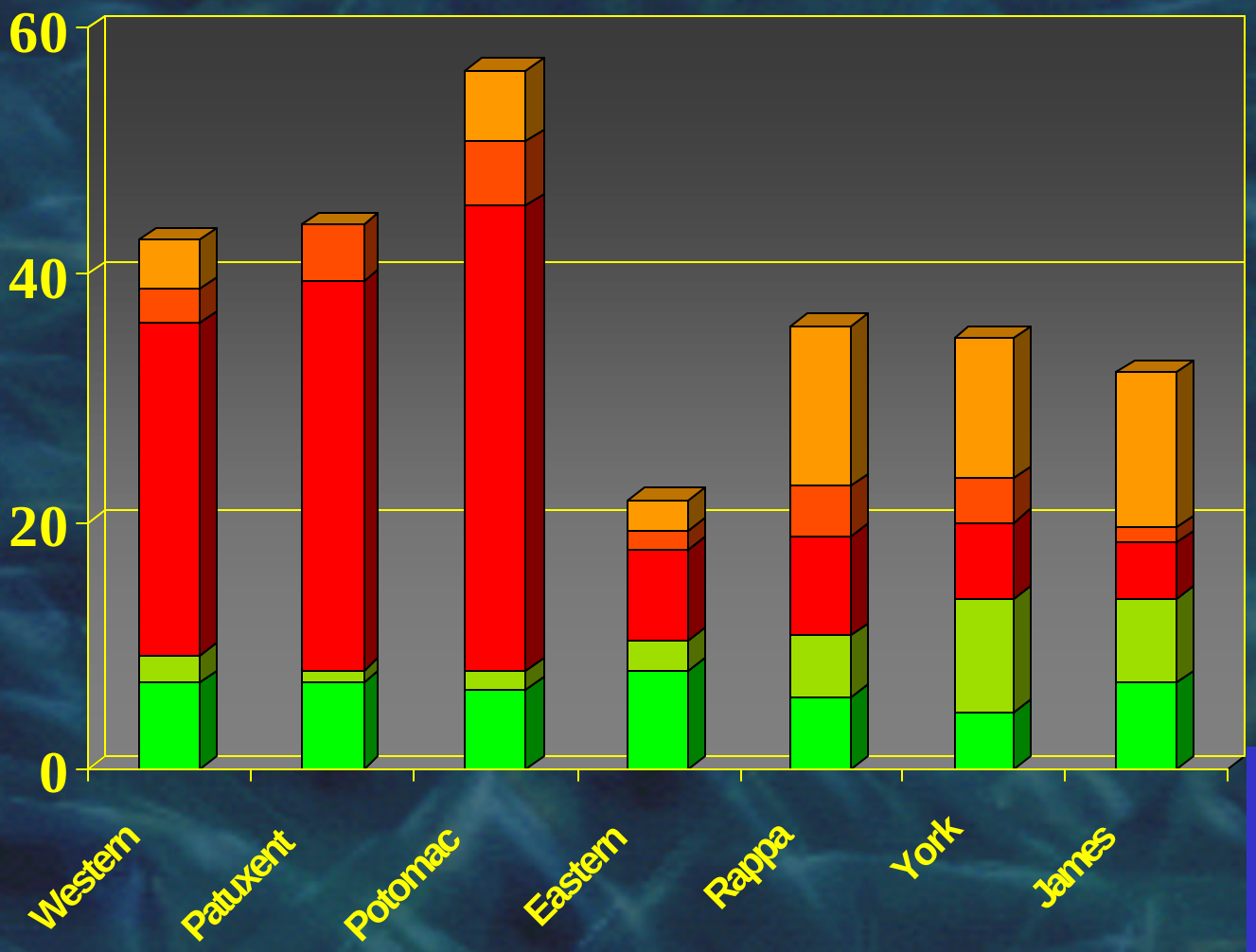
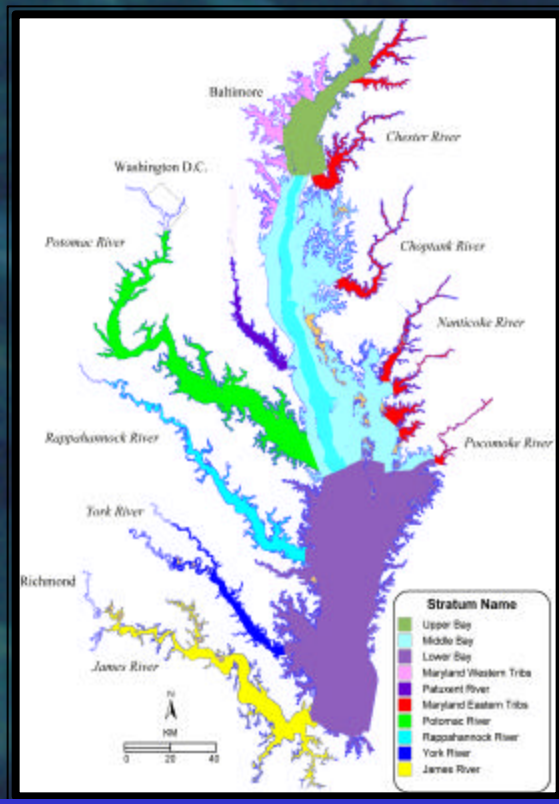
- Excessive Abundance
- Insufficient Abundance



Degradation Categories

Excessive abundance in samples with a BIBI < 3.0



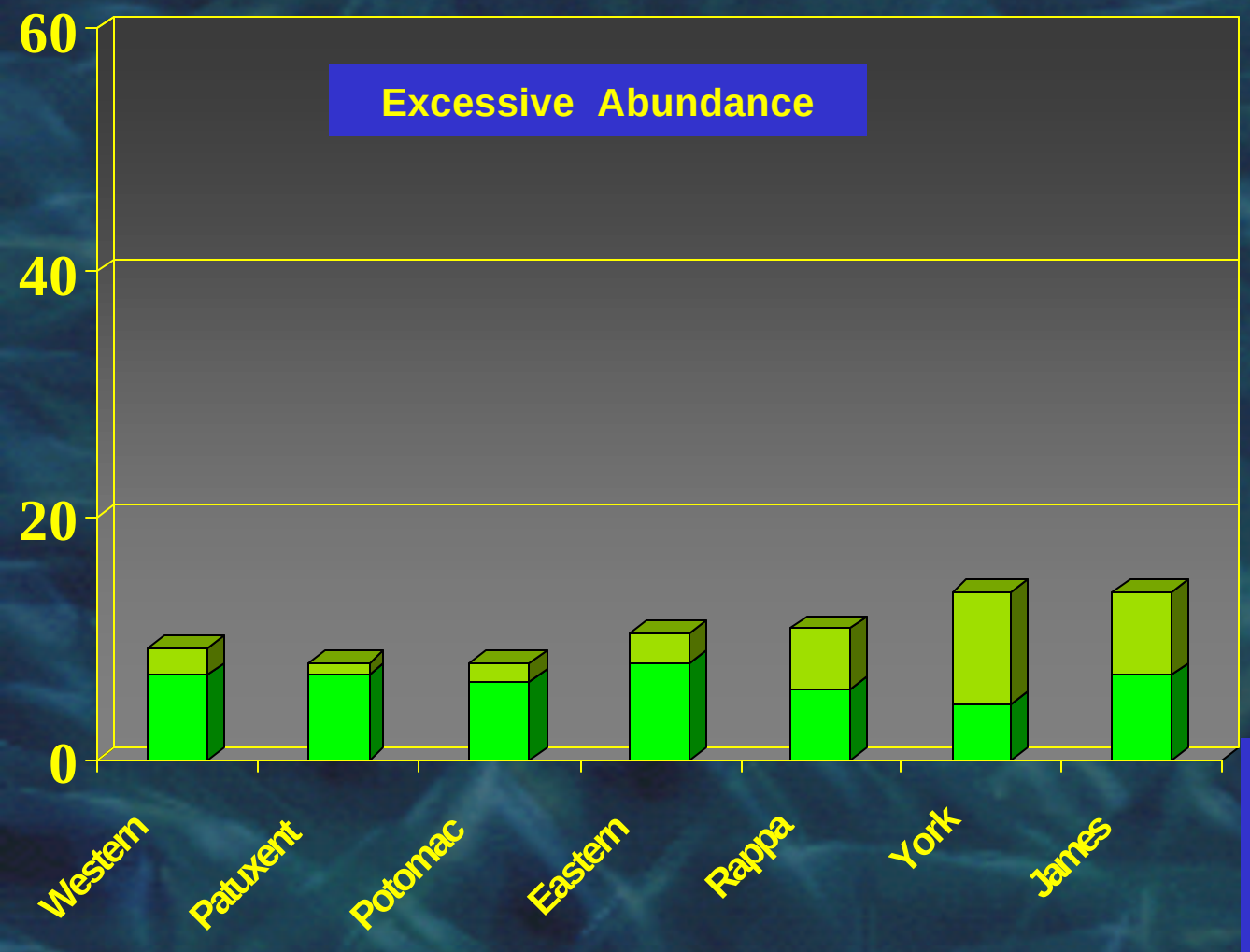


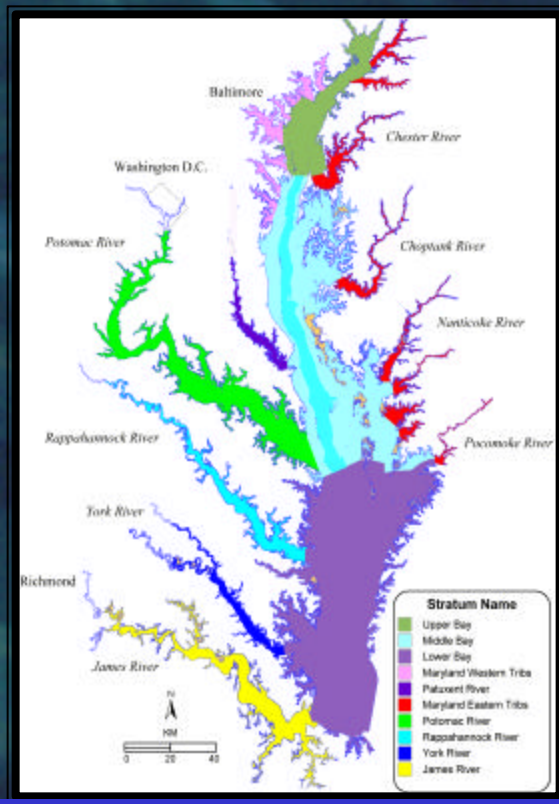
- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

Tributary strata

Degradation Categories

Excessive abundance in samples with a BIBI < 3.0





- Contaminant (Cont)
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Tributary strata

Degradation Categories

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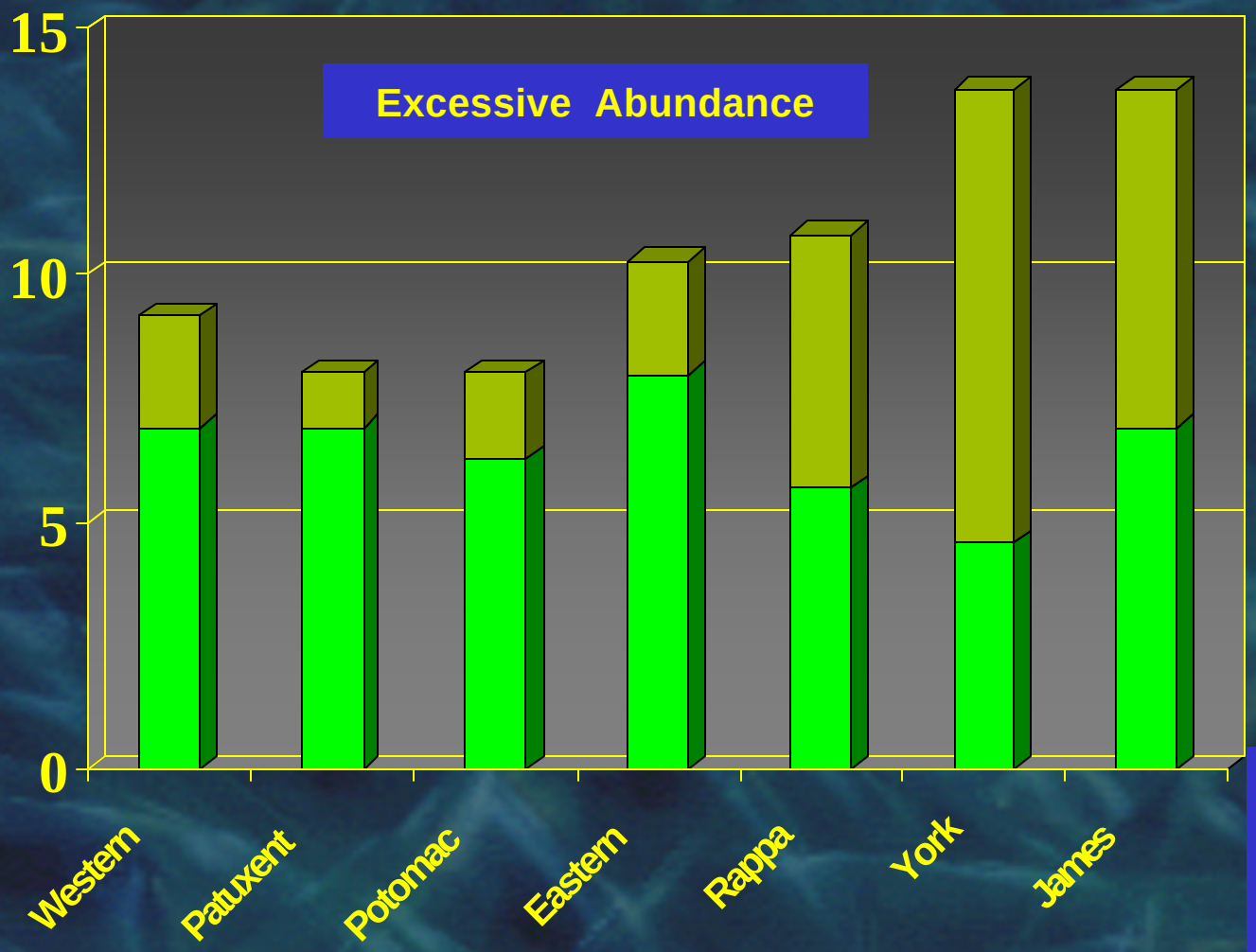

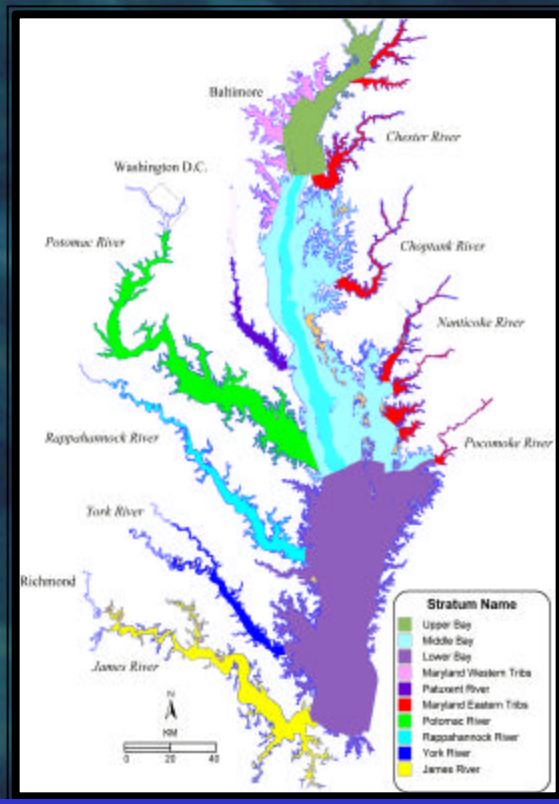

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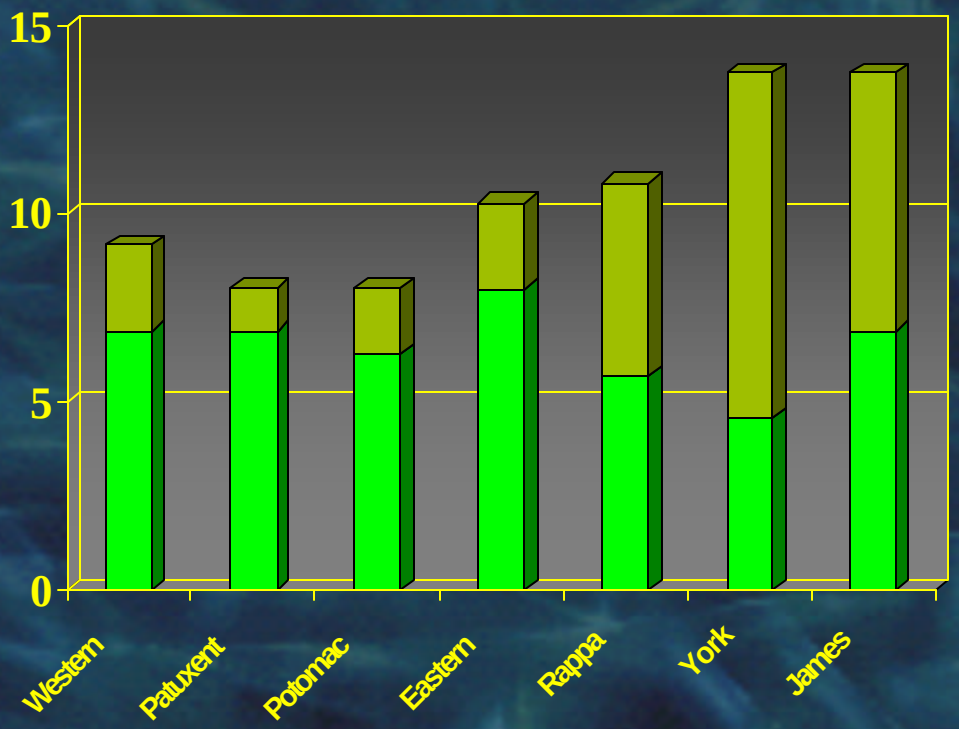
Tributary strata

Moderate Eutrophication



- Contaminant (Cont)
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- Excessive Abundance
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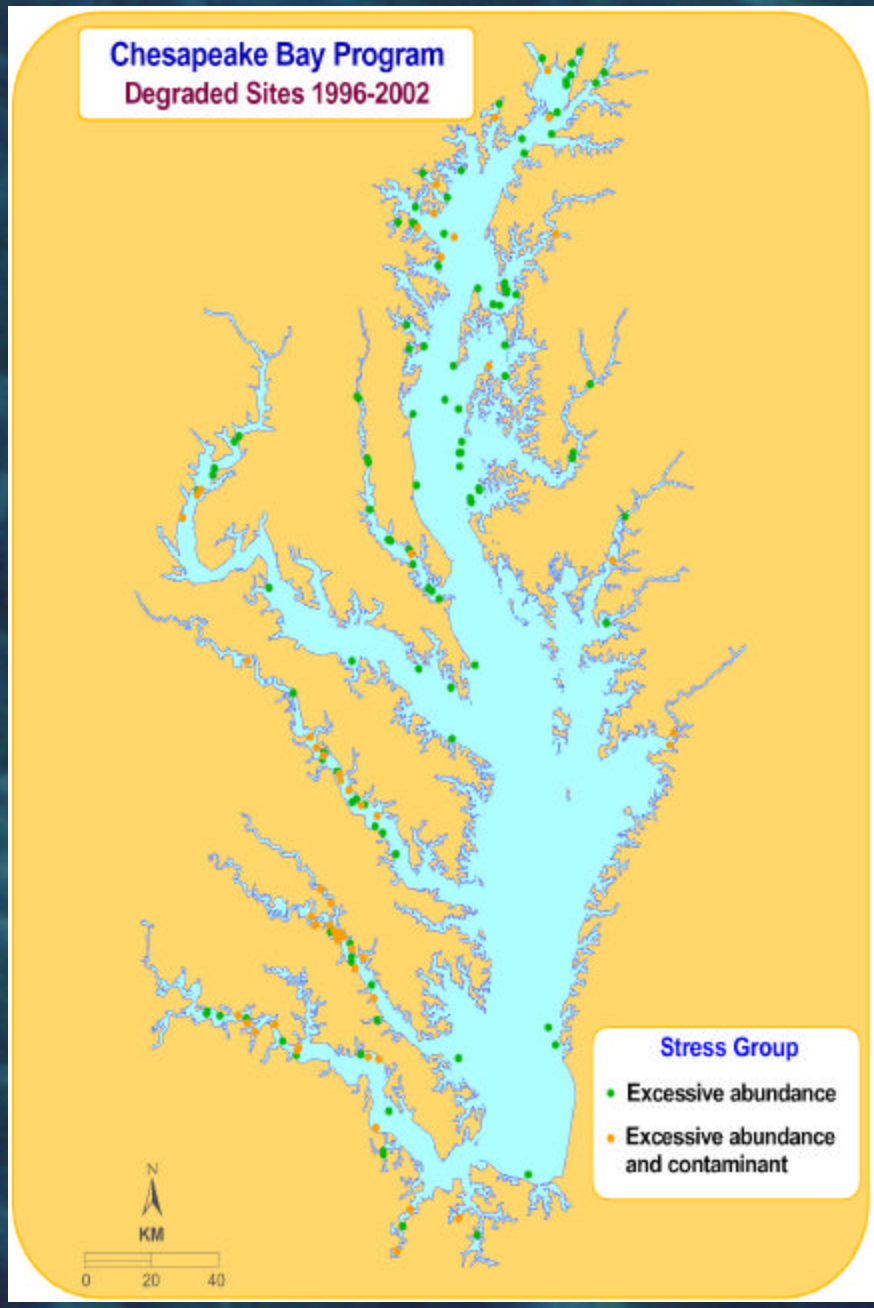

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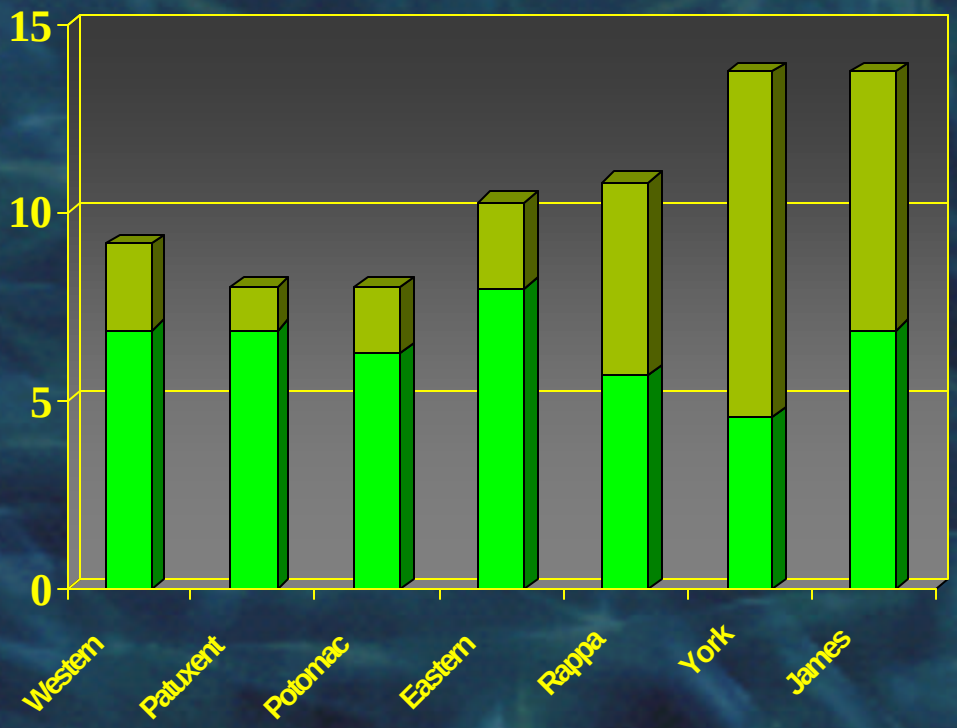

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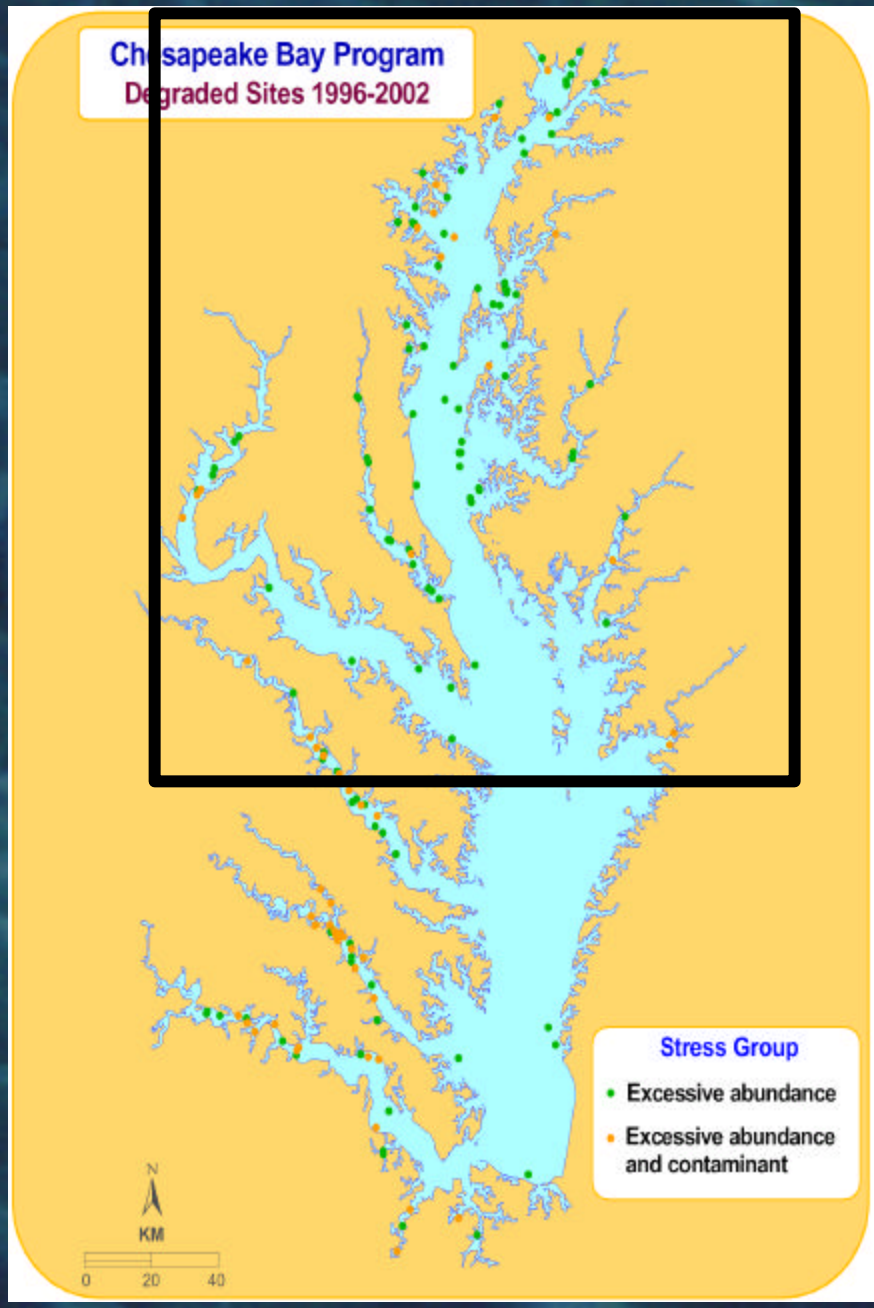
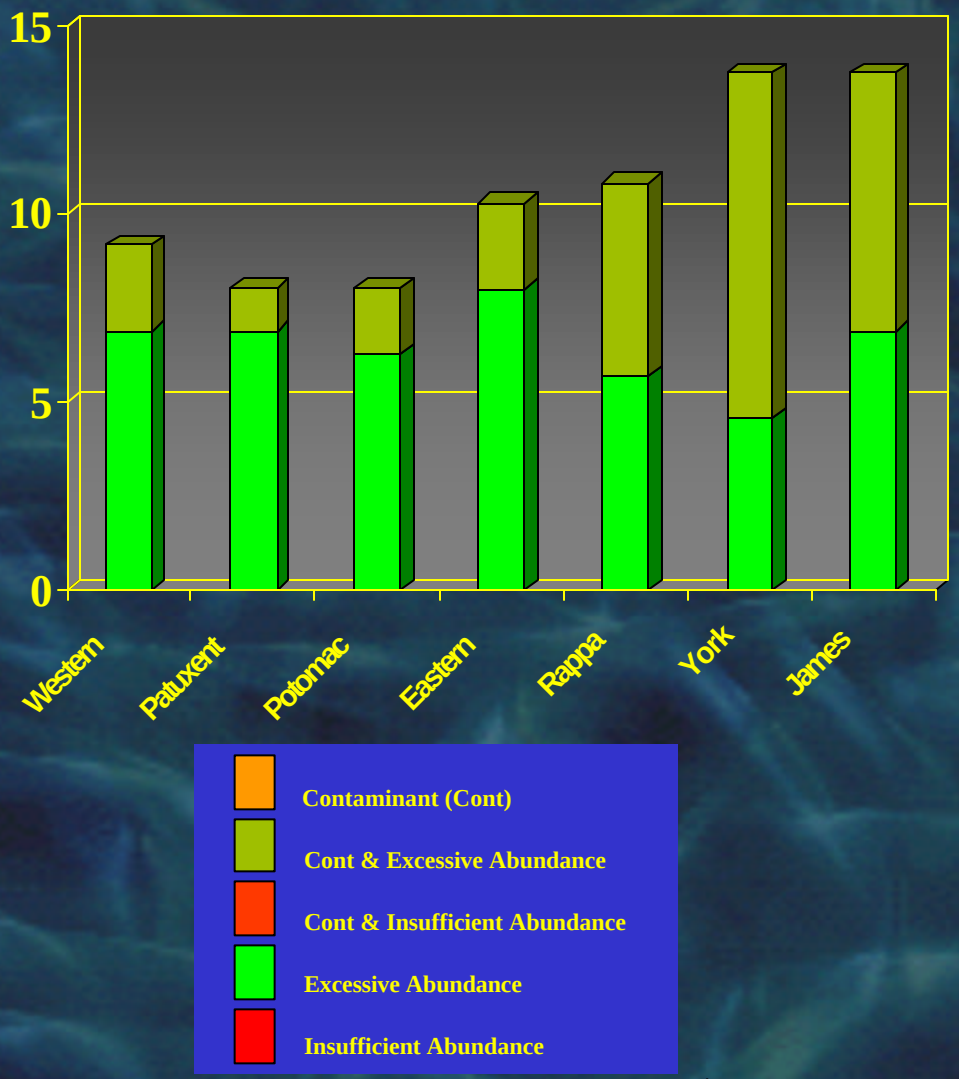
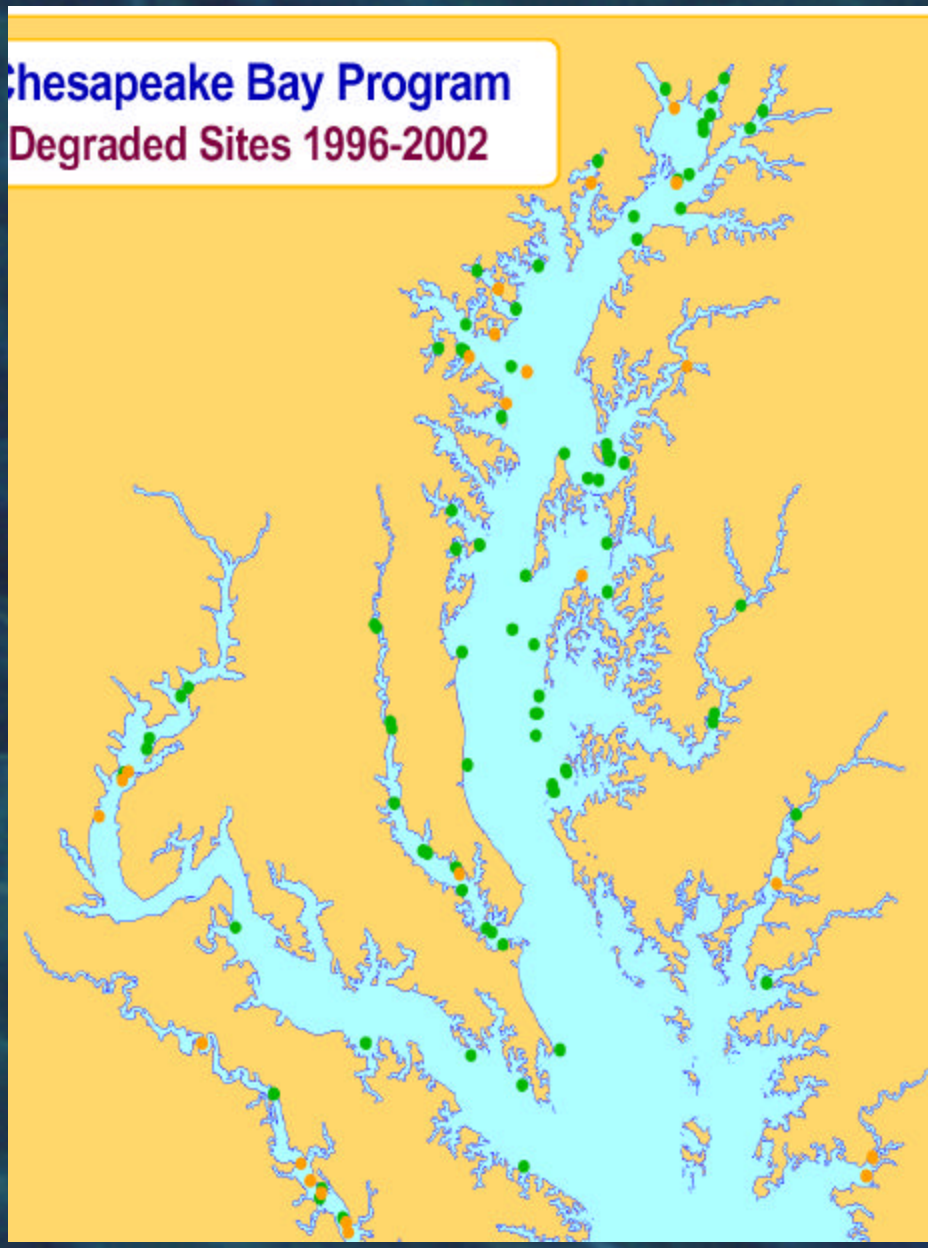


Moderate Eutrophication





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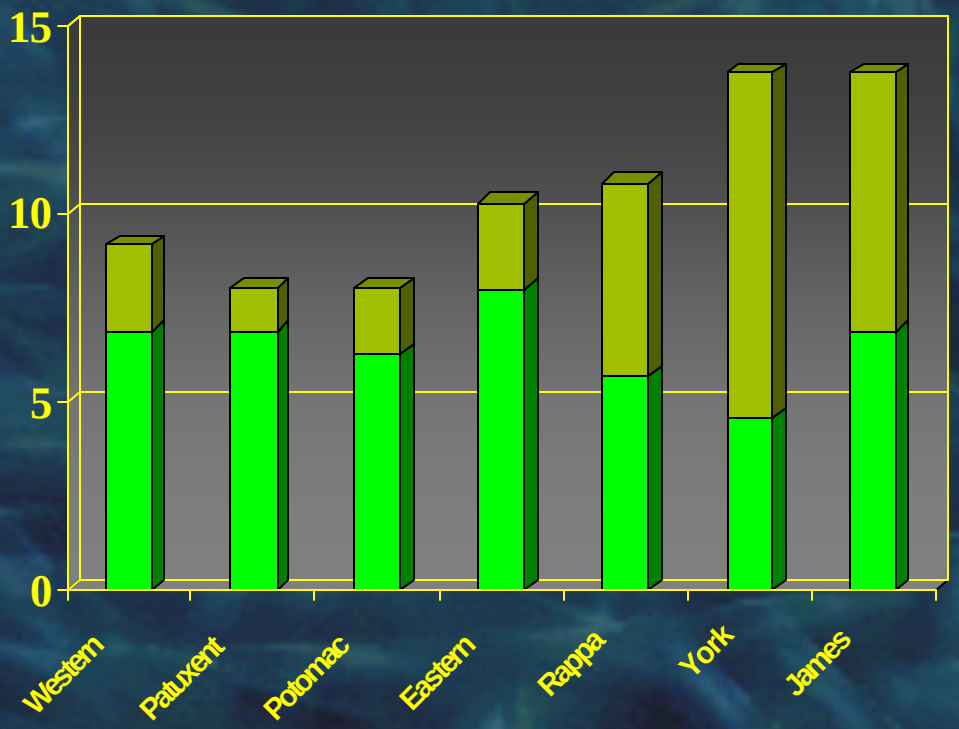

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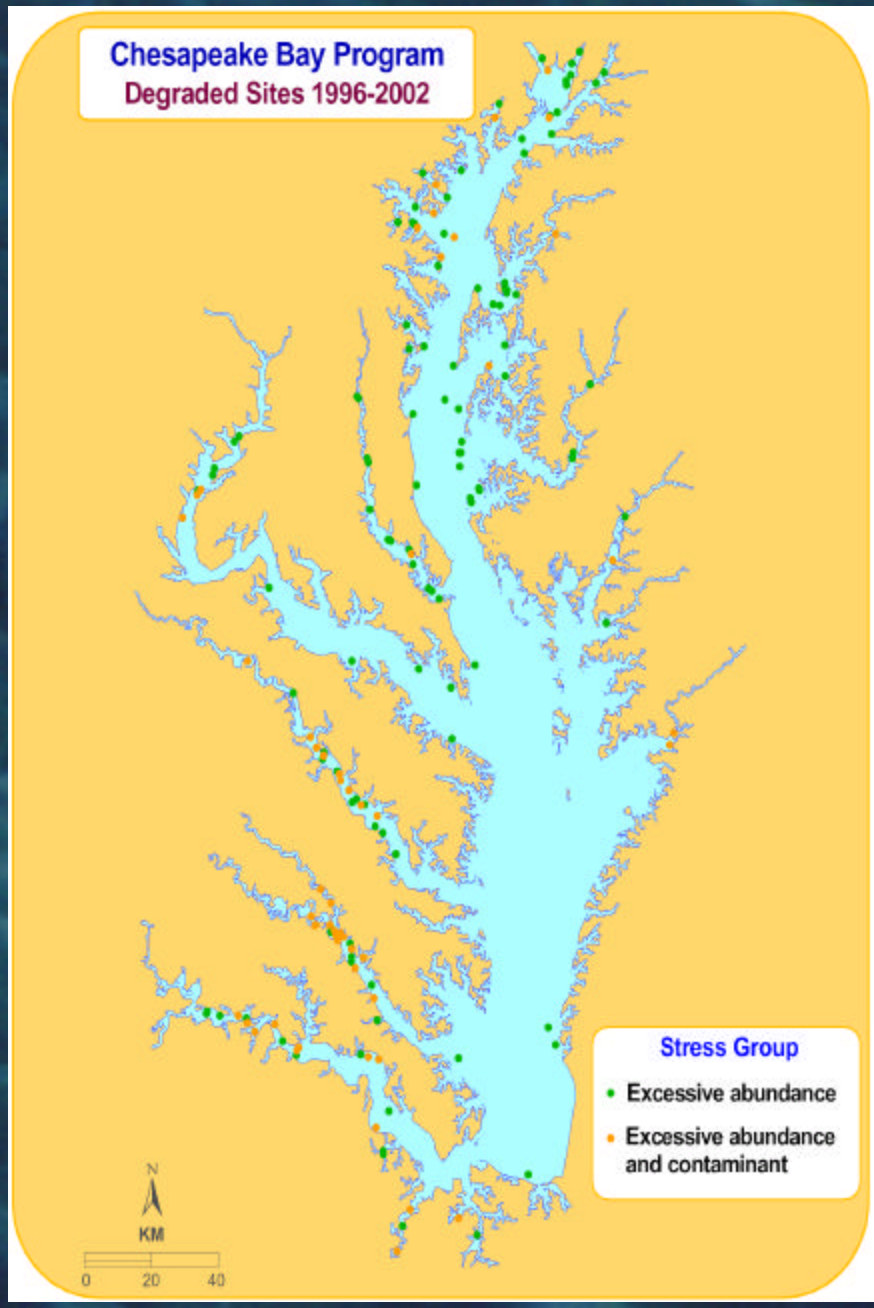

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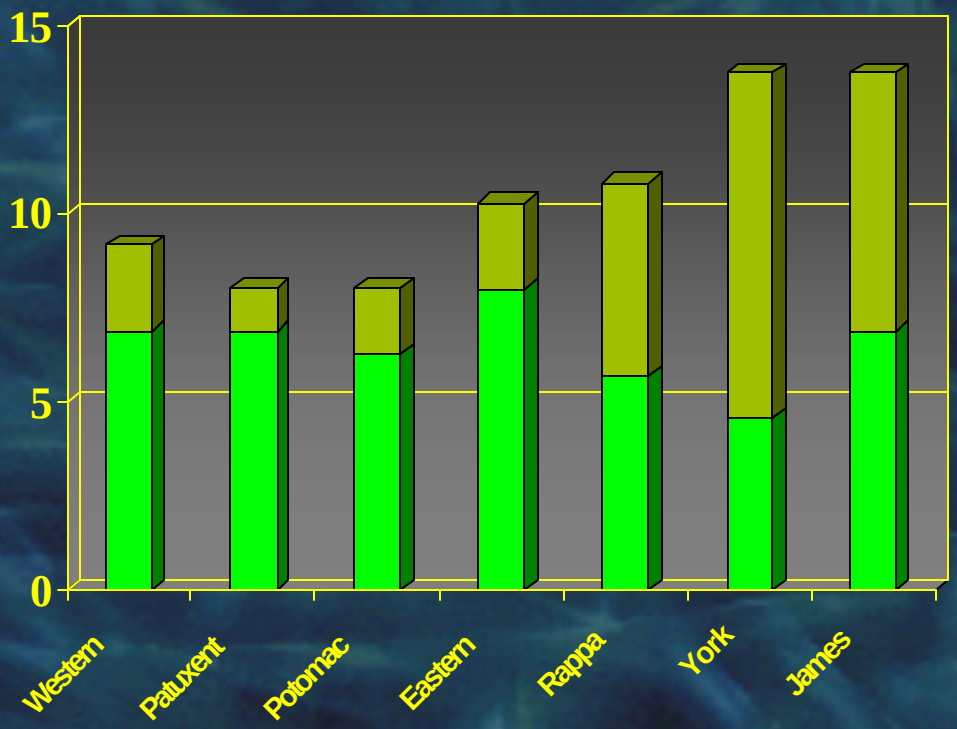

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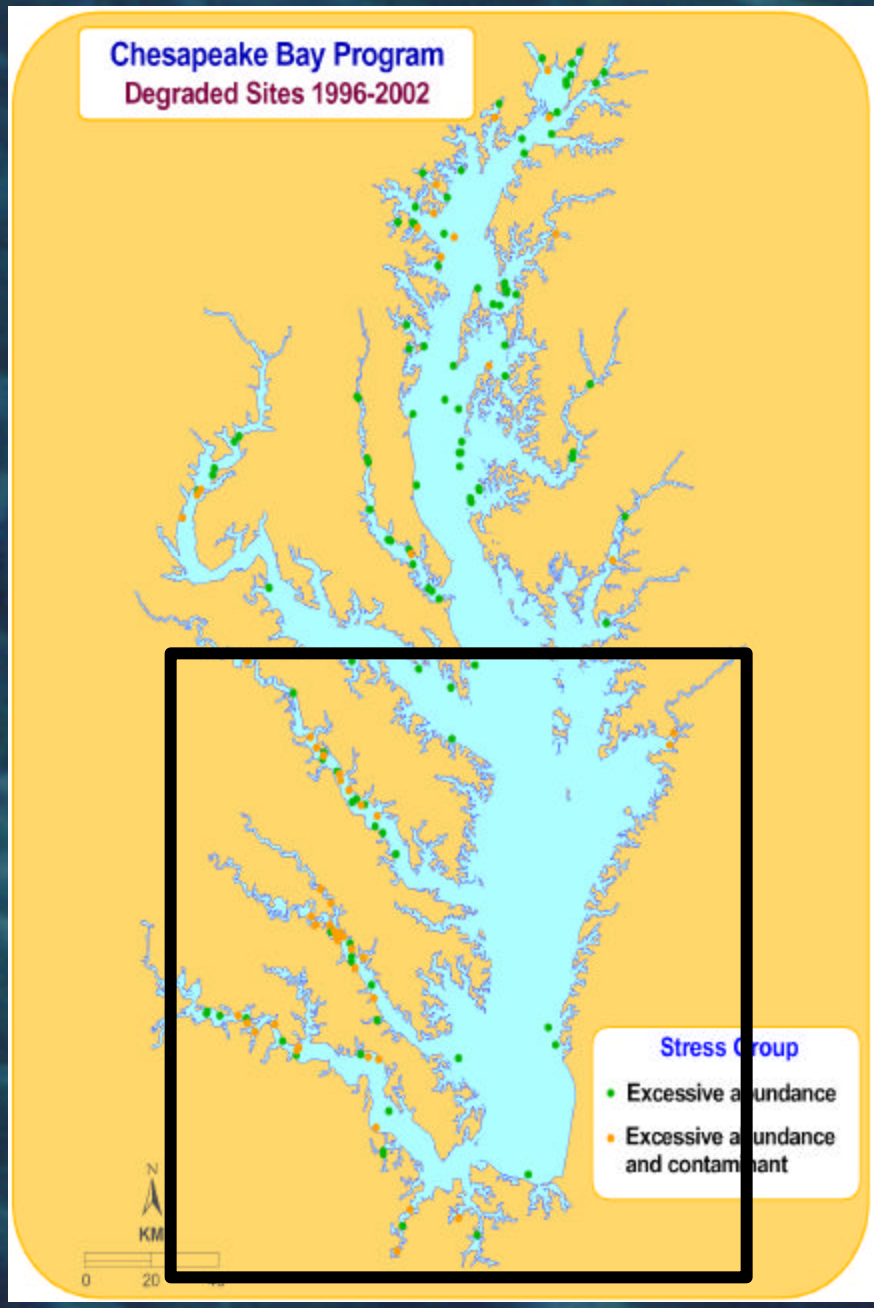

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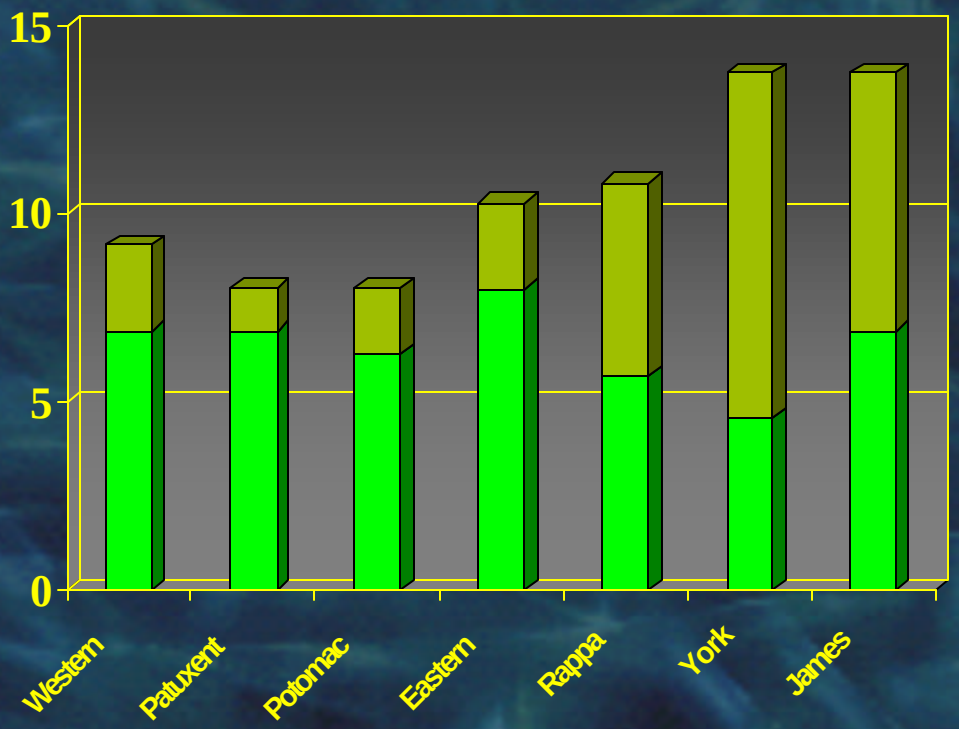

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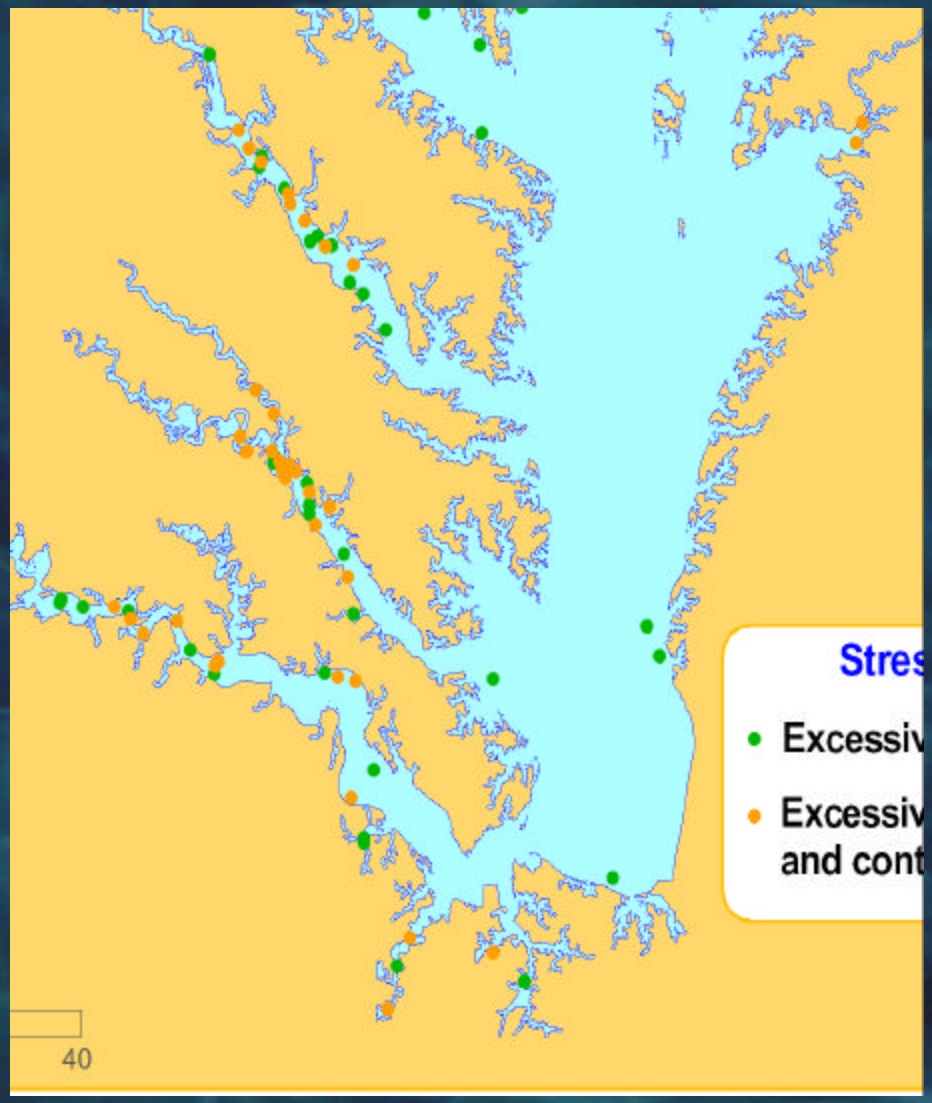

The Chesapeake Bay Benthic Experience

Causes of benthic community degradation

Contaminants

Complex DA function

Moderate Eutrophication

Simple – One Metric

Low Dissolved Oxygen

Simple – One Metric

The Bottom Line

The ultimate fate of all contaminants is to be deposited to the bottom.

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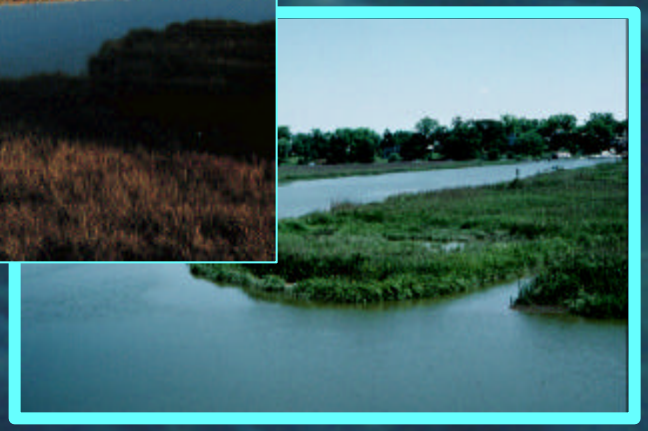
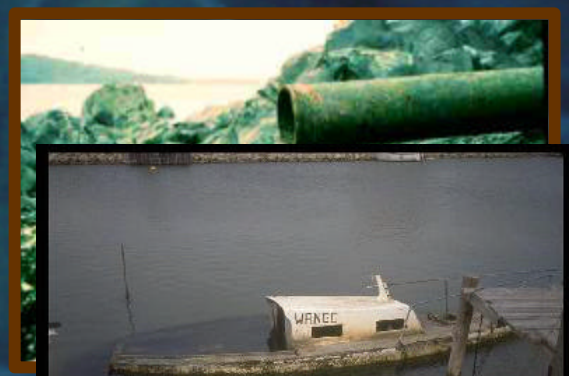
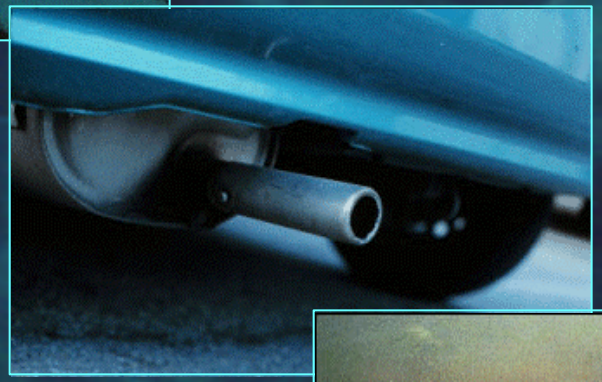
The End





WANEC