Chesapeake Bay Benthic Monitoring Program
Innovations and Accomplishments

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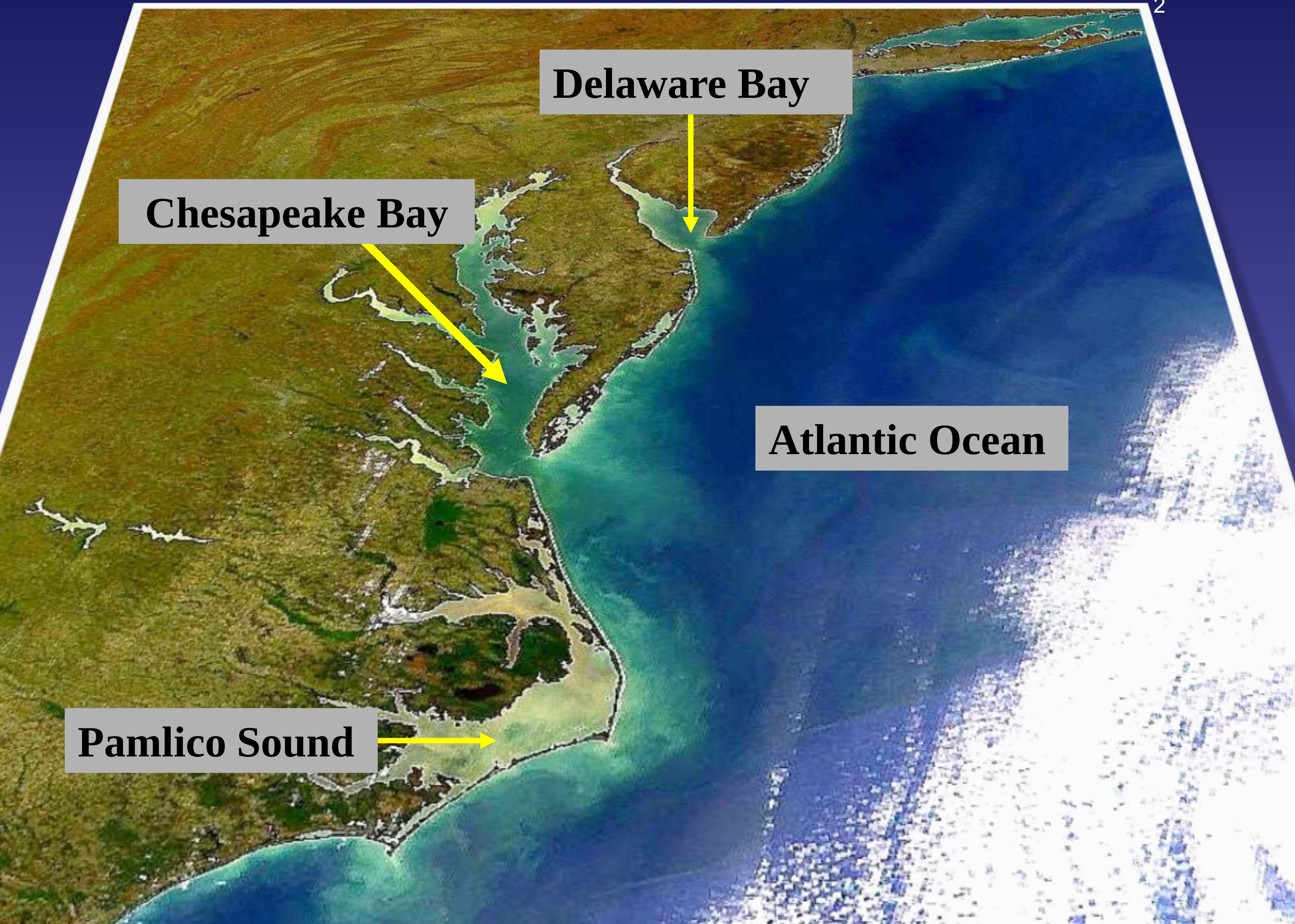

Delaware Bay
Chesapeake Bay
Atlantic Ocean
Pamlico Sound

Benthic Indicators, Monitoring Design and Interpretation Issues

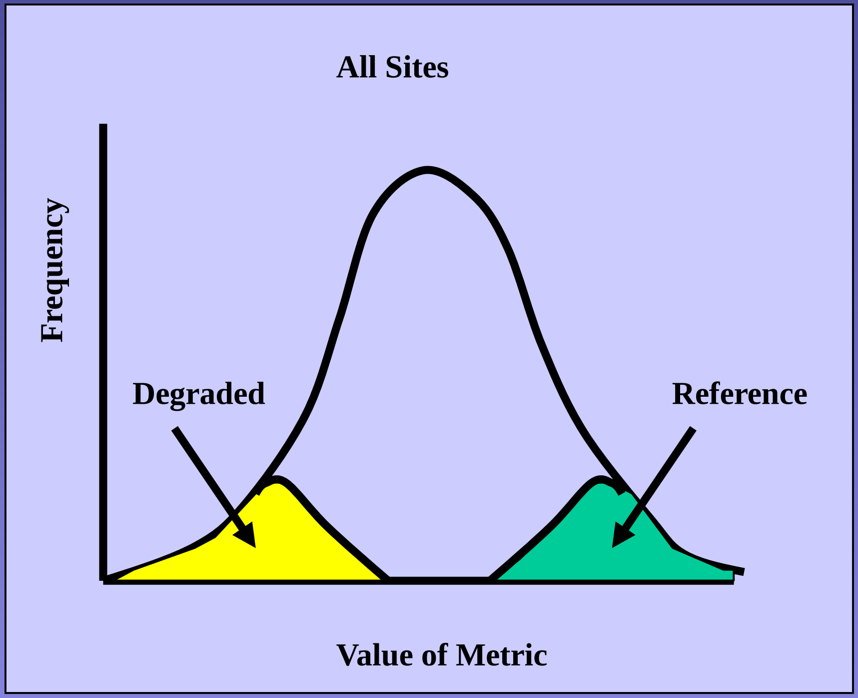
Overview

Chesapeake Bay accomplishments

1. Index development
2. Index relationship to watershed stressors
3. Sample allocation
4. Index relationship to habitat quality
5. Causes of degradation (diagnostics)
6. Impaired waters designations – 303(d)
7. Functional metric/index (Secondary productivity)
8. BIBI recalibration
9. International collaboration

(1) Benthic Index of Biotic Integrity (BIBI).

(Weisberg et al. 1997. Estuaries; Alden et al. 2002. Environmetrics)



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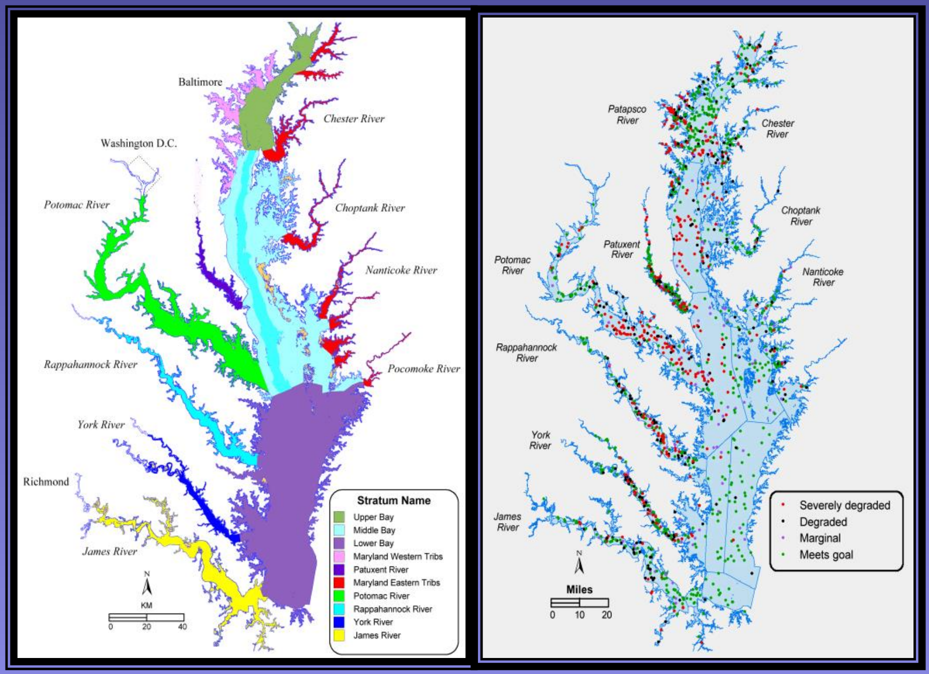

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(4) **Quantifying the relationship between benthic biotic integrity and benthic habitat quality.**

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

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

Low dissolved oxygen
Eutrophication
Sediment Contamination

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(7) Functional metric/index approach

Benthic Secondary Productivity

(Dauer et al. 2011. VADEQ Technical Report;
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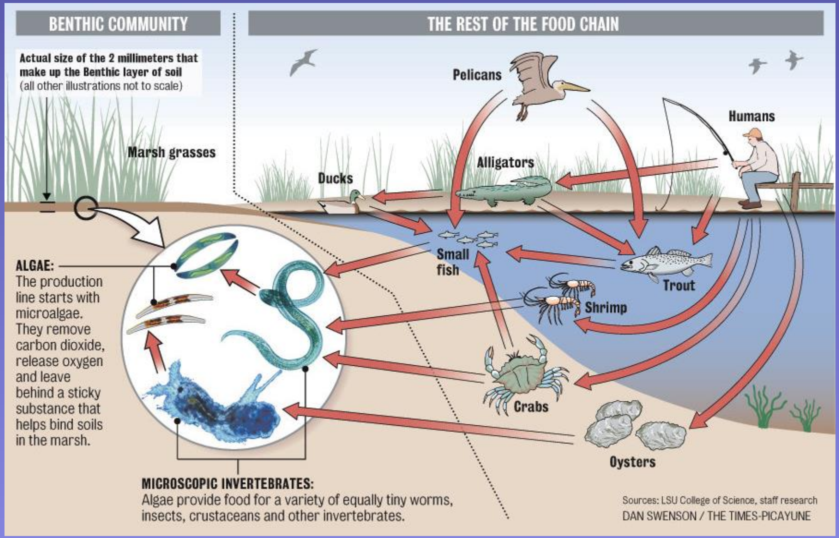

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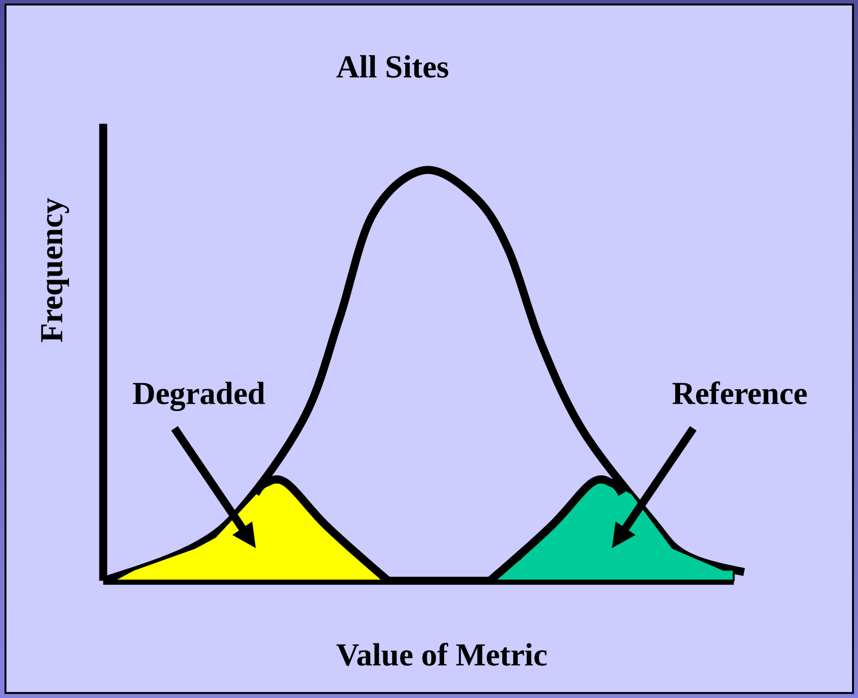

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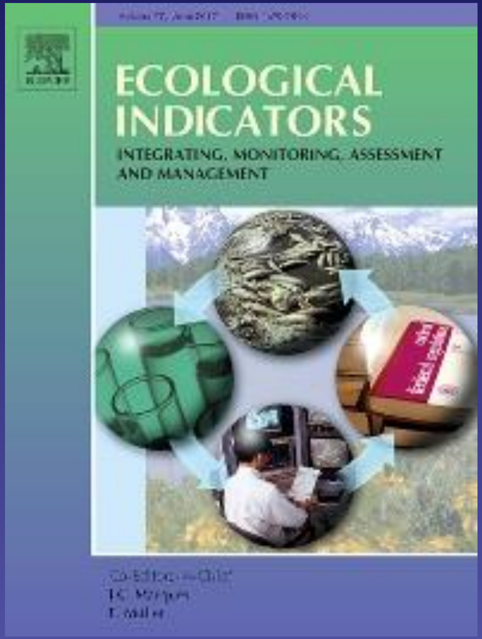

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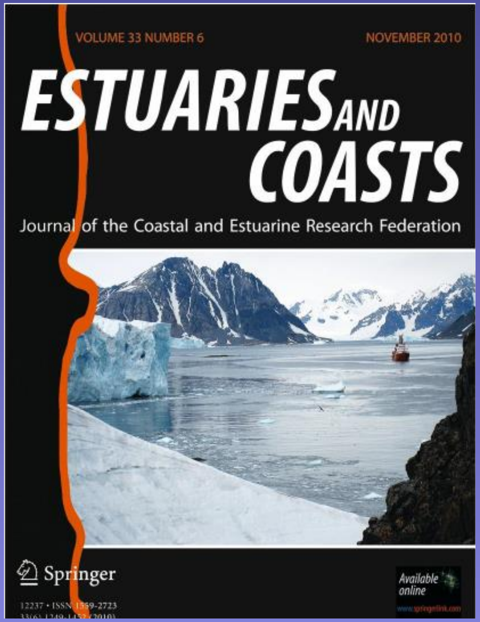

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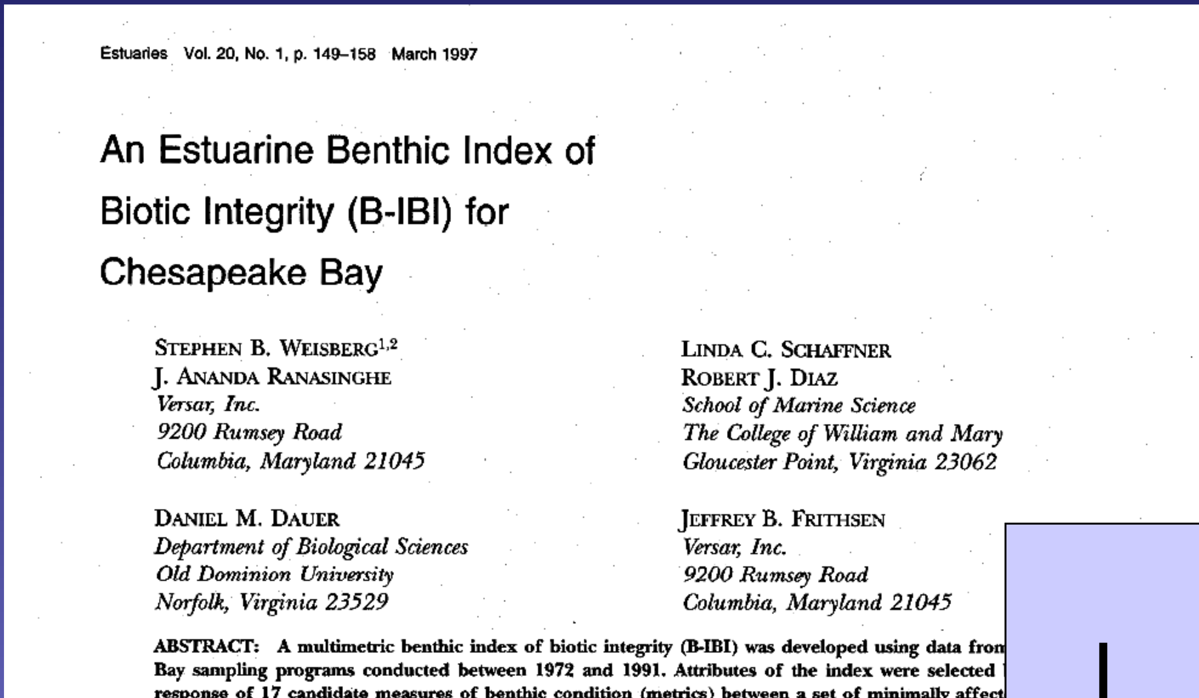

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An Estuarine Benthic Index of Biotic Integrity (B-IBI) for Chesapeake Bay

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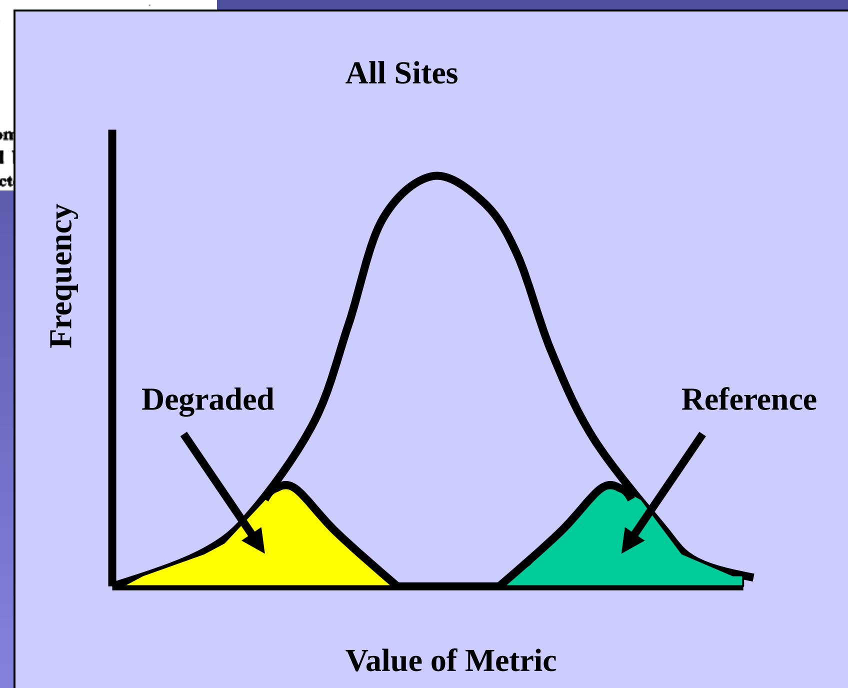
Columbia, Maryland 21045

ABSTRACT: A multimetric benthic index of biotic integrity (B-IBI) was developed using data fron
Bay sampling programs conducted between 1972 and 1991. Attributes of the index were selected
response of 17 candidate measures of benthic condition (metrics) between a set of minimally affect



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ENVIRONMETRICS
Environmetrics 2002; 13: 473–498 (DOI: 10.1002/env.548)

Statistical verification of the Chesapeake Bay benthic index of biotic integrity

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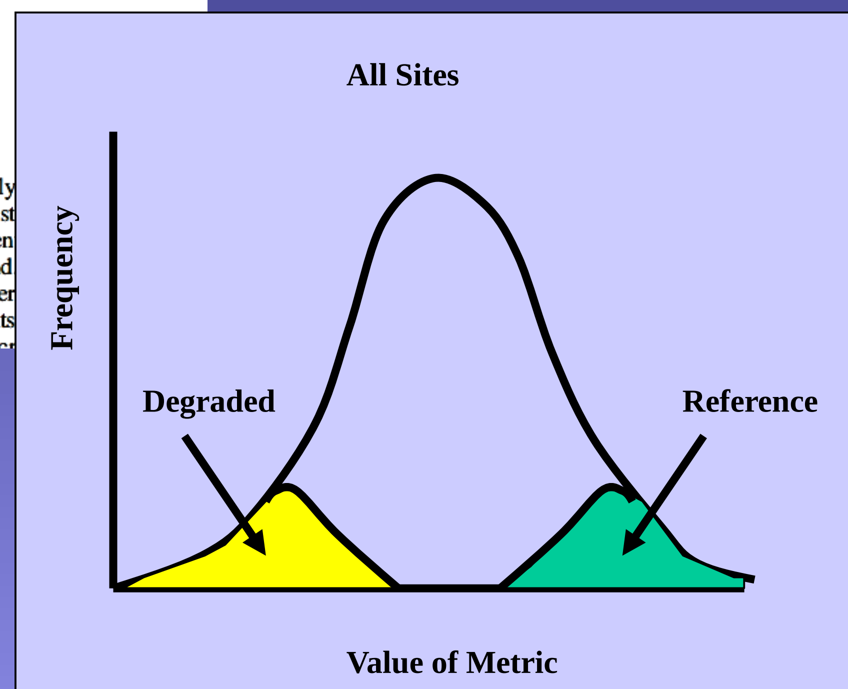
SUMMARY

The benthic index of biotic integrity (B-IBI) developed for the Chesapeake Bay was statistically simulations and a suite of multivariate statistical techniques. The B-IBI uses a simple scoring syst community metrics to assess benthic community health and to infer environmental quality of ben the Bay. Overall, the B-IBI was verified as being sensitive, stable, robust and statistically sound effectiveness of the B-IBI increased with salinity, from marginal performance for tidal freshwater excellent results for polyhaline areas. The greater classification uncertainty in low salinity habitats



Benthic Index of Biotic Integrity (B-IBI)

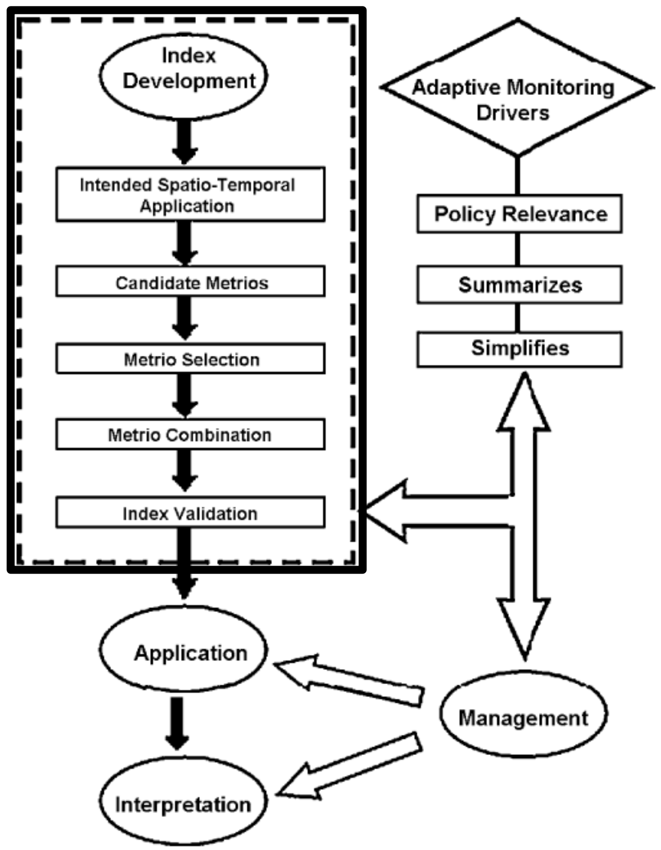
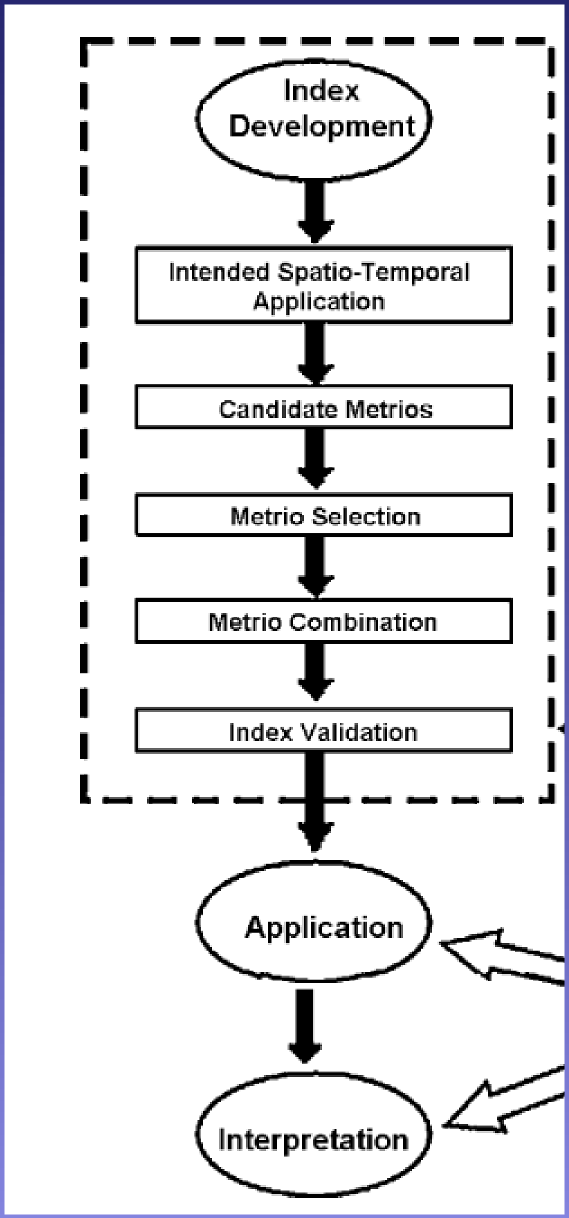


Fig. 2 – Index development, application and interpretation. Dashed rectangle encloses the primary steps in index development. Adaptive monitoring feedback loops and adaptive change decision drivers are indicted by open arrows.

Benthic Index of Biotic Integrity (B-IBI)



(i) Defining criteria for degraded and undegraded sites based on nonbiological measures such as bottom-water dissolved oxygen and sediment contaminant concentrations;

(ii) identifying biological measures which respond to (and differ among) degraded and undegraded sites;

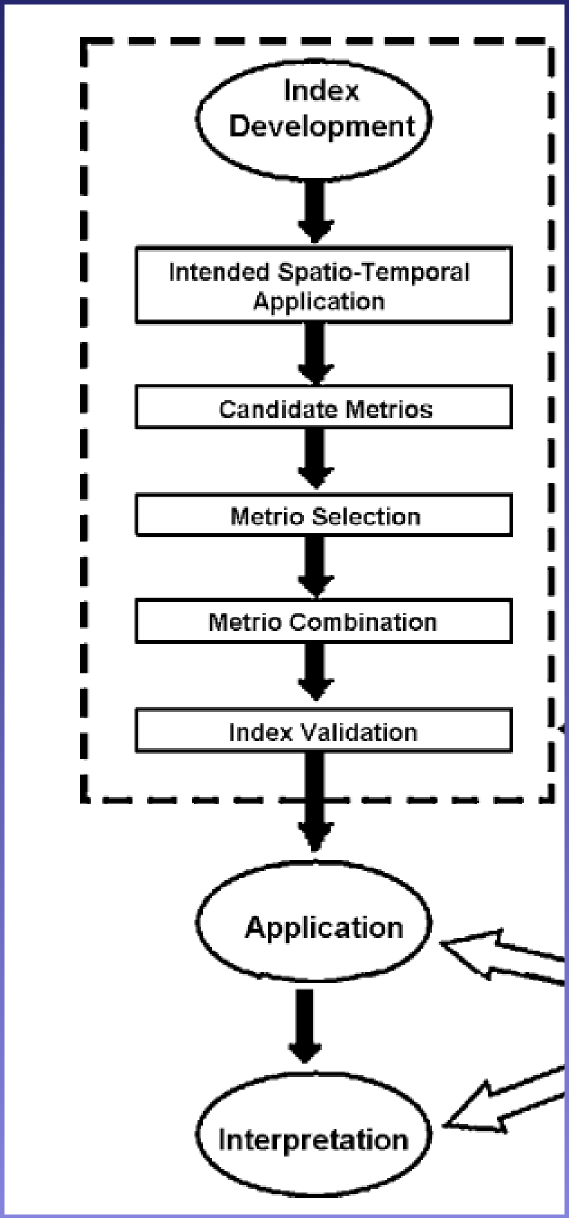
(iii) adjusting these responses for habitat differences, if necessary;

(iv) combining responsive measures into an index; and

(v) validating the index using independent data.

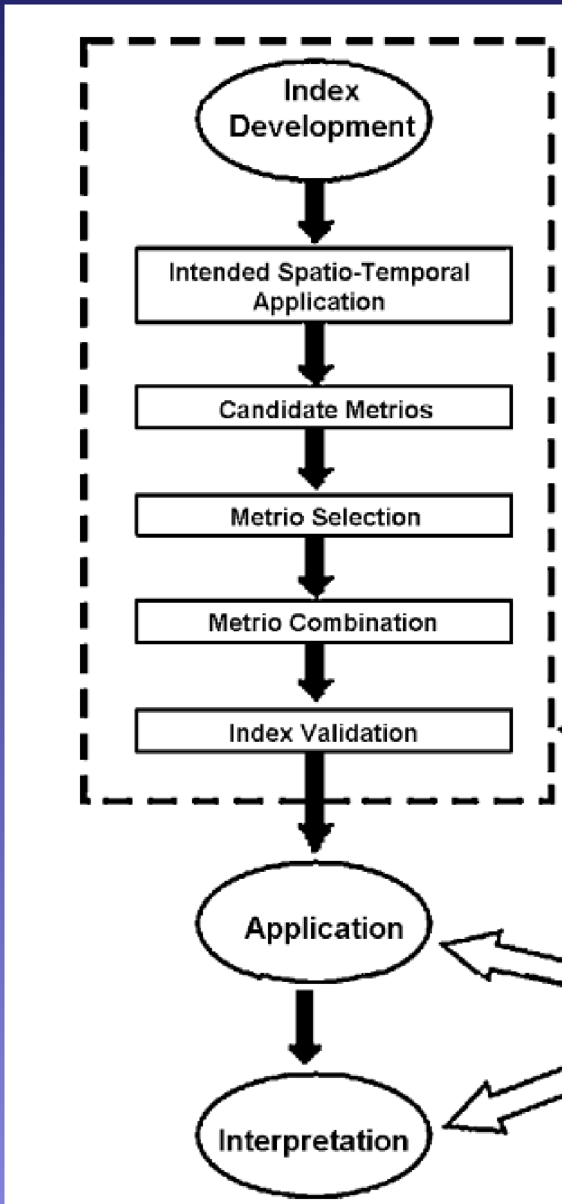
Indices formulated on ecological principles and properly validated will better communicate the complexity of ecological integrity.

Benthic Index of Biotic Integrity (B-IBI)



- Summer Index period July 15 – Sept. 30
- 17 Candidate Metrics
- Test Candidate Metrics (reference against degraded)
- Scaled scoring (1-3-5- or 1-3-5-3-1)
- Independent data set

Benthic Index of Biotic Integrity (B-IBI)



Eleven metrics are used to calculate the B-IBI:

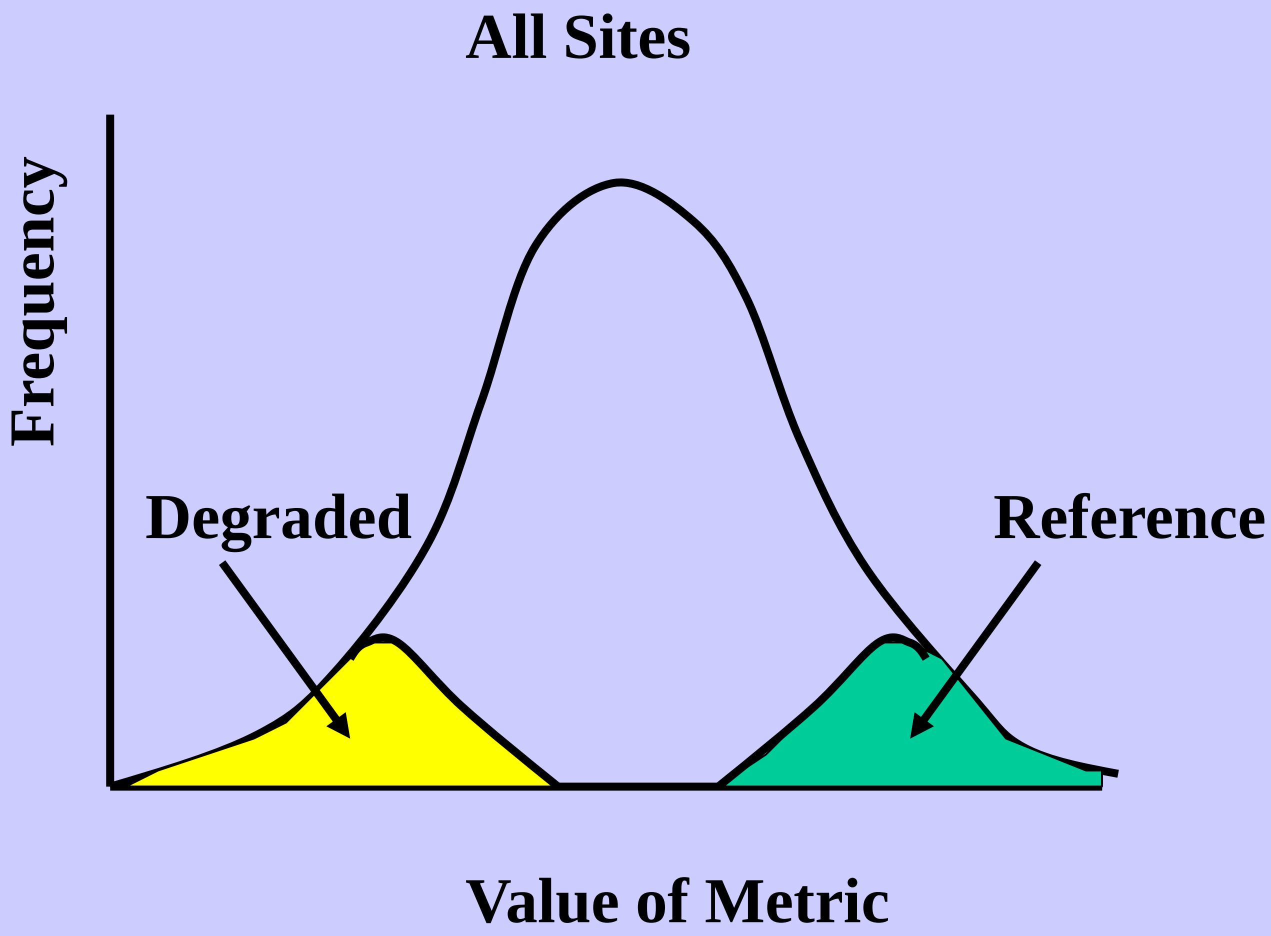
- Shannon-Wiener species diversity index
- Total species abundance
- Total species biomass
- Percent abundance of pollution-indicative taxa
- Percent abundance of pollution-sensitive taxa
- Percent biomass of pollution-indicative taxa
- Percent biomass of pollution-sensitive taxa
- Percent abundance of carnivore and omnivores
- Percent abundance of deep-deposit feeders
- Tolerance Score
- Tanypodini to Chironomidae percent abundance ratio

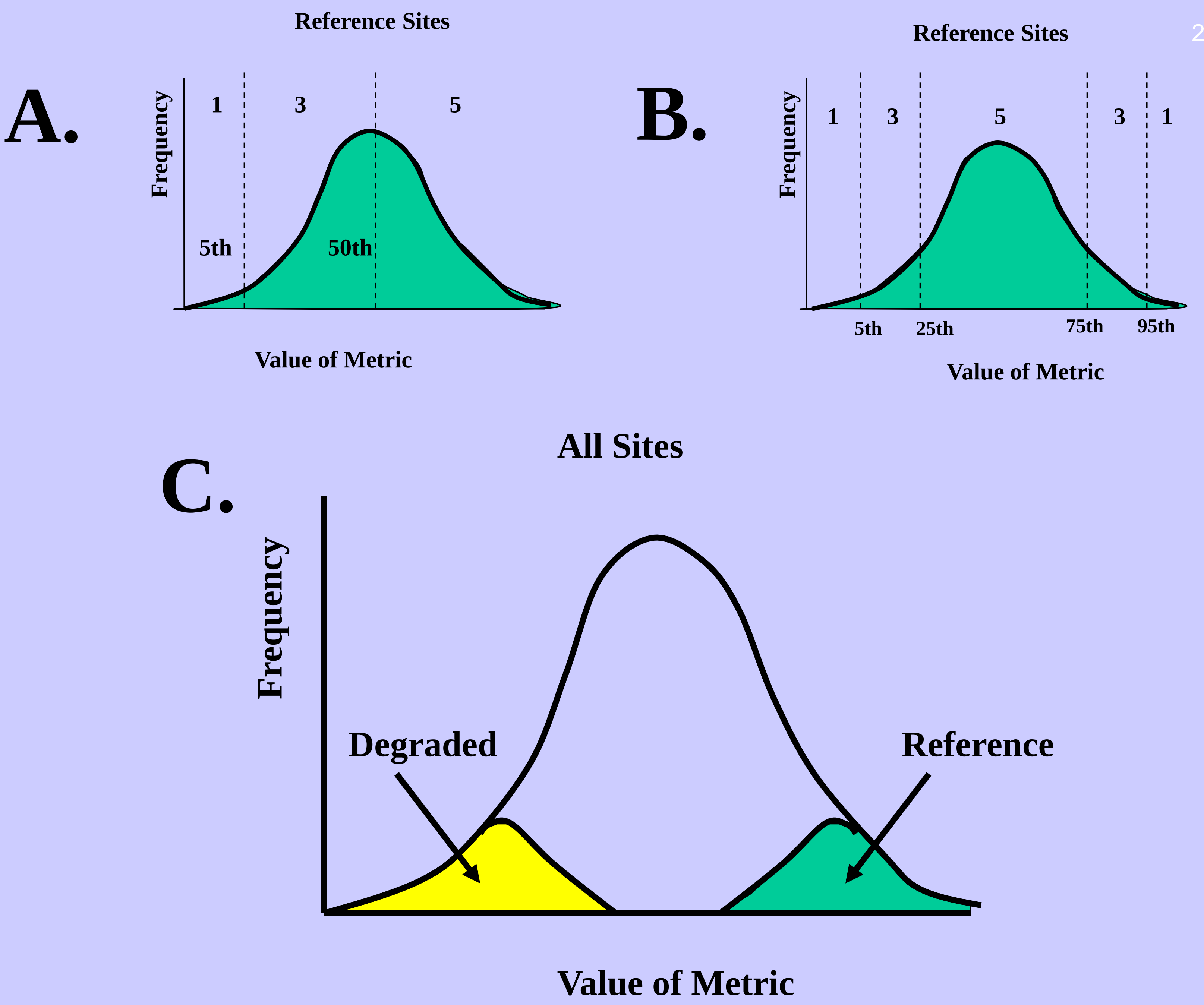
Benthic Index of Biotic Integrity (B-IBI)

Metric selection and scoring thresholds habitat specific (7 habitats determined)

Habitat	Bottom Salinity (psu)	Silt-clay (<63 µ) content by weight (%)
Tidal freshwater	< 0.5	N/A
Oligohaline	≥ 0.5 - 5	N/A
Low Mesohaline	≥ 5 – 12	N/A
High Mesohaline sand	≥ 12 - 18	0 - 40
High Mesohaline mud	≥ 12 - 18	> 40
Polyhaline sand	≥ 18	0 - 40
Polyhaline mud	≥ 18	> 40

Index of Biotic Integrity (IBI)




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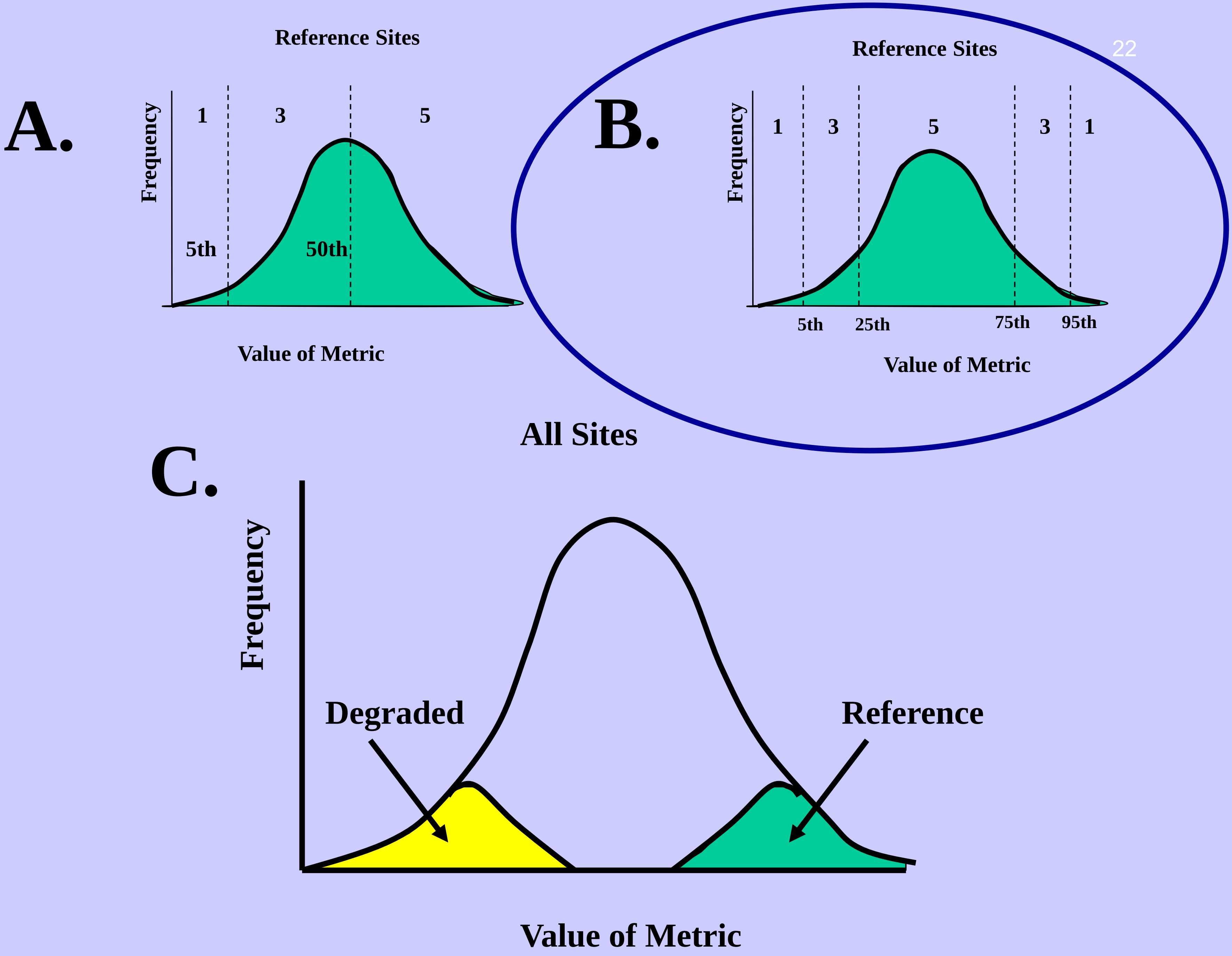
Frequency
1
3
5
5th
50th
Value of Metric
Reference Sites
B.
Frequency
1
3
5
3
1
5th
25th
75th
95th
Value of Metric
All Sites
C.
Frequency
Degraded
Reference
Value of Metric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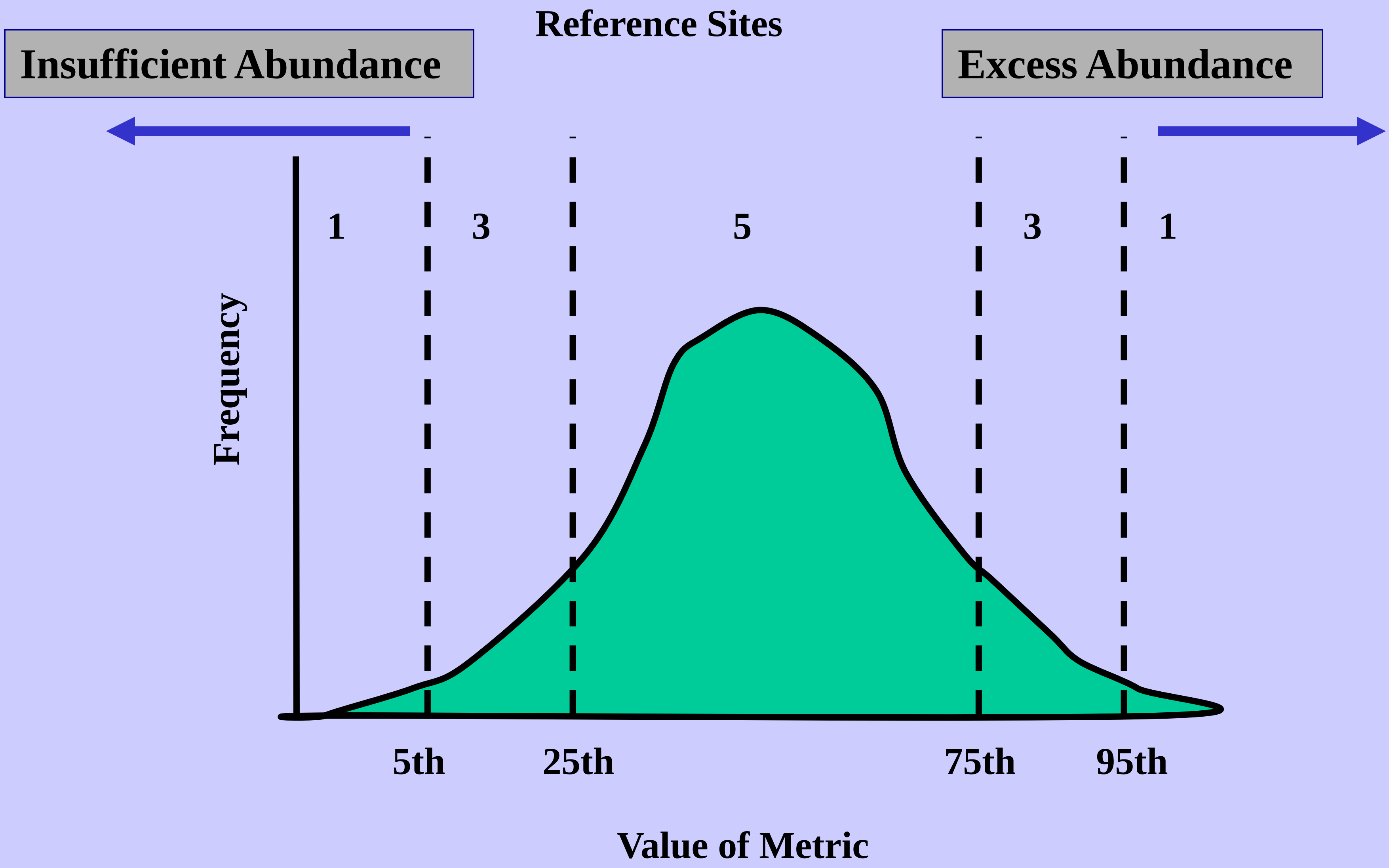


Chesapeake Bay - B-IBI

- Value is the mean of the metric scores
- Range is 1-5
- Values < 3 represent degraded benthos
- Values ≥ 3 represent undegraded benthos

B-IBI Thresholds
Example of Polyhaline Sand Habitat

	Score		
	5	3	1
Shannon-Wiener	≥3.5	2.7-3.5	<2.7
Abundance (m^{-2})	≥3,000-5,000	1,500-3,000 or ≥5,000-8,000	<1,500 or ≥8,000
Biomass ($g\ m^{-2}$)	≥5-20	1-5 or ≥20-50	<1 or ≥50
Pollution Indicative species biomass (%)	≤ 5	5-15	> 15
Pollution Sensitive species abundance (%)	≥50	25-50	<25
Deep deposit feeder abundance (%)	≥25	10-25	<10

B-IBI

Summary Advantages

Simple communication

Binomial categories

≥ 3 represent undegraded condition

< 3 represent degraded condition

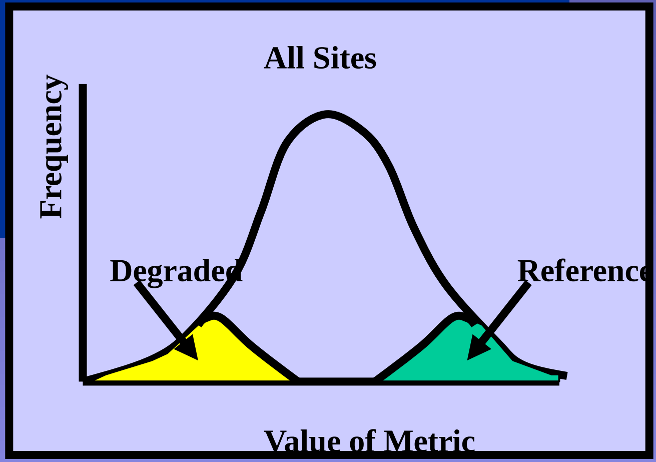
Additional categories

≥ 3 represent undegraded condition

2.9 – 2.7 – Marginal

2.6 – 2.1 – Degraded

≥ 2.0 – Severely degraded



B-IBI

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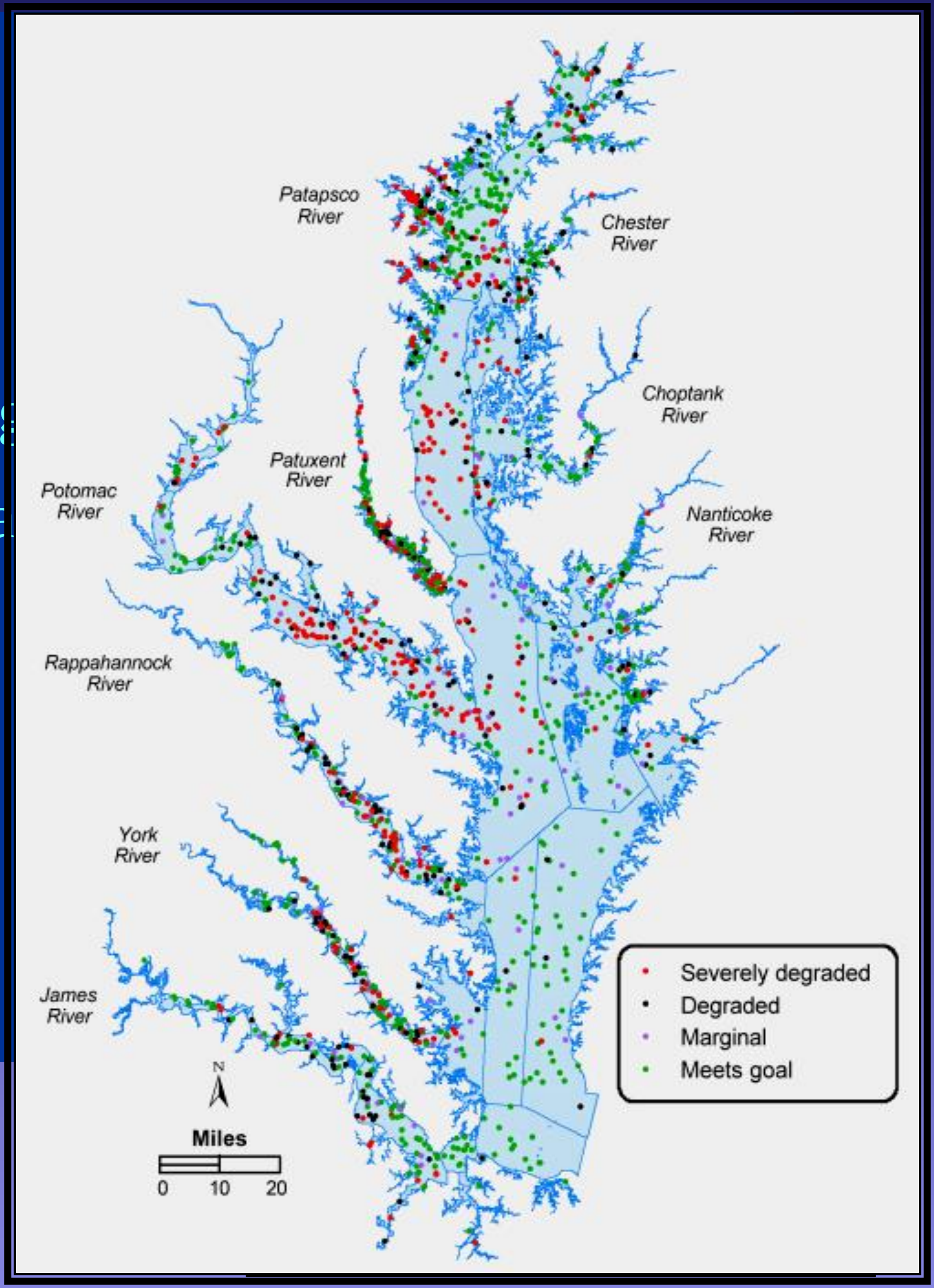
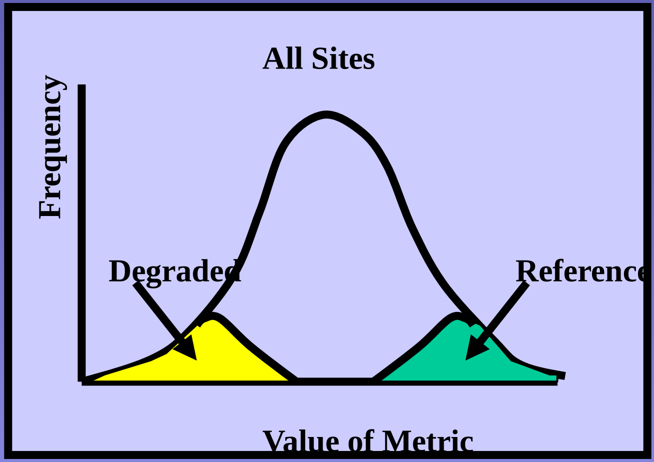


B-IBI

Summary Advantages

1. Simple communication
2. Metric thresholds become Restoration Goals
3. Metrics can be examined for additional insight into causes of degradation



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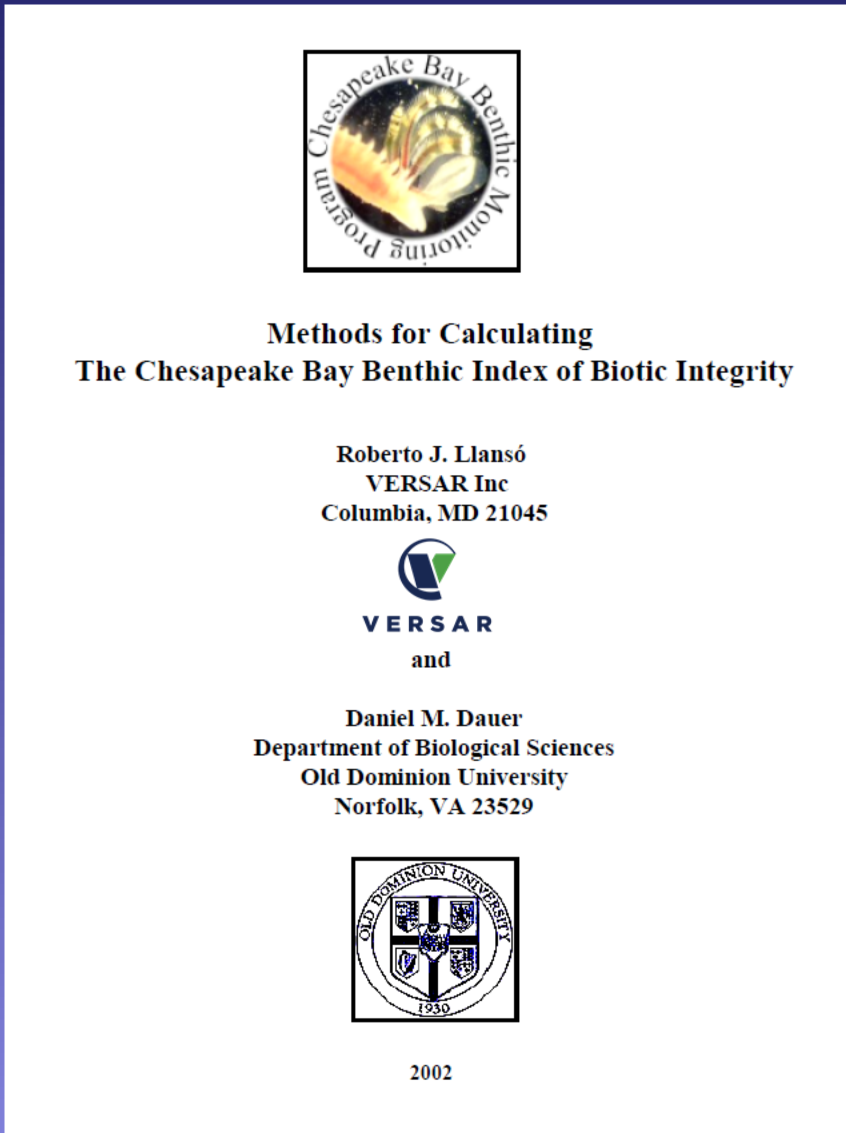
Chesapeake Bay Benthic Monitoring Program

Methods for Calculating
The Chesapeake Bay Benthic Index of Biotic Integrity

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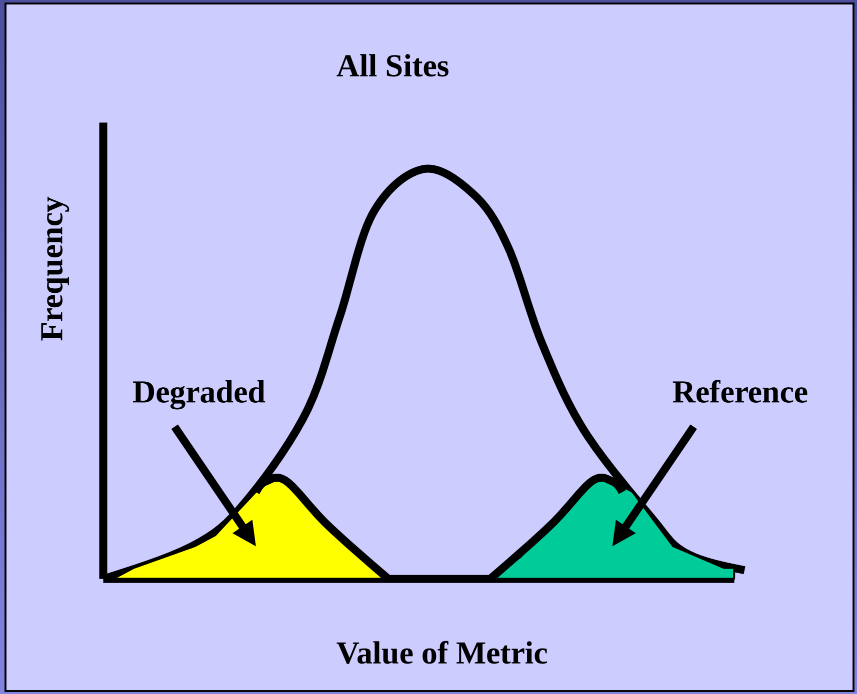
2002



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Relationships Between Benthic Community Condition, Water Quality, Sediment Quality, Nutrient Loads, and Land Use Patterns in Chesapeake Bay

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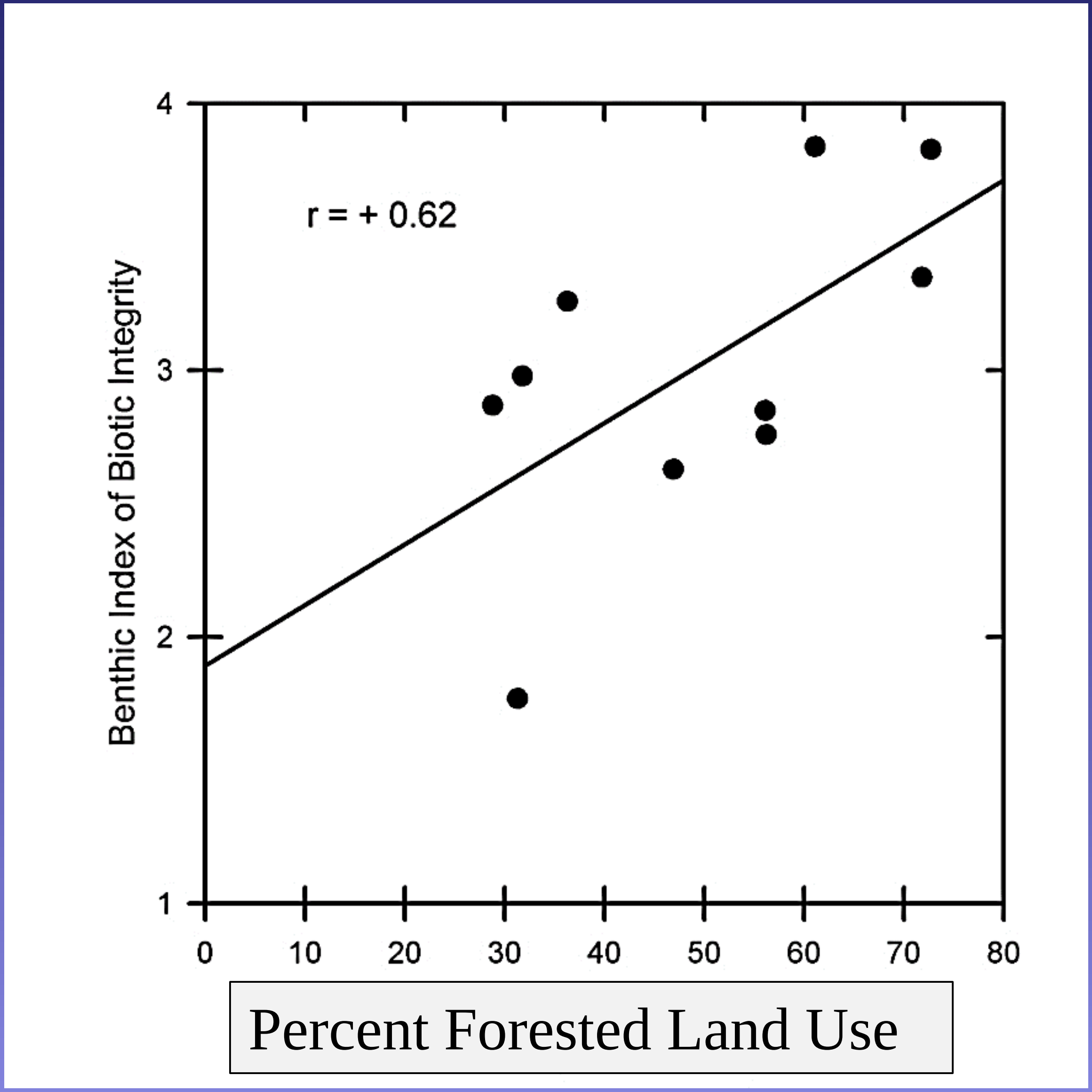
ABSTRACT: Associations between macrobenthic communities, measures of water column and sediment ex
measures of anthropogenic activities throughout the watershed were examined for the Chesapeake Bay, U.S
dition of the macrobenthic communities was indicated by a multimetric benthic index of biotic integrity (
compares deviation of community metrics from values at reference sites assumed to be minimally altered b
genic sources of stress. Correlation analysis was used to examine associations between sites with poor benthi
and measures of pollution exposure in the water column and sediment. Low dissolved oxygen events we
extensive and strongly correlated with benthic community condition, explaining 42% of the variation in the
iment contamination was spatially limited to a few specific locations including Baltimore Harbor and the South

BIBI and Land Use



BIBI and Land Use

Marine Pollution Bulletin 59 (2009) 14–25

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Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Development and evaluation of a spatially-explicit index of Chesapeake Bay health

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ARTICLE INFO

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Environmental health index
Secchi depth
Submerged aquatic vegetation
Water quality

ABSTRACT

In an effort to better portray changing health conditions in Chesapeake Bay and support restoration efforts, a Bay Health Index (BHI) was developed to assess the ecological effects of nutrient and sediment loading on 15 regions of the estuary. Three water quality and three biological measures were combined to formulate the BHI. Water quality measures of chlorophyll-a, dissolved oxygen, and Secchi depth were averaged to create the Water Quality Index (WQI), and biological measures of the phytoplankton and benthic indices of biotic integrity (P-IBI and B-IBI, respectively) and the area of submerged aquatic vegetation (SAV) were averaged to create the Biotic Index (BI). The WQI and BI were subsequently averaged to give a BHI value representing ecological conditions over the growing season (i.e., March–October). Lower chlorophyll-a concentrations, higher dissolved oxygen concentrations, deeper Secchi depths,

BIBI and Land Use

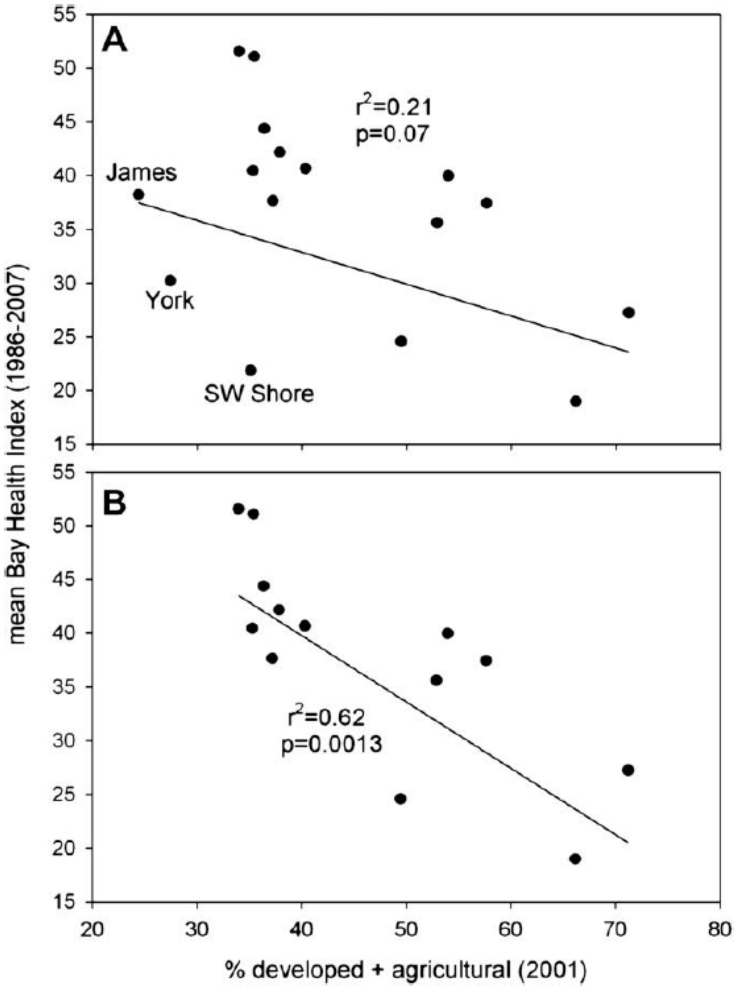
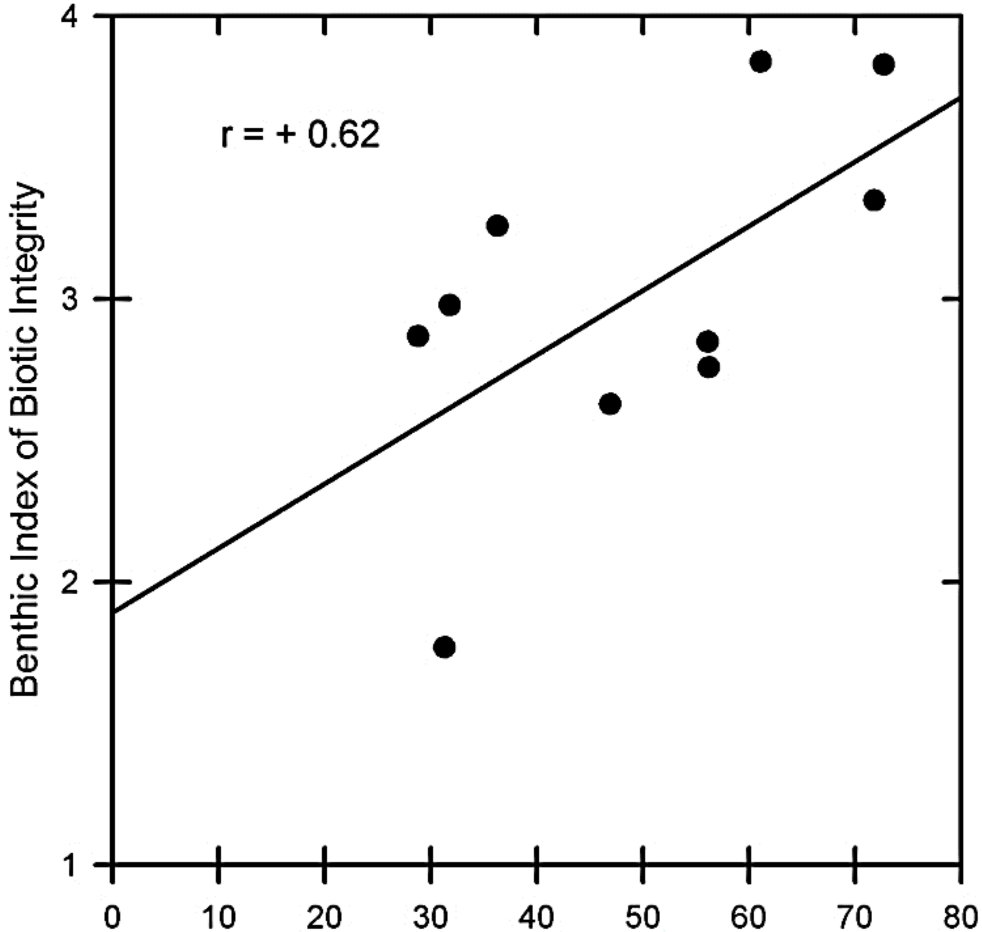
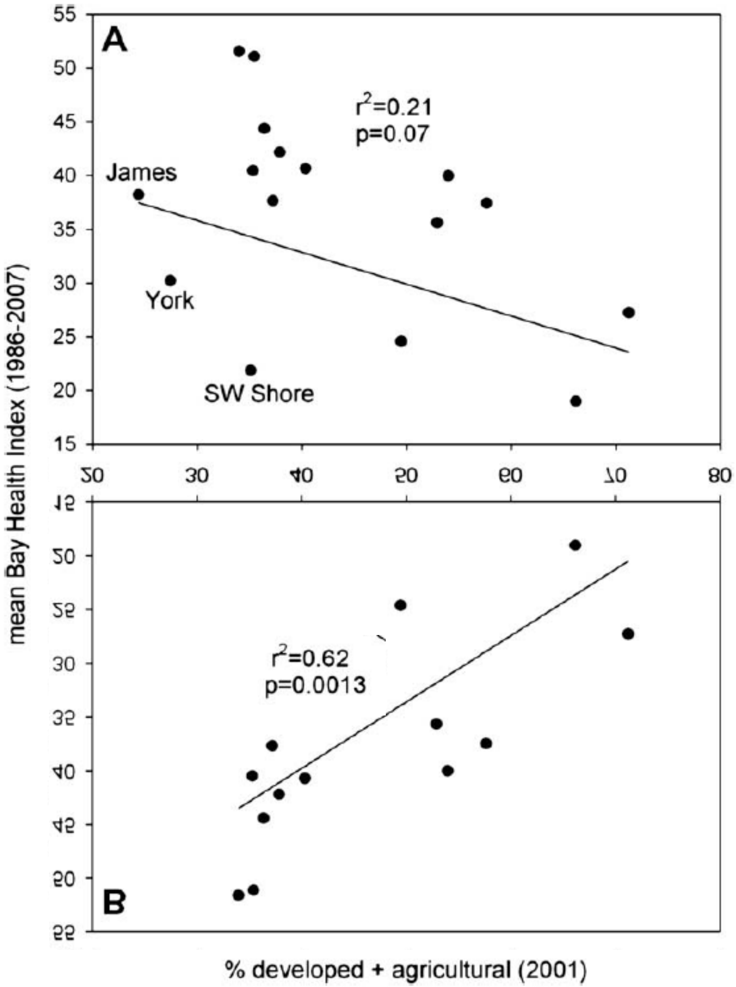


Fig. 6. The total of developed and agricultural land use (2001) (as % of total area in each reporting region) versus the mean Bay Health Index from 1985 to 2007 using all reporting regions (panel A) and without the James, York and SW tributary regions included (panel B).



Percent Forested Land Use

BIBI and Land Use



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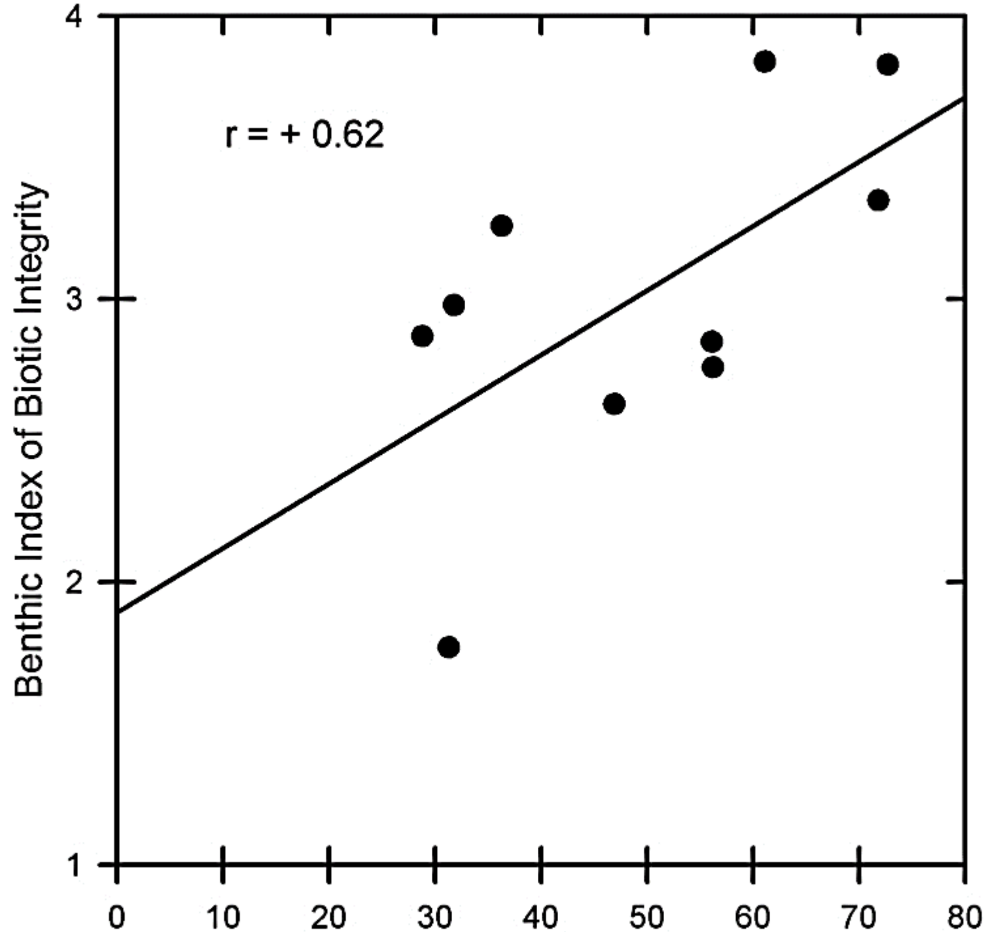
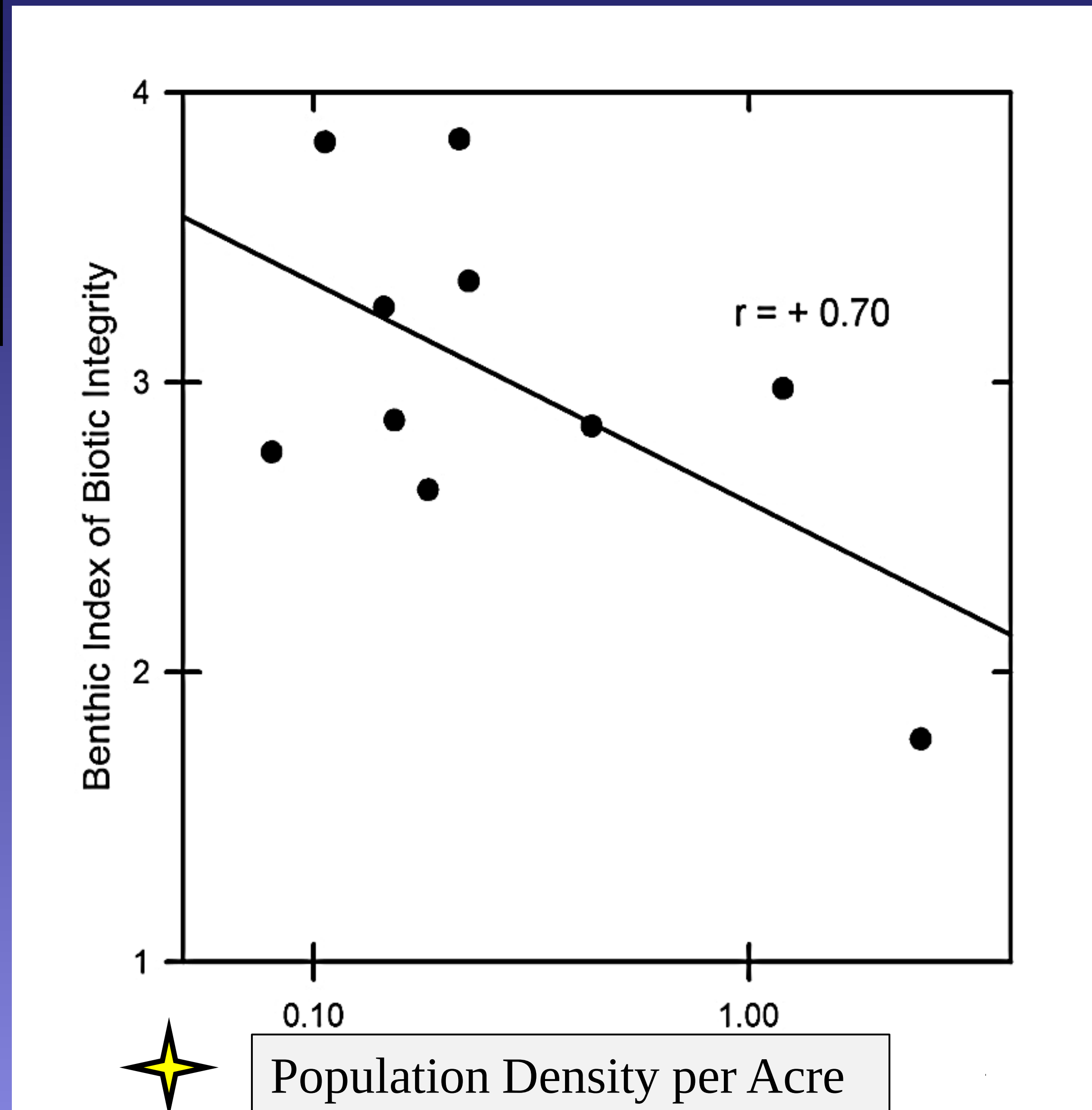
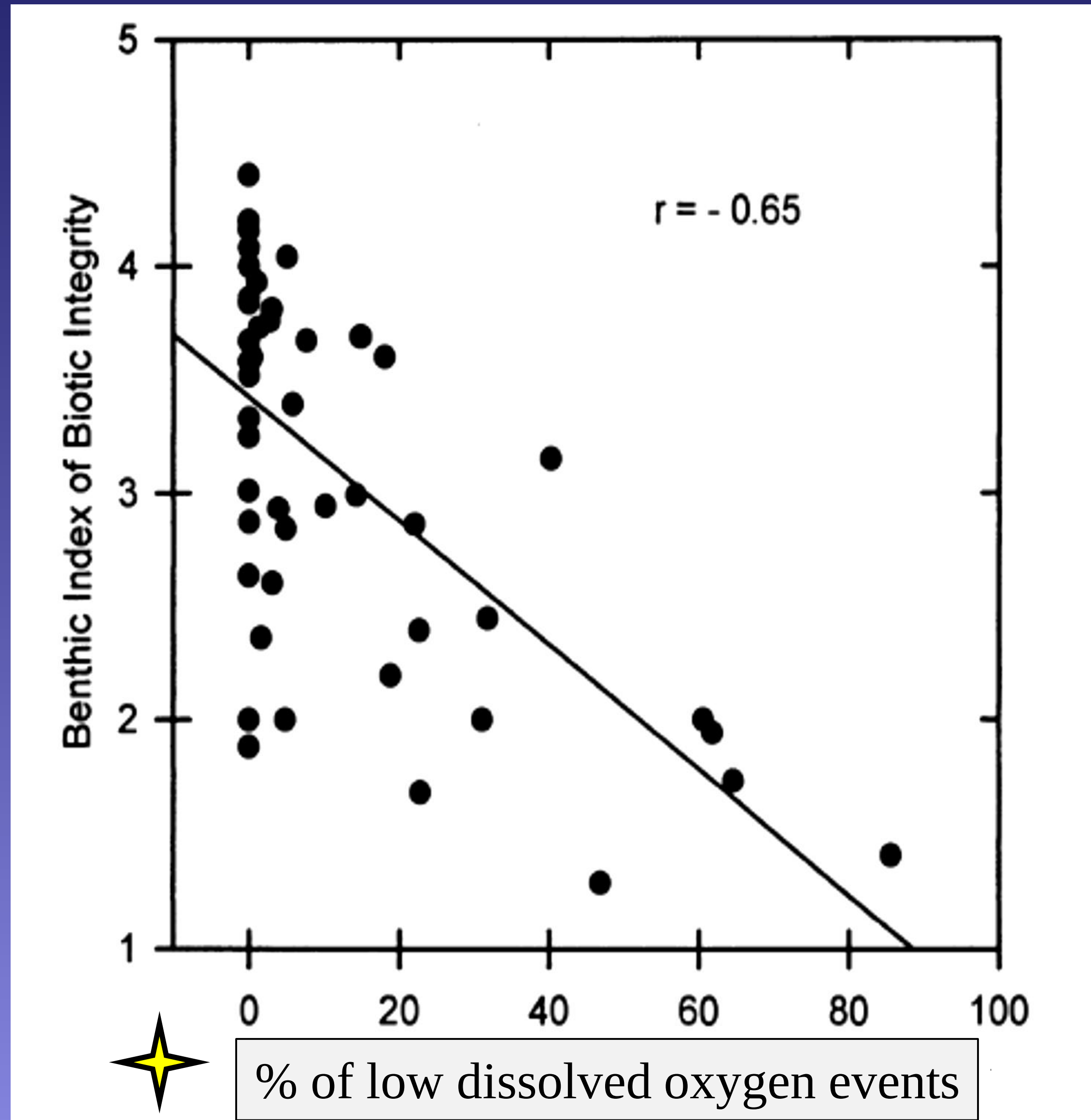


Percent Forested Land Use

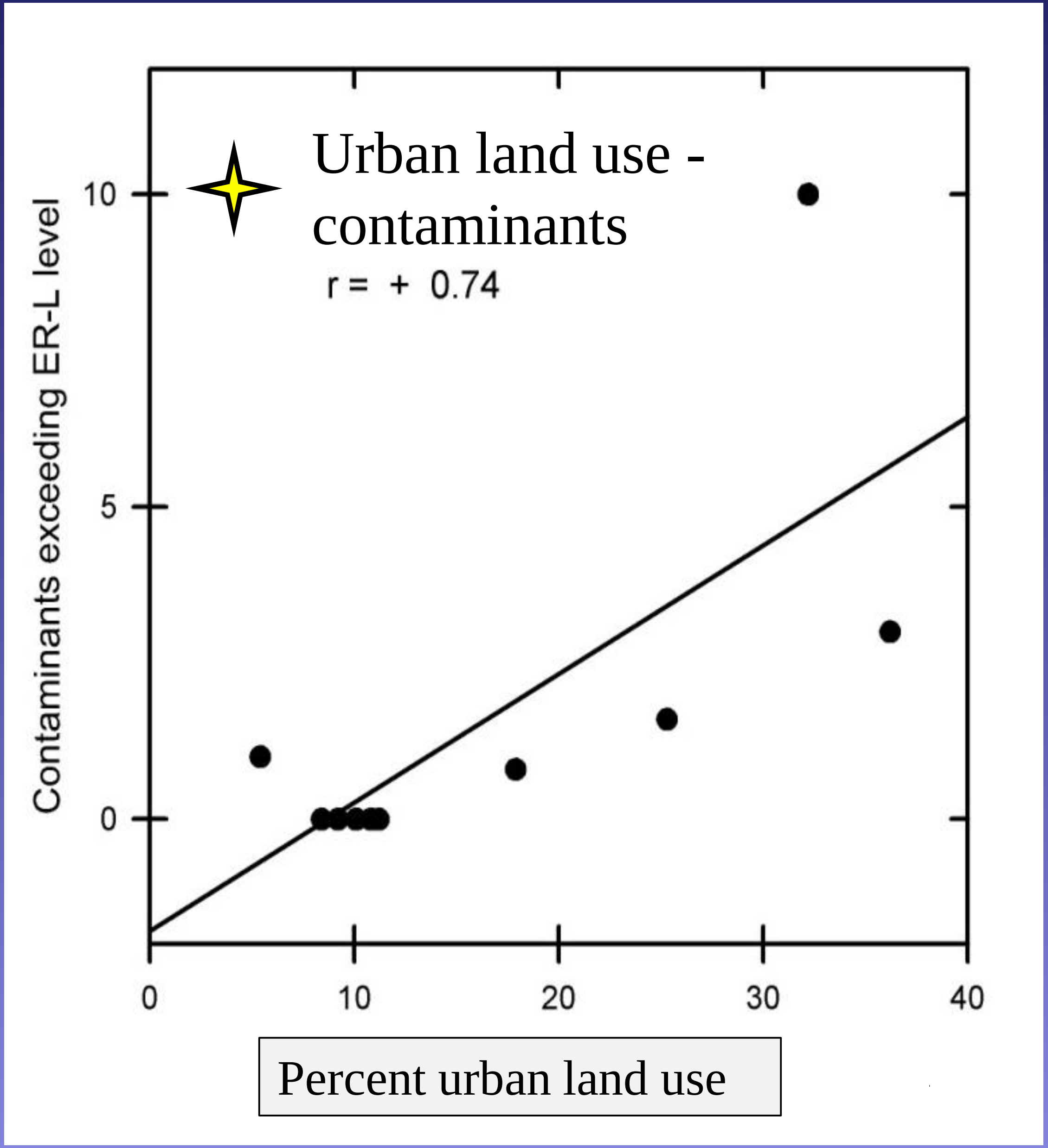
BIBI and Land Use



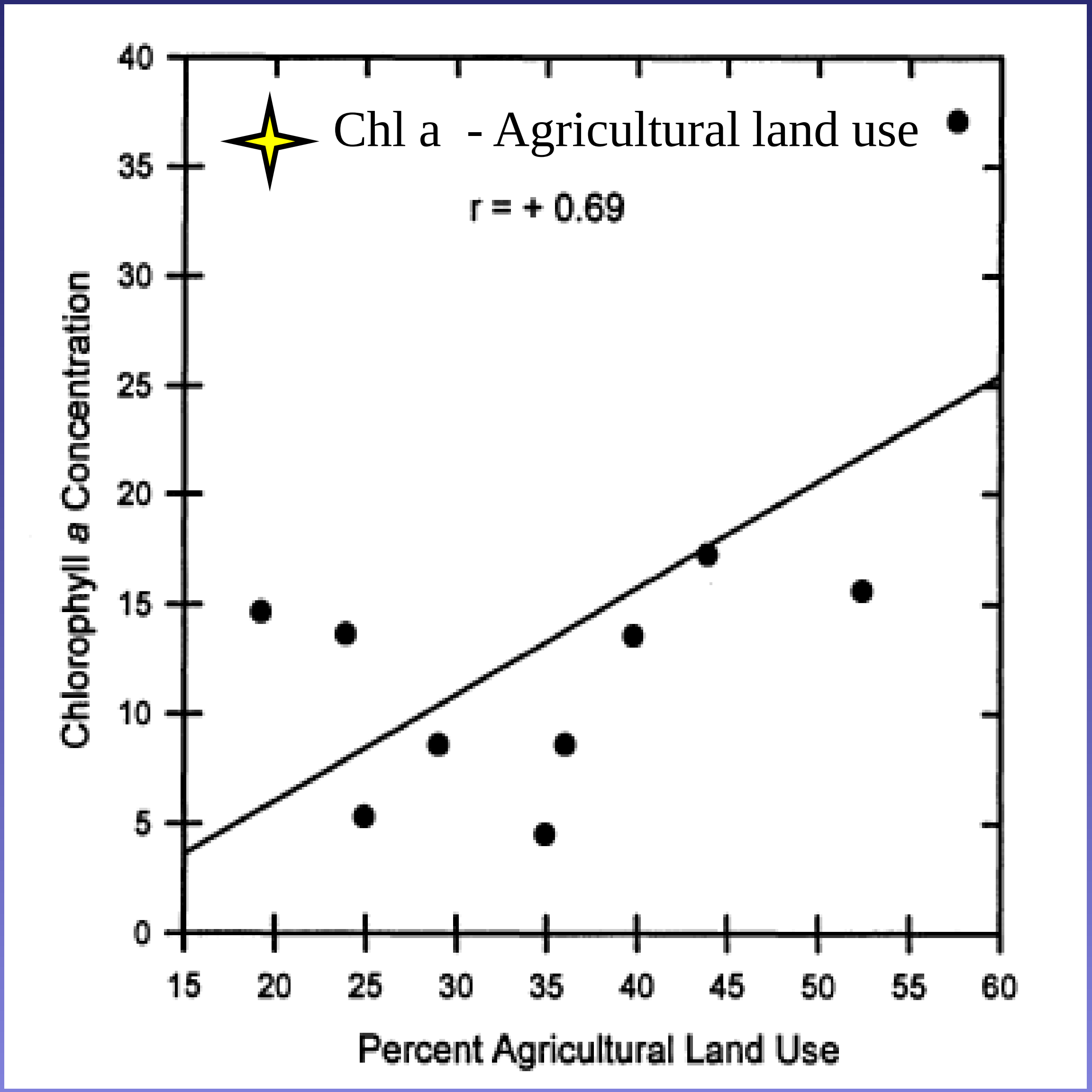
BIBI and Land Use



BIBI and Land Use



BIBI and Land Use



B-IBI relationships

TABLE 5. Correlation of area-weighted exposure variables with watershed variables. Pearson correlation coefficients, probability values, and number of replicates are presented for each watershed variable by exposure variable combination. DO = dissolved oxygen. ER-L = effects range-low of Long et al. (1995). TN, TP = total nitrogen, total phosphorus concentration in water column.

Watershed Variables	% Bottom DO obs <2 ppm	No. of Contaminants >ER-L	Mean TN (mg l^{-1})	Mean TP (mg l^{-1})	Mean Active Chlorophyll *a* (μg l^{-1})
Population density per unit land area	0.679	0.977	−0.473	−0.593	−0.381
	0.031	0.001	0.167	0.071	0.278
	10	9	10	10	10
% Area under agriculture	−0.059	−0.219	0.757	0.446	0.686
	0.871	0.572	0.011	0.196	0.029
	10	9	10	10	10
% Forested area	−0.440	−0.385	−0.328	−0.023	−0.341
	0.204	0.307	0.355	0.949	0.366
	10	9	10	10	10
% Urban area	0.685	0.742	−0.424	−0.517	−0.353
	0.029	0.022	0.222	0.126	0.317
	10	9	10	10	10
Total nitrogen loadings per unit land area	0.127	0.479	0.302	−0.278	−0.025
	0.726	0.192	0.397	0.437	0.946
	10	9	10	10	10
Point source nitrogen loadings per unit land area	0.529	0.970	−0.360	−0.466	−0.255
	0.116	0.001	0.307	0.174	0.477
	10	9	10	10	10
Nonpoint-source nitrogen loadings per unit land area	−0.240	−0.212	0.663	0.032	0.187
	0.451	0.583	0.037	0.929	0.603
	10	9	10	10	10
Total phosphorus loadings per unit land area	−0.133	0.052	0.546	−0.076	0.116
	0.713	0.894	0.103	0.835	0.750
	10	9	10	10	10
Point source phosphorus loadings per unit land area	0.488	0.963	−0.343	−0.460	−0.254
	0.152	0.001	0.331	0.181	0.479
	10	9	10	10	10
Nonpoint-source phosphorus loadings per unit land area	−0.223	−0.216	0.650	0.049	0.322
	0.535	0.577	0.042	0.892	0.365
	10	9	10	10	10

B-IBI relationships

Summary Relationships

1. Exposure variables
   - Low dissolved oxygen events
   - Sediment contaminants
2. Negative with anthropogenic inputs & activities
   - Population density
   - Point source loads
   - Total nitrogen loads
3. Positive with forested land use

(1) Benthic Index of Biotic Integrity (BIBI).
(Weisberg et al. 1997. Estuaries; Alden et al. 2002. Environmetrics)

(2) Establishing relationships between the BIBI and land use patterns, nutrient loads, low dissolved oxygen events, and sediment contaminants at watershed levels. (Dauer et al. 2000. Estuaries)

(3) Implementation of probability-based sampling to generate areal estimates of levels of degraded benthos.

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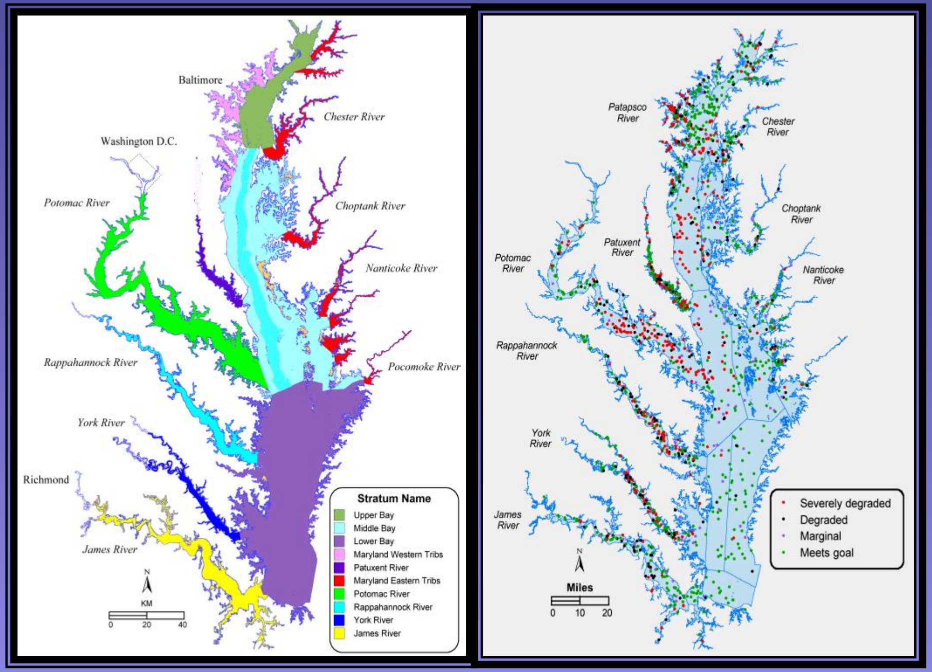

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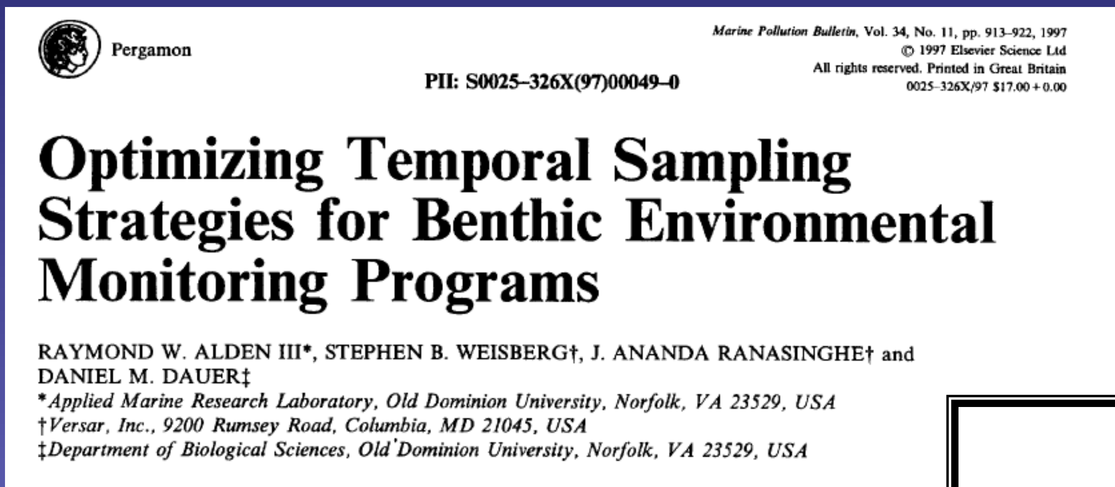
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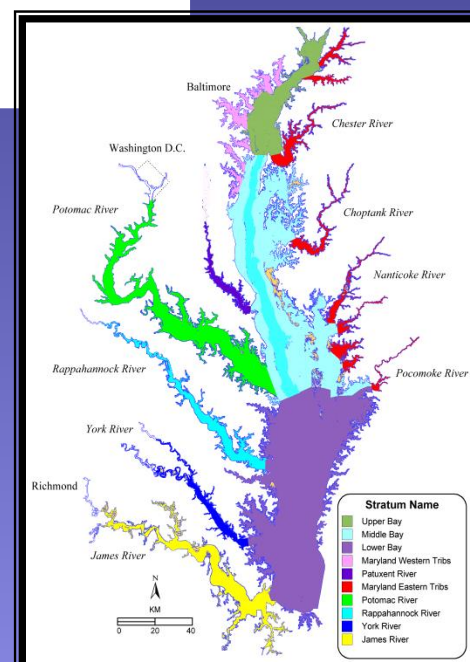
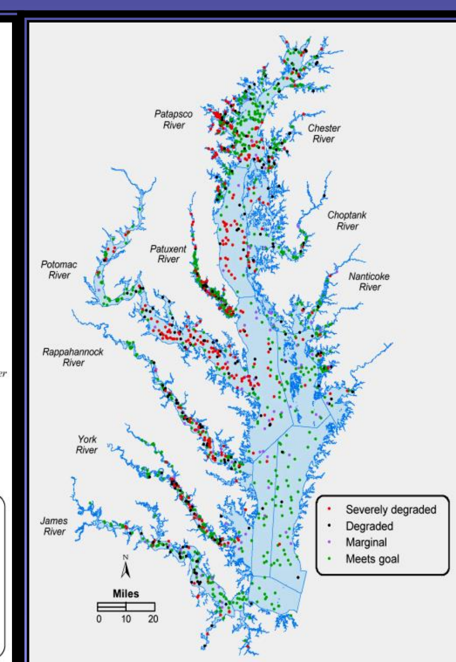
PII: S0025–326X(97)00049–0

Optimizing Temporal Sampling Strategies for Benthic Environmental Monitoring Programs

RAYMOND W. ALDEN III*, STEPHEN B. WEISBERG†, J. ANANDA RANASINGHE† and DANIEL M. DAUER‡
**Applied Marine Research Laboratory, Old Dominion University, Norfolk, VA 23529, USA*
†Versar, Inc., 9200 Rumsey Road, Columbia, MD 21045, USA
‡Department of Biological Sciences, Old Dominion University, Norfolk, VA 23529, USA





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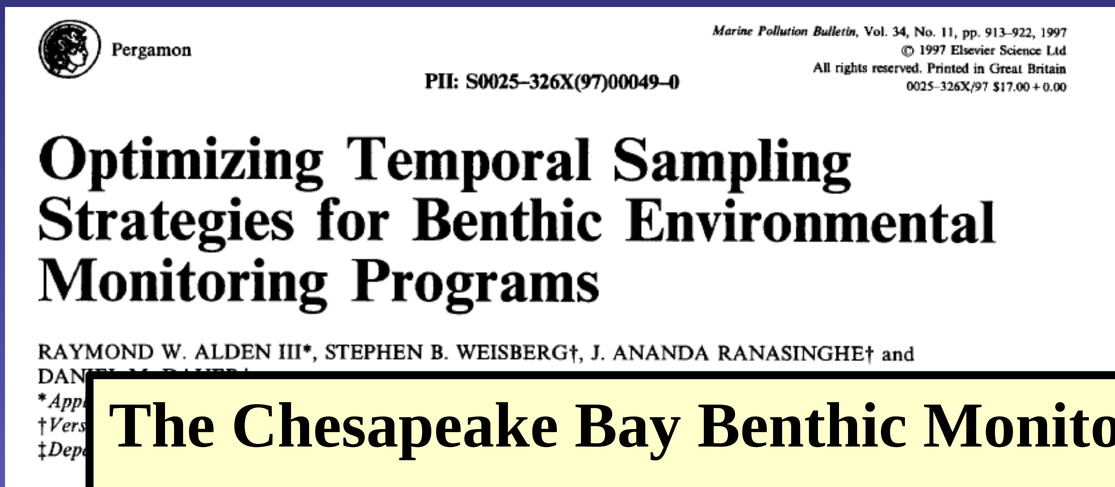
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Optimizing Temporal Sampling Strategies for Benthic Environmental Monitoring Programs

RAYMOND W. ALDEN III*, STEPHEN B. WEISBERG†, J. ANANDA RANASINGHE† and
DAN

The Chesapeake Bay Benthic Monitoring Team:

(1) Evaluated the sampling design of the EMAP-VA program.

(2) Recognized the essential importance of **areal based estimates of benthic community condition** with known confidence intervals unavailable with a fixed-point station design.

(3) Adding probability-based sampling would require reduction in intra-annual seasonal sampling (zero sum budgeting).

(4) An effort to **optimize spatial interpretation** and **minimize reduction in statistical power** to detect long-term trends in benthic community condition.

(3) Implementation of probability-based sampling to generate areal estimates of levels of degraded benthos.

(Llansó et al. 2003. Environmental Monitoring and Assessment; Dauer and Llansó. 2003. Ibid; Alden et al. 1997)

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Optimizing Temporal Sampling Strategies for Benthic Environmental Monitoring Programs

RAYMOND W. ALDEN III*, STEPHEN B. WEISBERG†, J. ANANDA RANASINGHE† and

Tested

(1) Homogeneity among seasons.

(2) Power to detect trends in (a) abundance, (b) biomass, (c) diversity and (d) proportional abundance of opportunistic taxa.

(3) Magnitude of differences between reference and degraded sites.

(4) Summer was the optimal season to sample for both power and magnitude of difference between reference and degraded sites.

(3) Implementation of probability-based sampling to generate areal estimates of levels of degraded benthos.

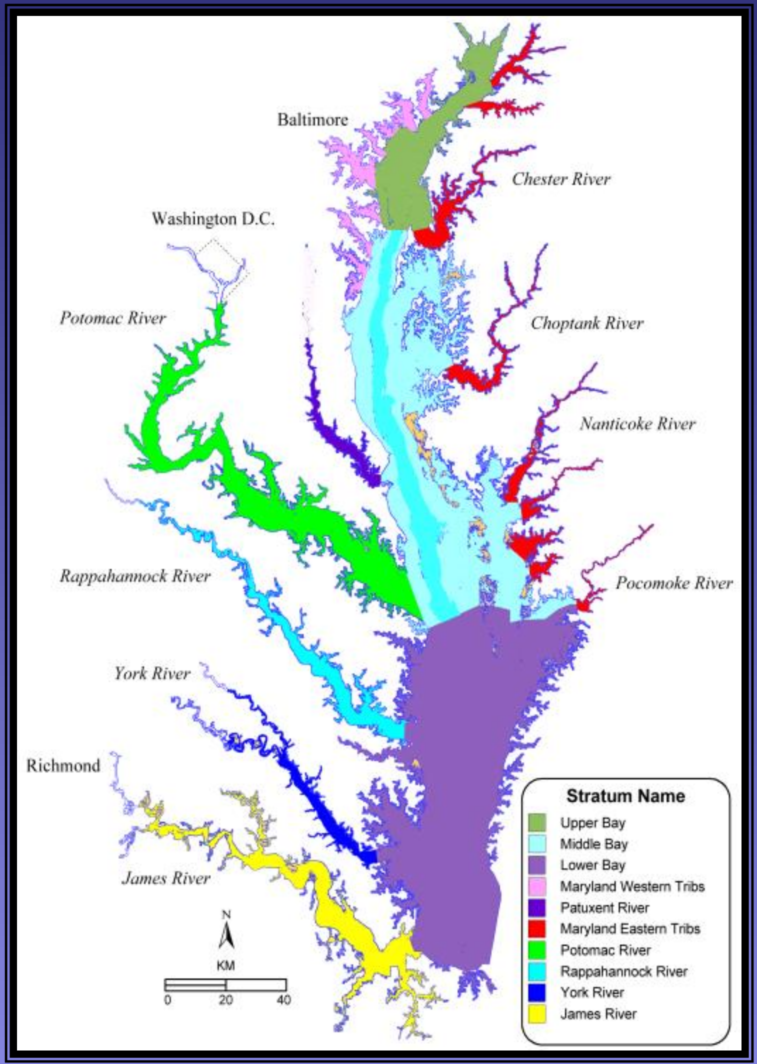
(Llansó et al. 2003. Environmental Monitoring and Assessment; Dauer and Llansó. 2003. Ibid)

Samples allocated among 10 strata

25 random sites per stratum

Data can be summarized

- **A. Bay-wide**
- **B. State-wide**
- **C. Tributary**
- **D. Segment**



(3) Implementation of probability-based sampling to generate areal estimates of levels of degraded benthos.

(Llansó et al. 2003. Environmental Monitoring and Assessment; Dauer and Llansó. 2003. Ibid)

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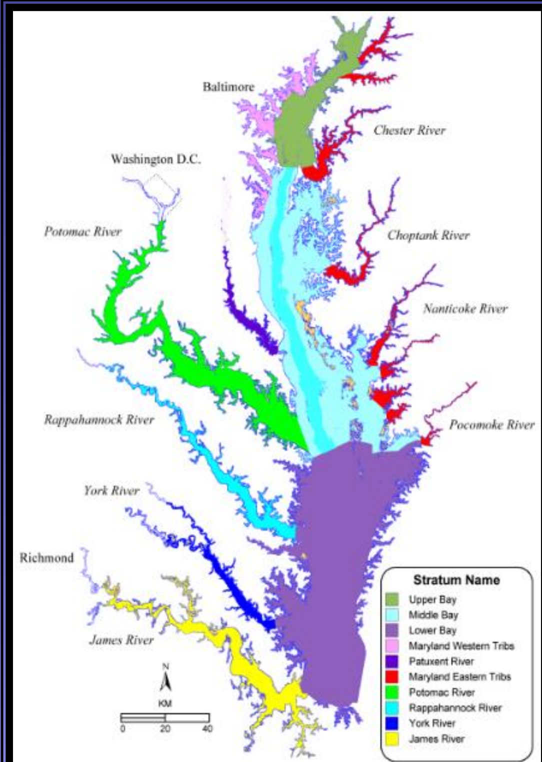
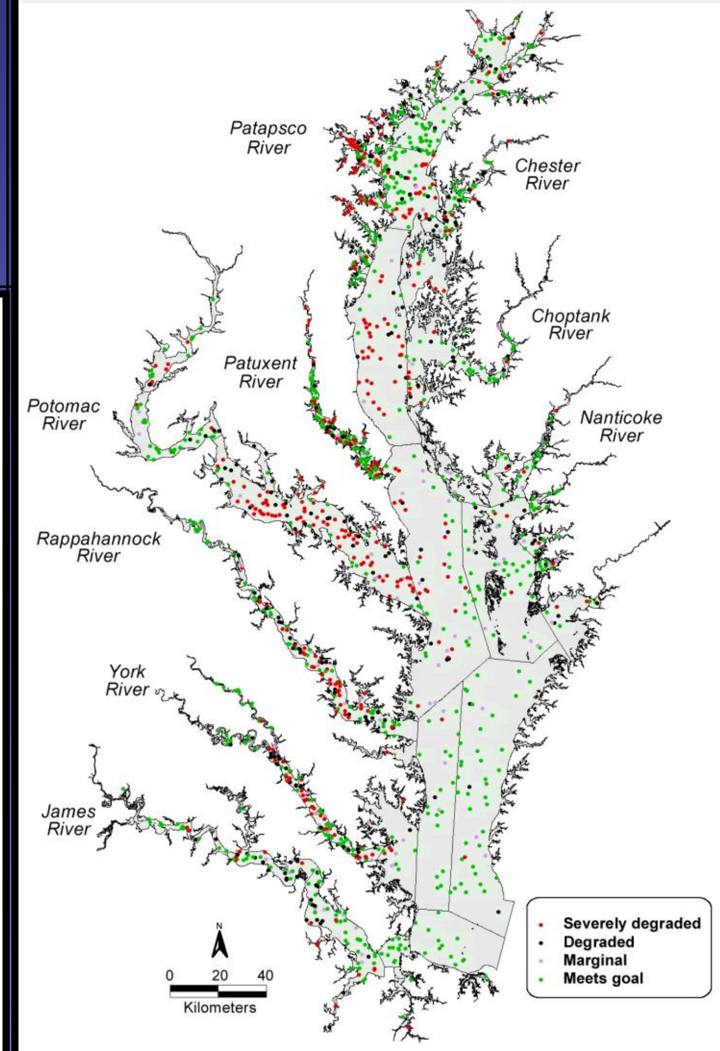


Samples from 1994 – 2000
n = 1,446



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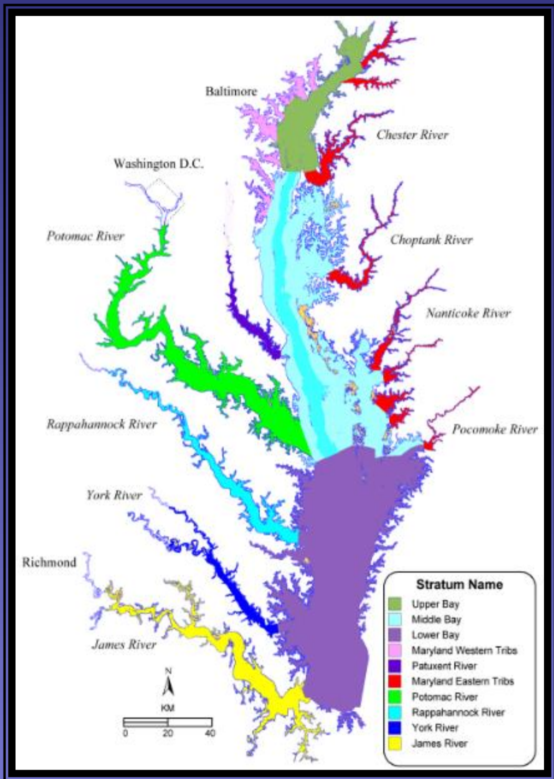

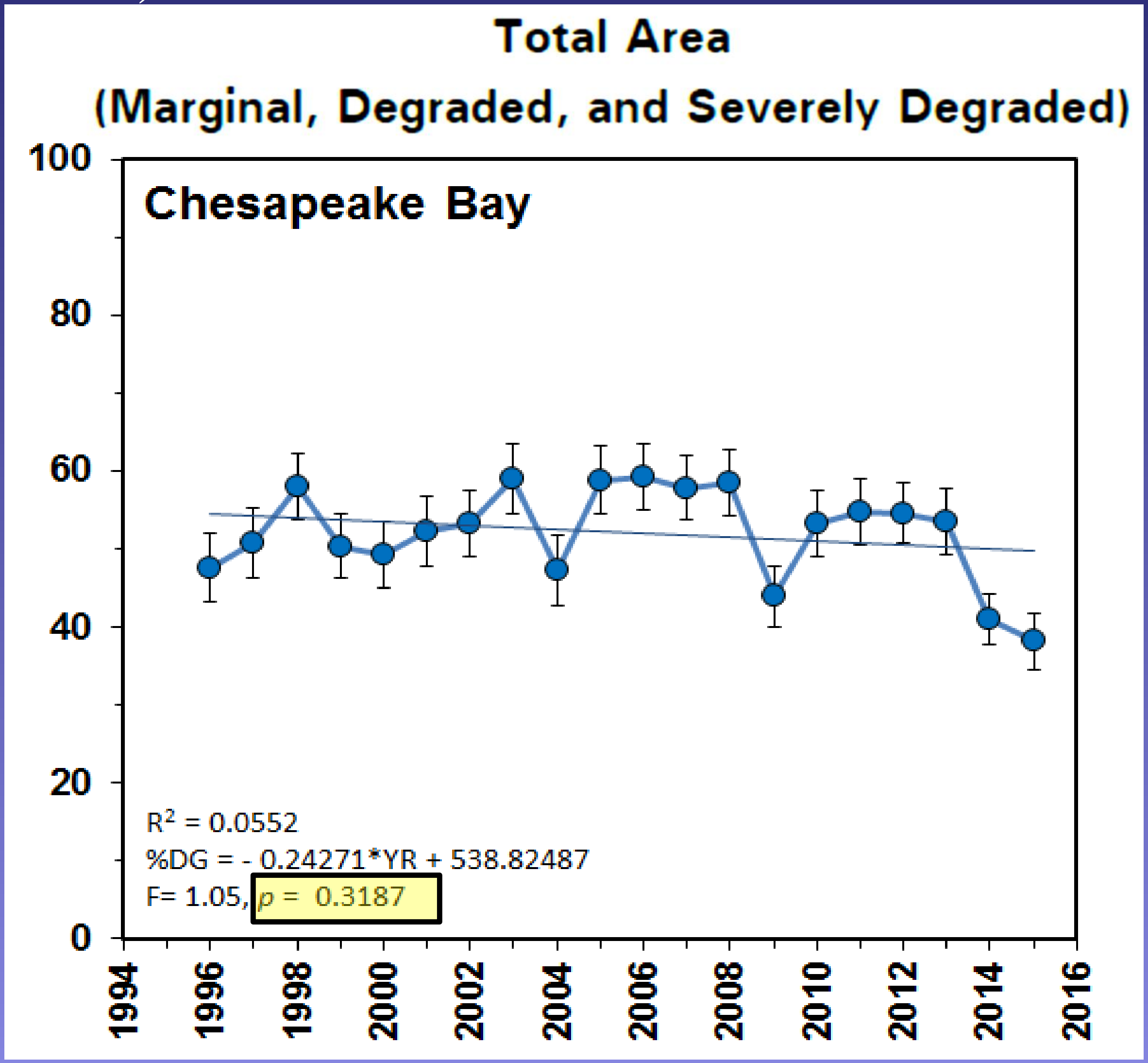

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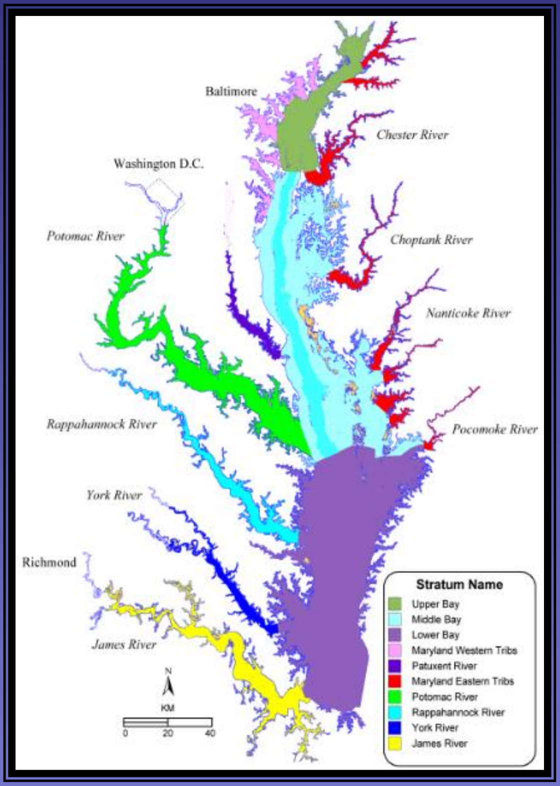

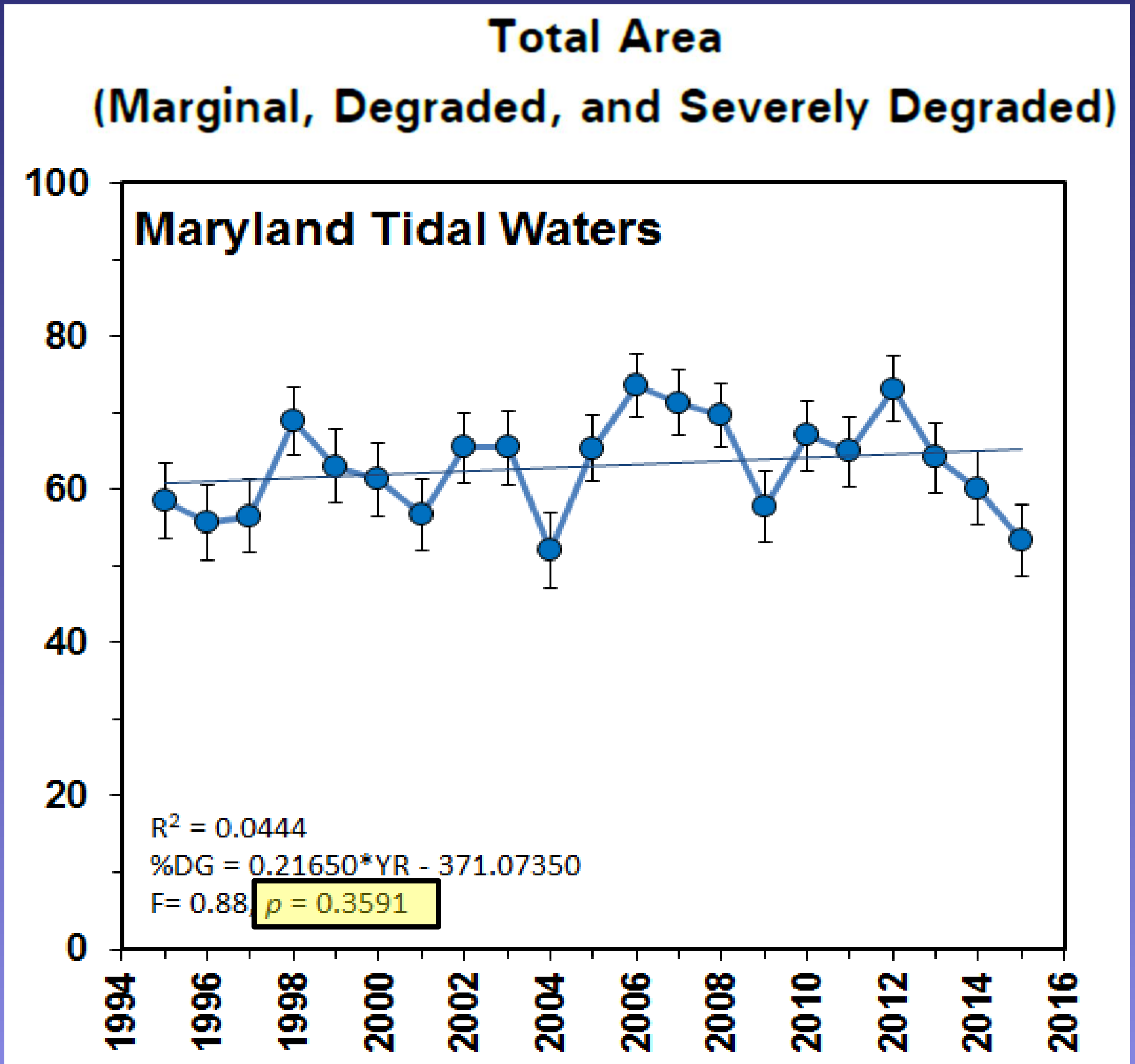

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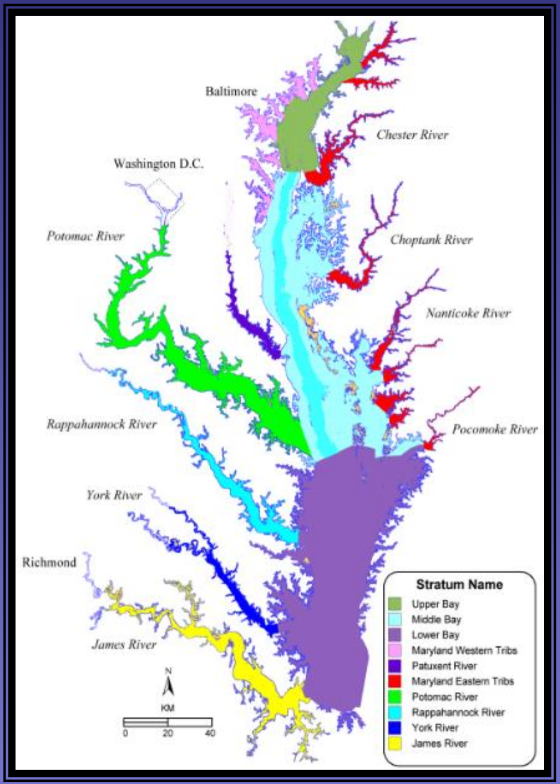

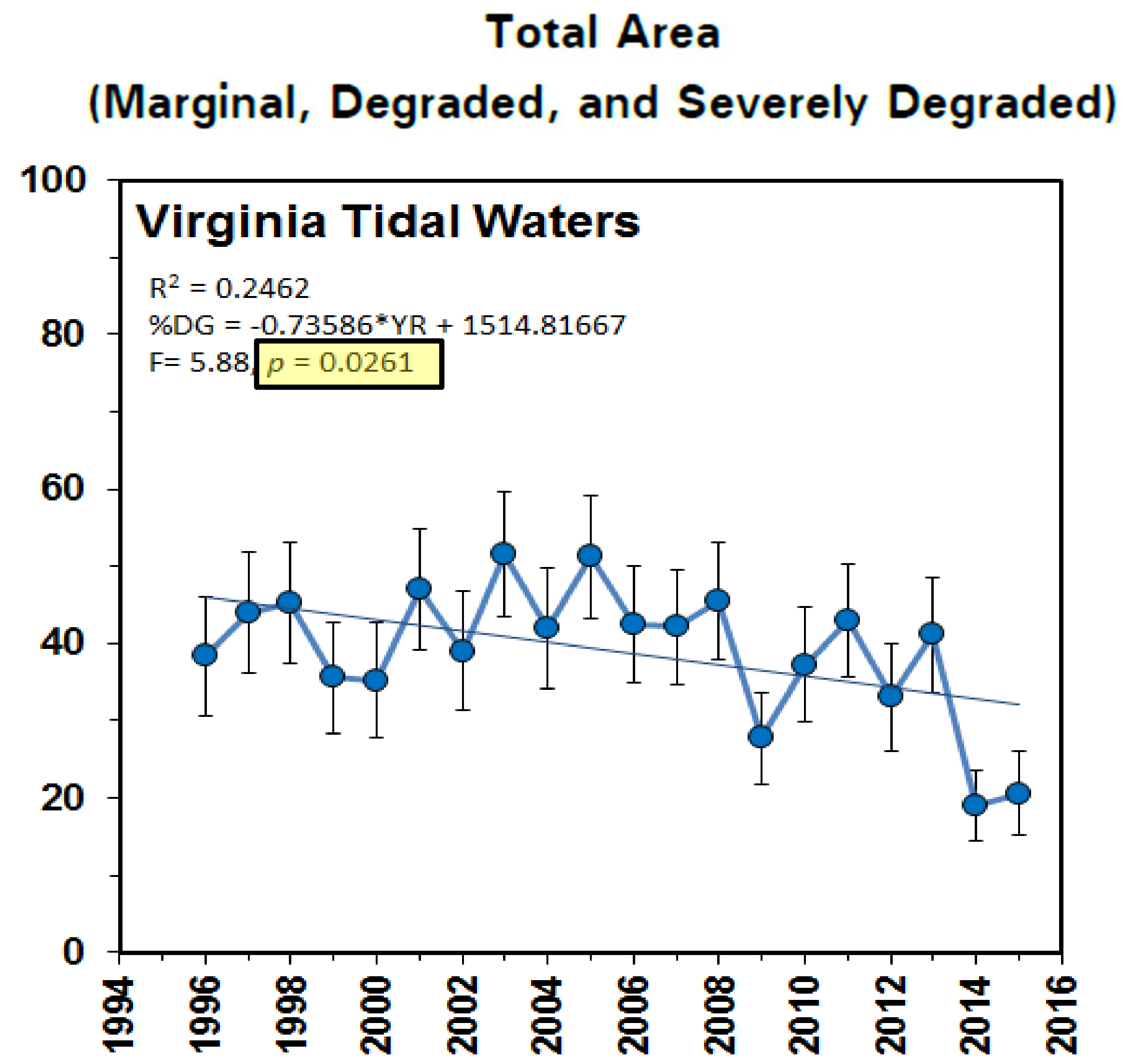

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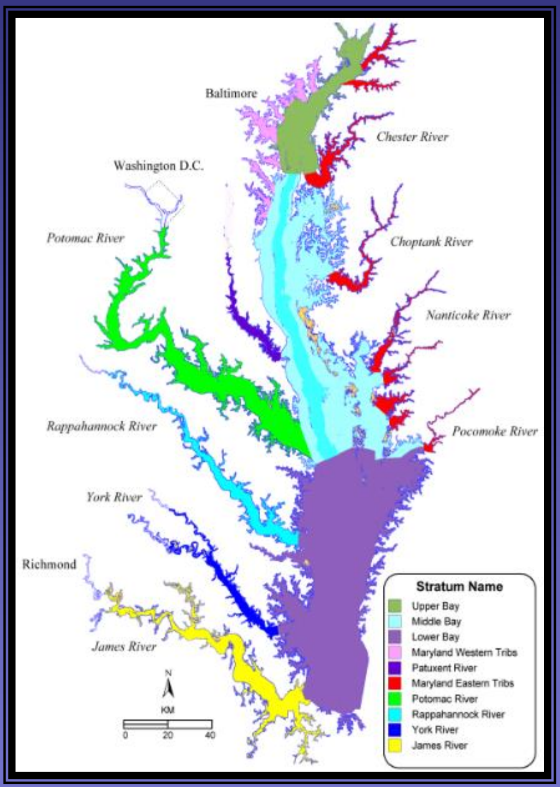

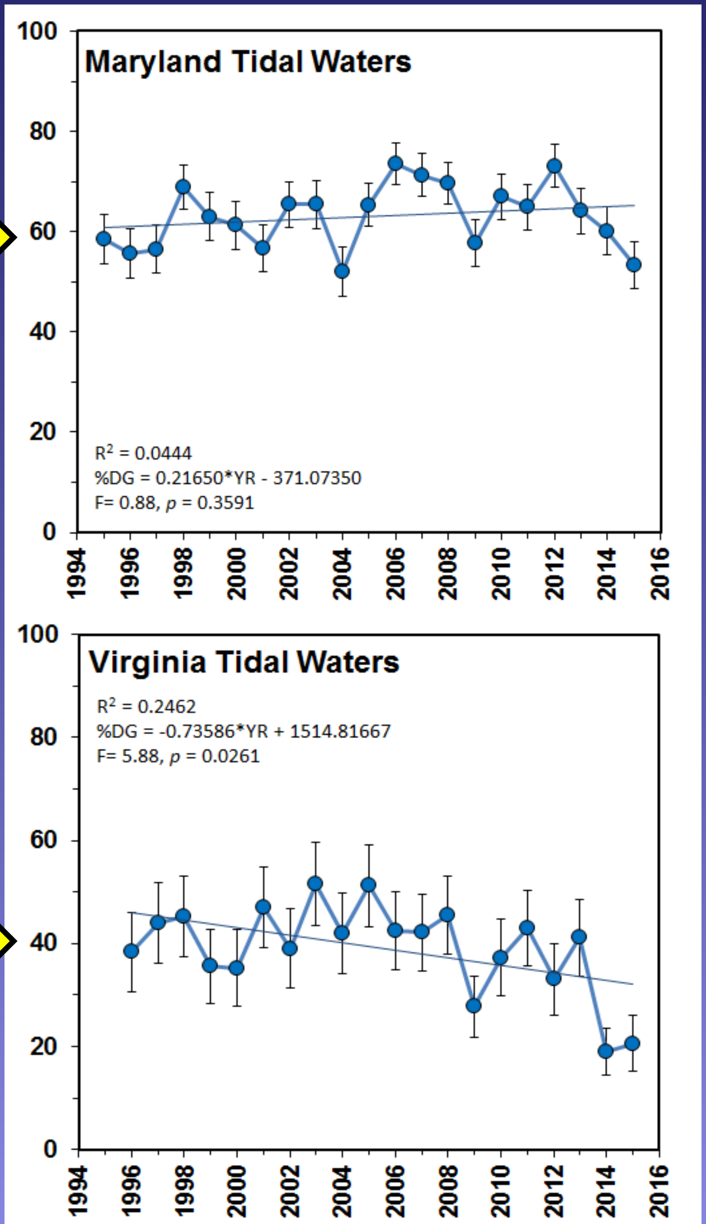

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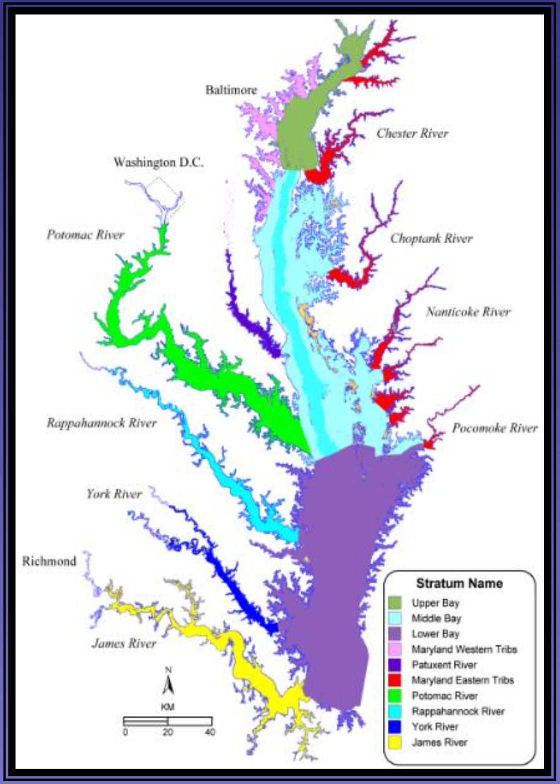

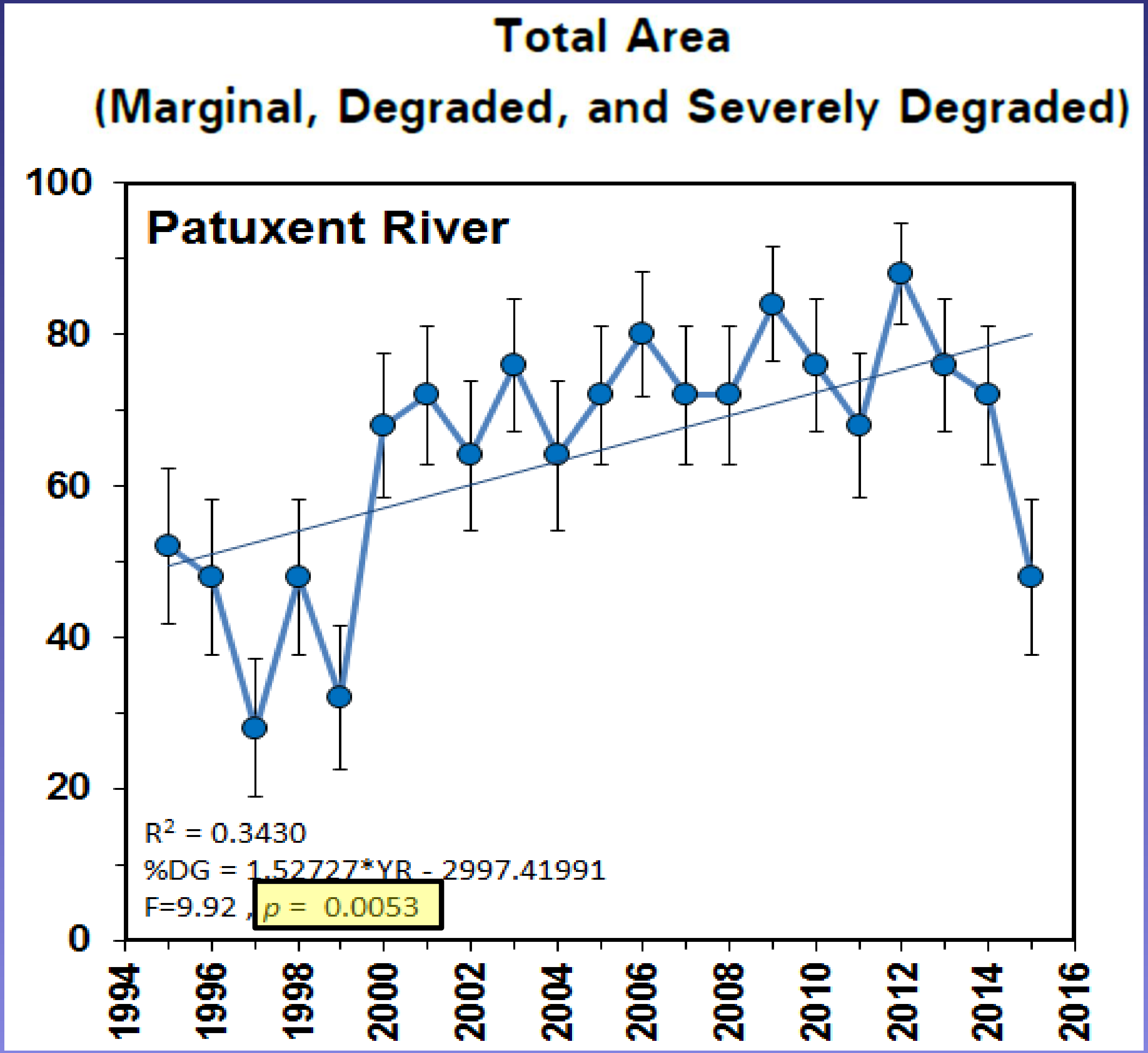

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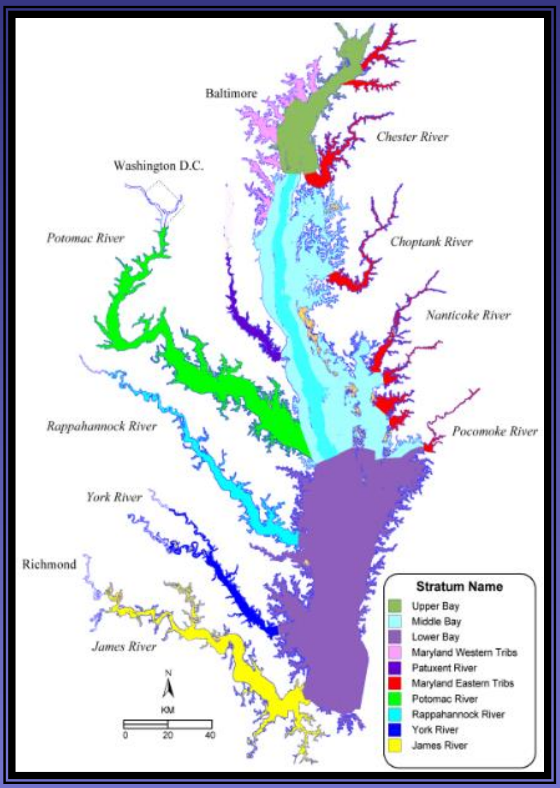

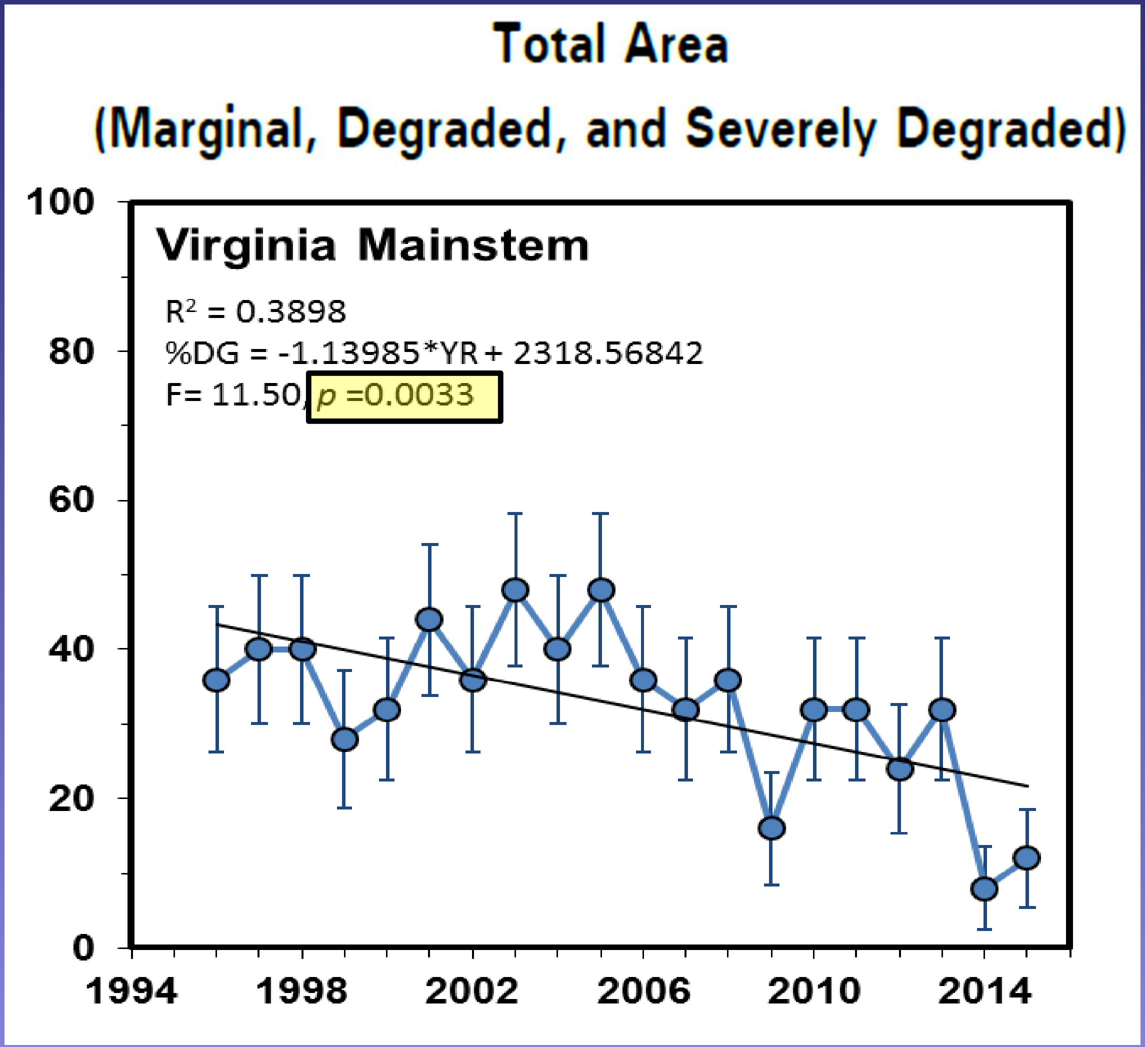

Probability (Random) Sampling

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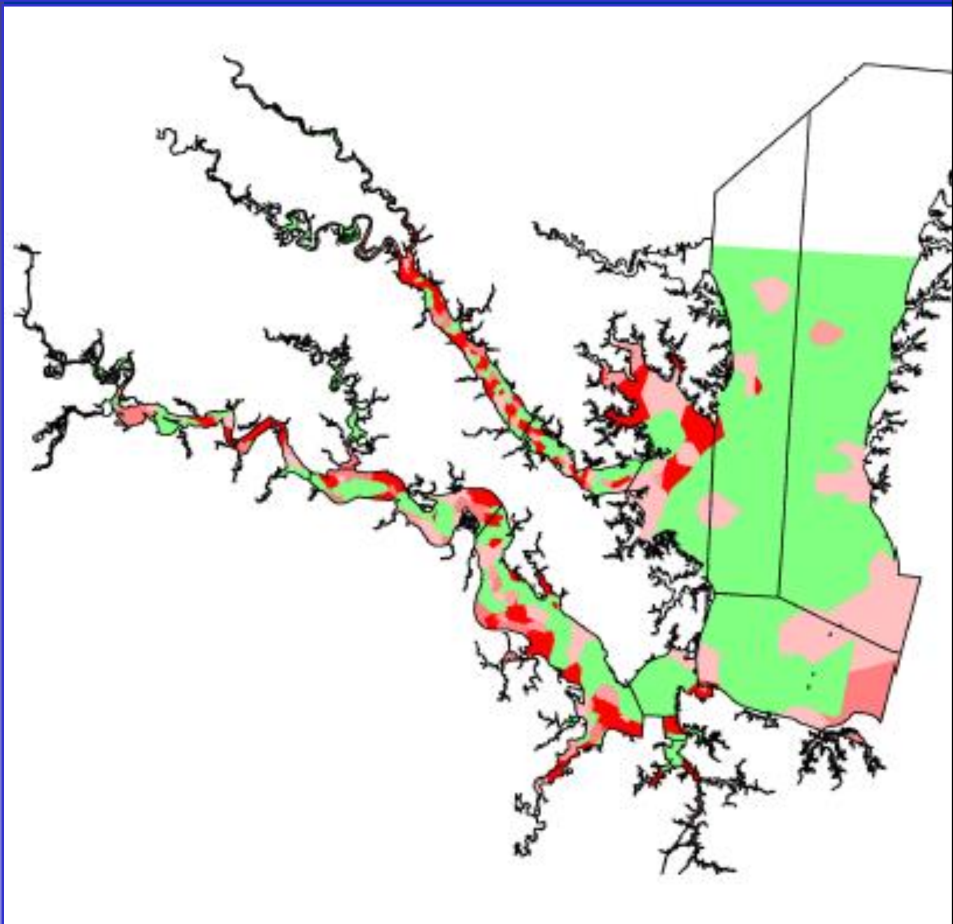
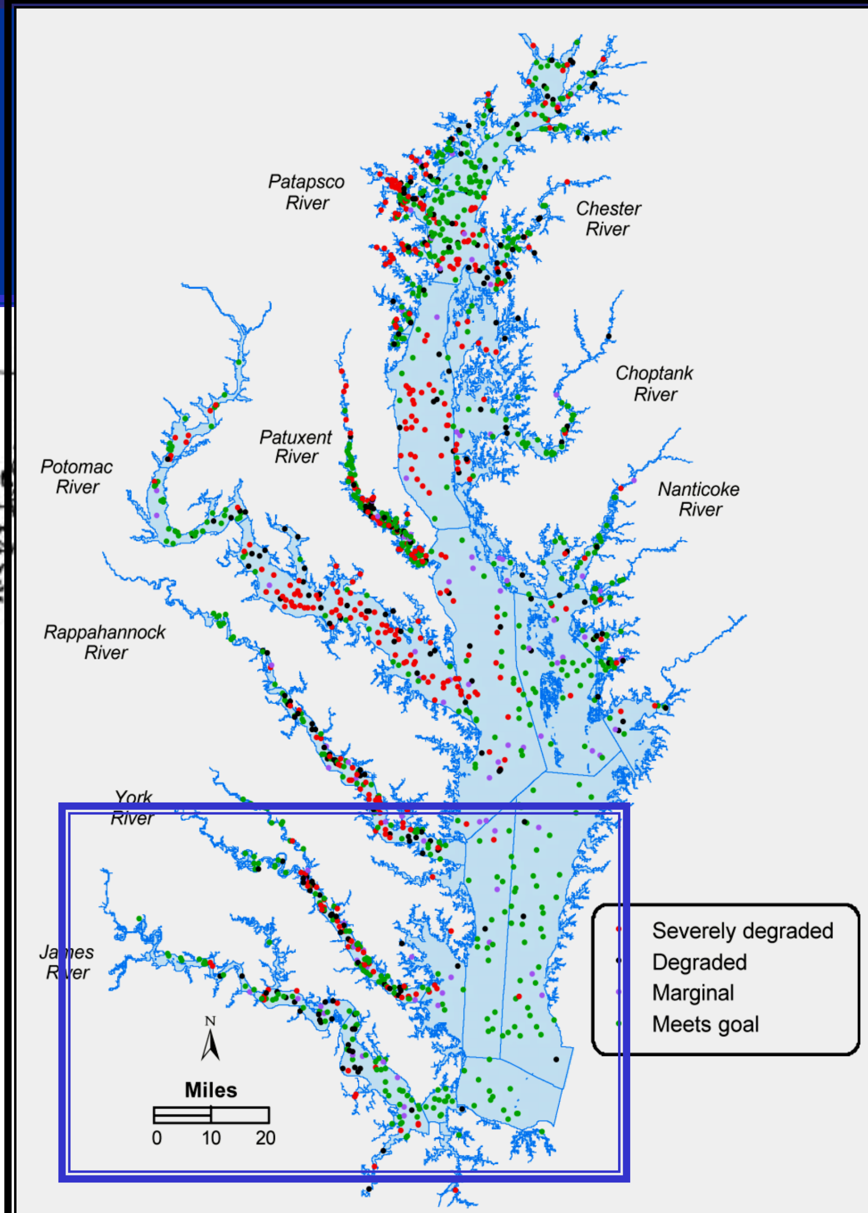
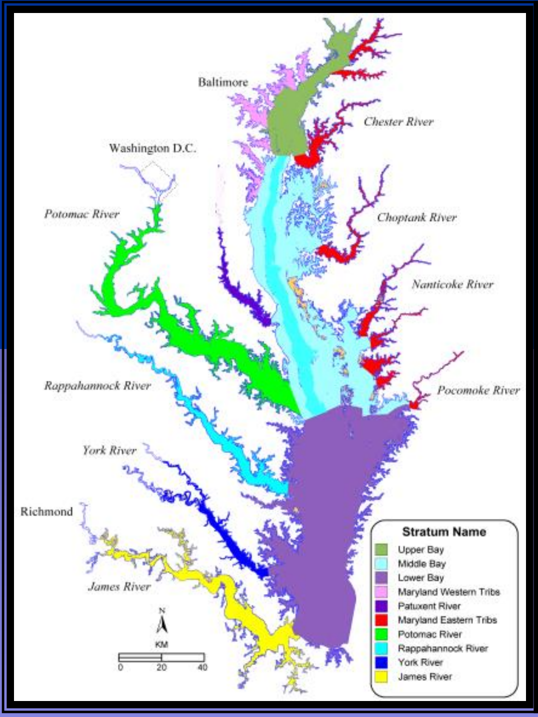


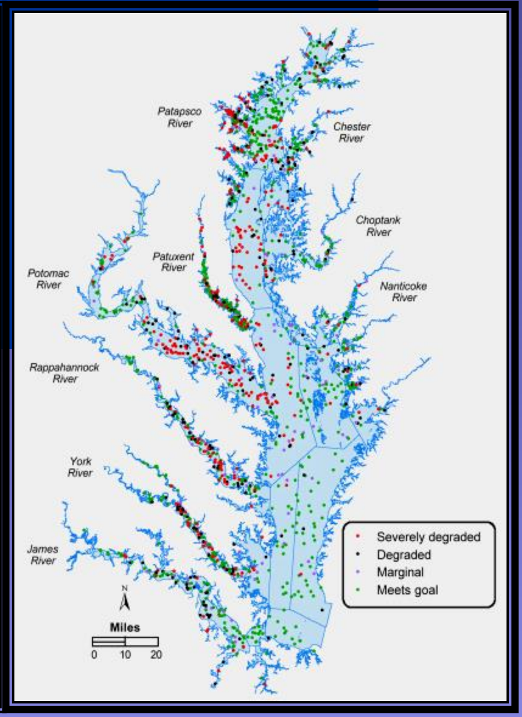


Probability (Random) Sampling

Summary Advantages

1. Areal estimates of strata with known CIs
2. Data can be post-hoc stratified
3. Strata can be combined by areal weighting





(1) Benthic Index of Biotic Integrity (BIBI).
(Weisberg et al. 1997. Estuaries; Alden et al. 2002. Environmetrics)

(2) Establishing relationships between the BIBI and land use patterns, nutrient loads, low dissolved oxygen events, and sediment contaminants at watershed levels. (Dauer et al. 2000. Estuaries)

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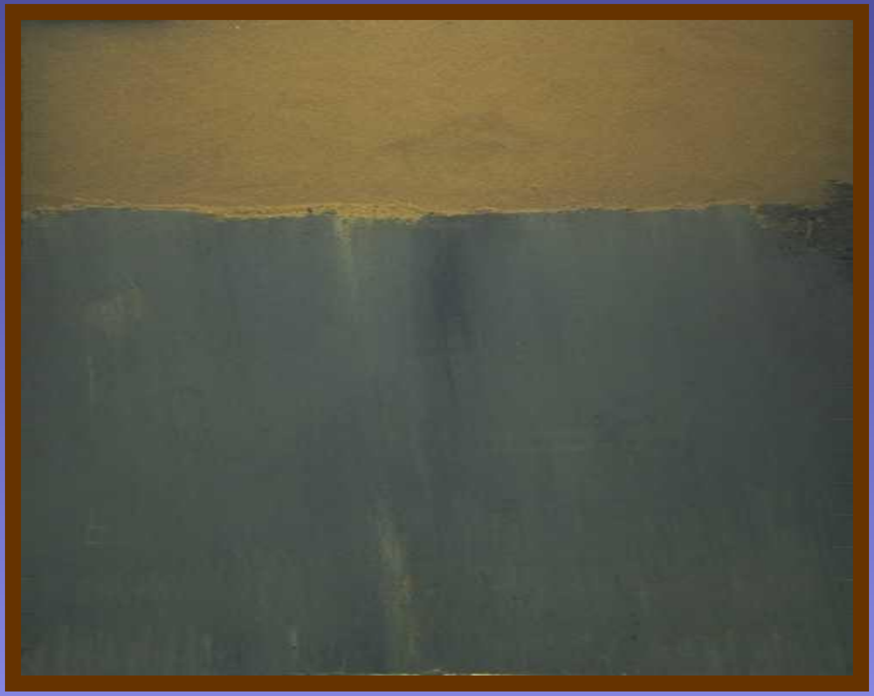
(Alden et al. 1997. Marine Pollution Bulletin; Llansó et al. 2003. Environmental Monitoring and Assessment; Dauer and Llansó. 2003. Ibid)

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

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



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

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

Journal of Experimental Marine Biology and Ecology
285-286 (2003) 371–381

Journal of EXPERIMENTAL MARINE BIOLOGY AND ECOLOGY

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A comparison of two methods for estimating the status of benthic habitat quality in the Virginia Chesapeake Bay

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[b] *Center for Coastal and Ocean Mapping, University of New Hampshire, 24 Colovos Rd., Durham, NH 03824, USA*
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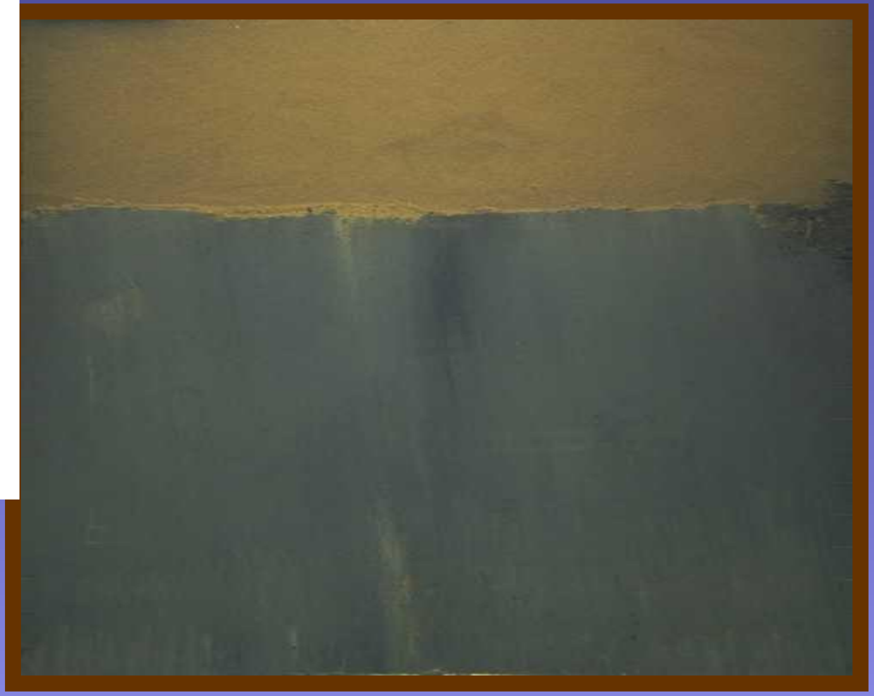
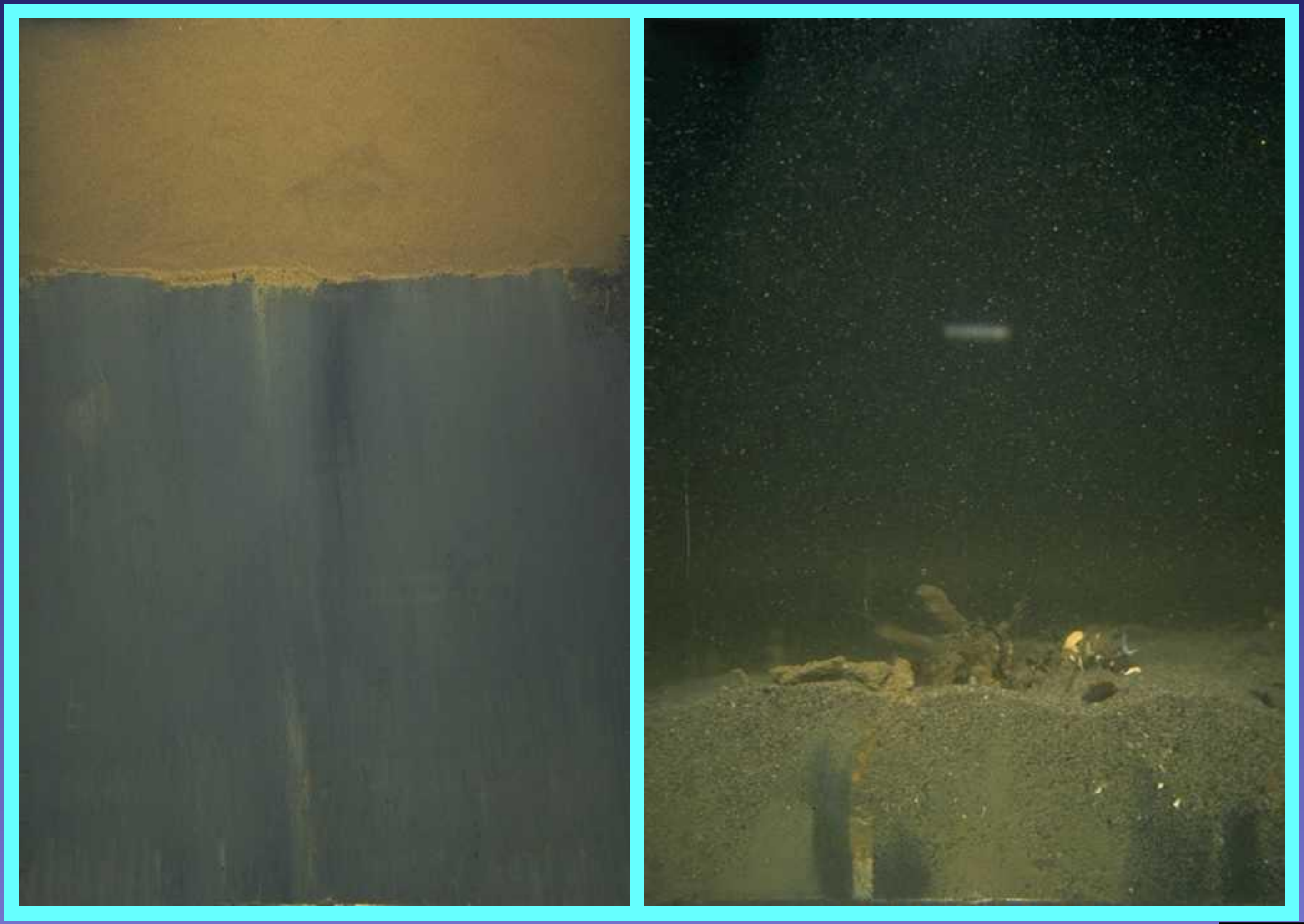
Received 7 June 2002; received in revised form 31 August 2002; accepted 13 September 2002

Abstract

Macrobenthic communities in Chesapeake Bay, USA, have been intensively monitored since 1985. In 1996, the monitoring was expanded to include summertime stratified random sampling to produce unbiased estimators of community metrics that could be used to assess system wide trends





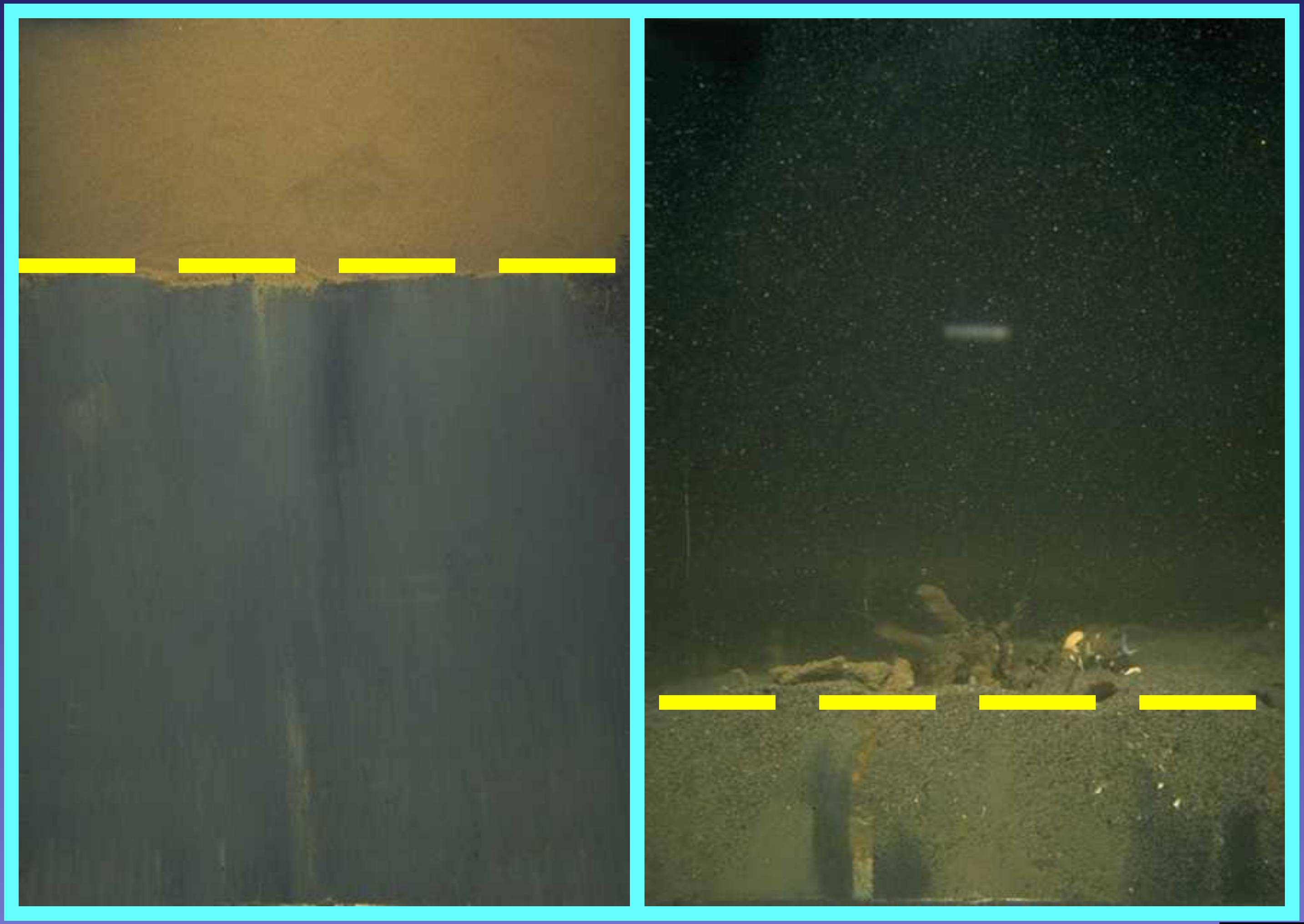


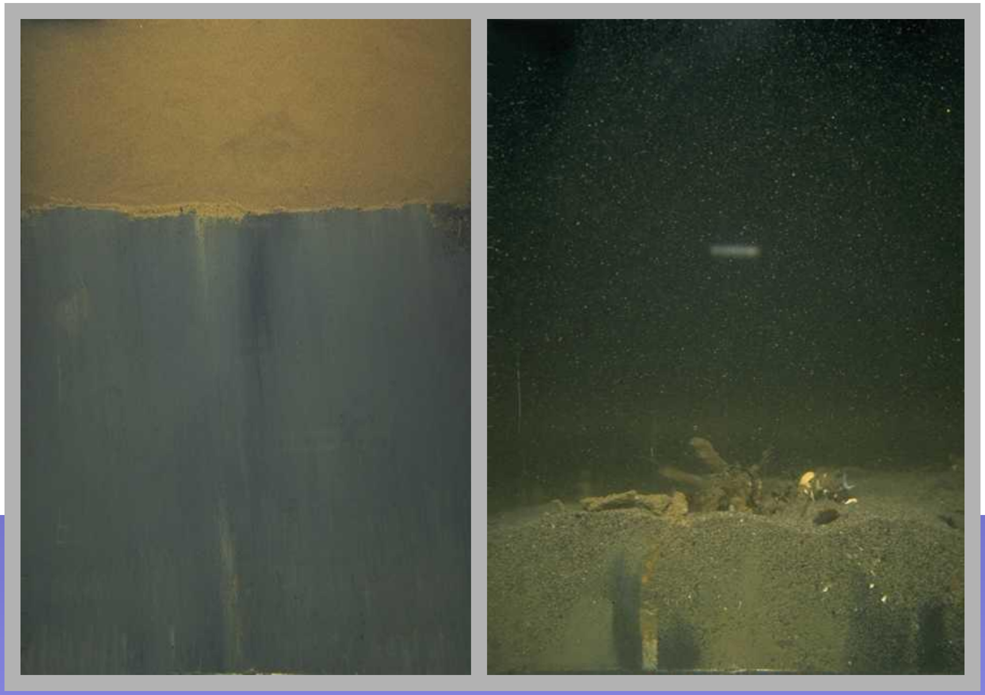
Table 1
Metrics used in the calculation of the benthic index of biotic integrity (BIBI) and organism–sediment index (OSI)

BIBI	OSI
Species diversity H'	Depth of apparent color RPD layer: Scored 0 for 0 RPD to 6 for >3.8 cm
Total abundance	Estimated successional stage: Scored −4 for azoic conditions to 6 for Stage III
Total biomass	Presence of gas voids in sediment: Scored −2
% Abundance of pollution-indicative taxa	Apparent presence of low dissolved oxygen: Scored −4
% Abundance of pollution-sensitive taxa	
% Biomass of pollution-sensitive taxa	
% Biomass >5 cm below sediment–water interface	

Each metric gets a score of:
- 5: >50th percentile of reference sites
- 3: 5th to 50th percentile
- 1: <5th percentile

Table 5
Association between indices of biotic integrity and habitat quality

Biotic integrity (BIBI)	Habitat quality OSI	
	Low	High
Low	Strong relationship, 24% (56 stations)	May occur due to biotic factors, 39% (89)
High	Not likely, 10% (23)	Strong relationship, 27% (62)



R.J. Diaz et al. / J. Exp. Mar. Biol. Ecol. 285-286 (2003) 371–381 379

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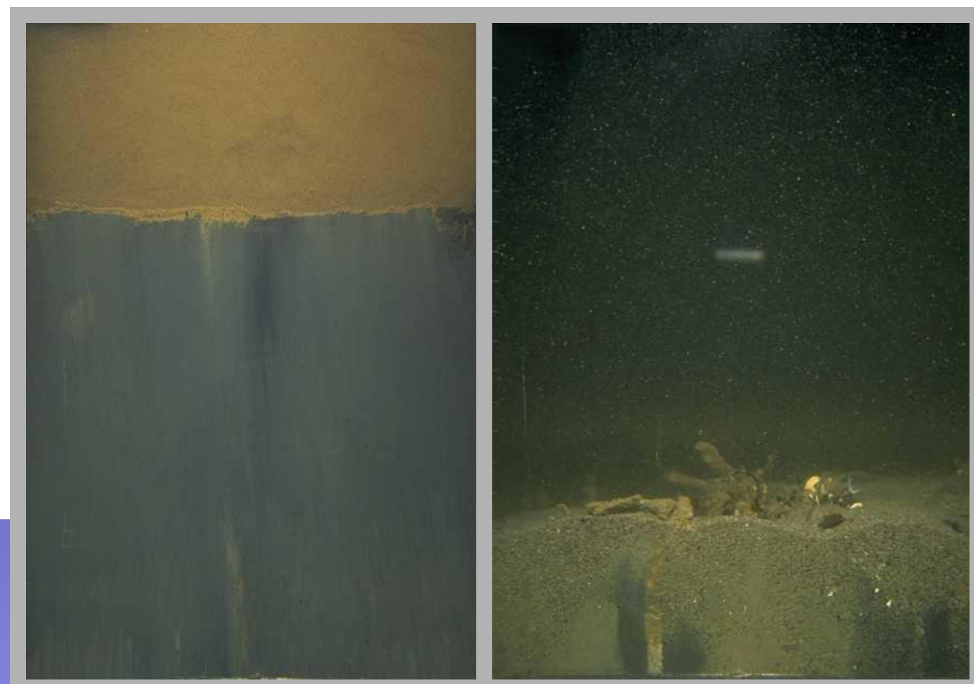

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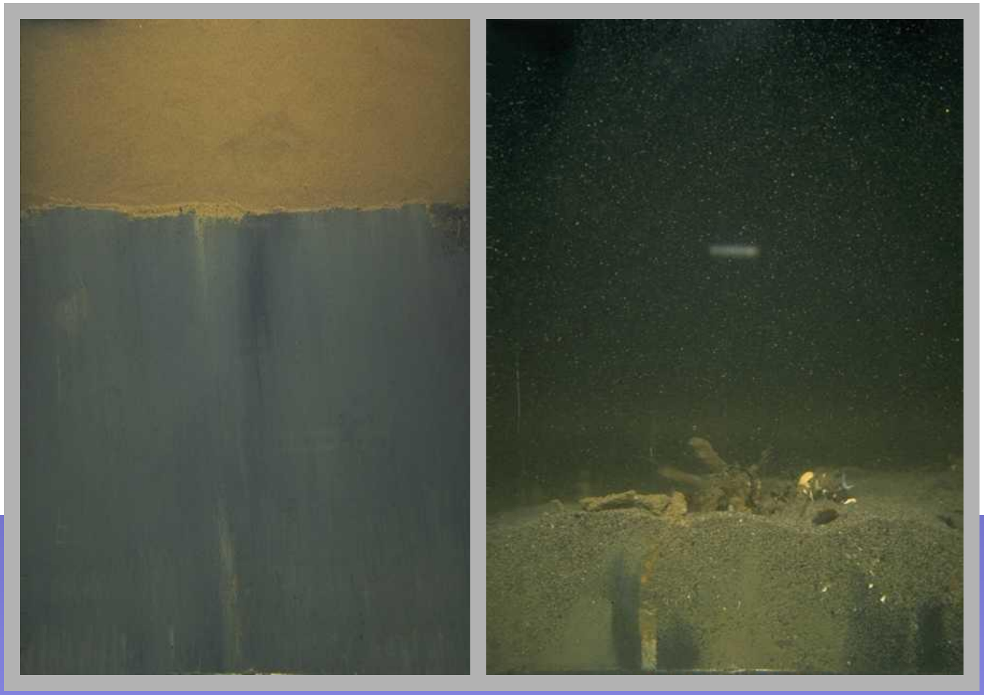
High	Not likely, 10% (23)	



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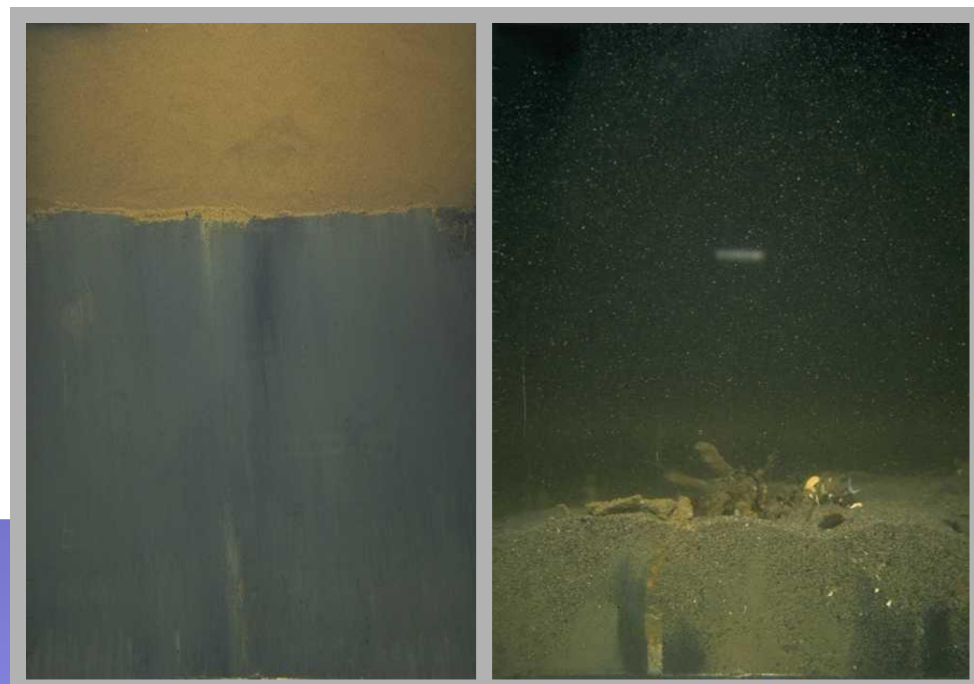

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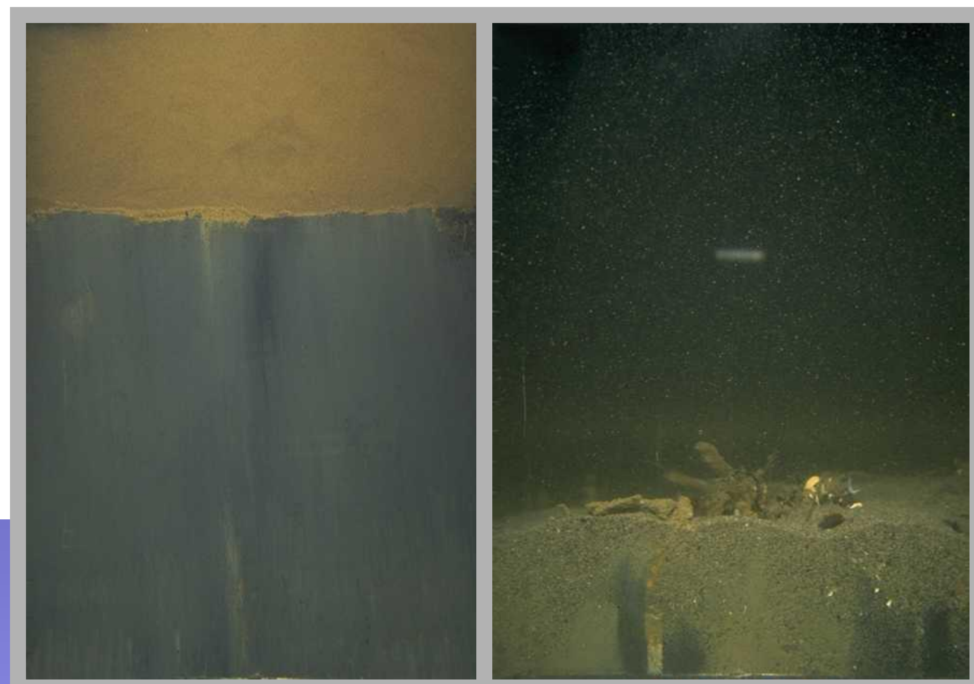
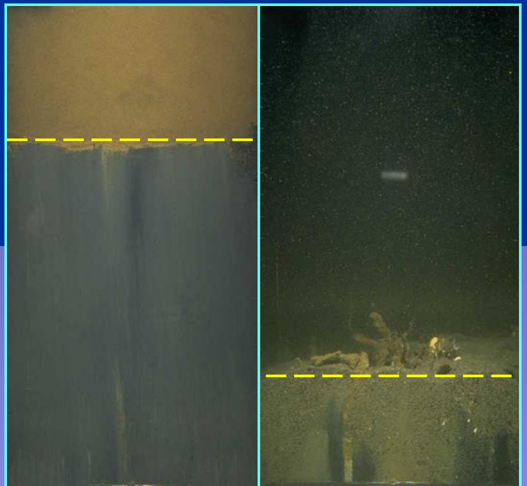


Habitat Quality and Biotic Integrity

Summary Relationships

1. Independent estimates of habitat quality and biotic integrity
2. Logical relationships confirmed

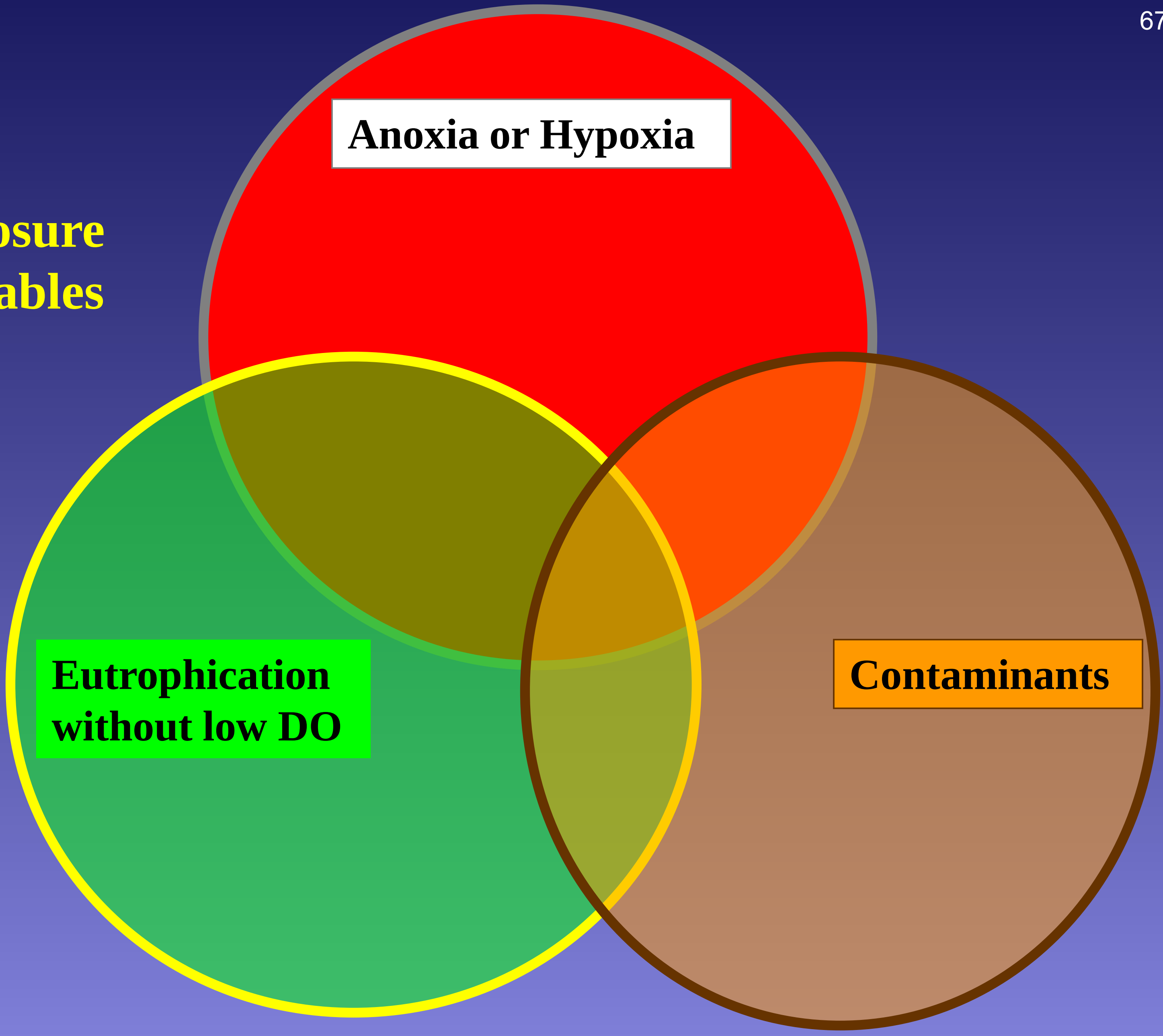


(5) Diagnostic approaches to causes of degradation of benthic communities.

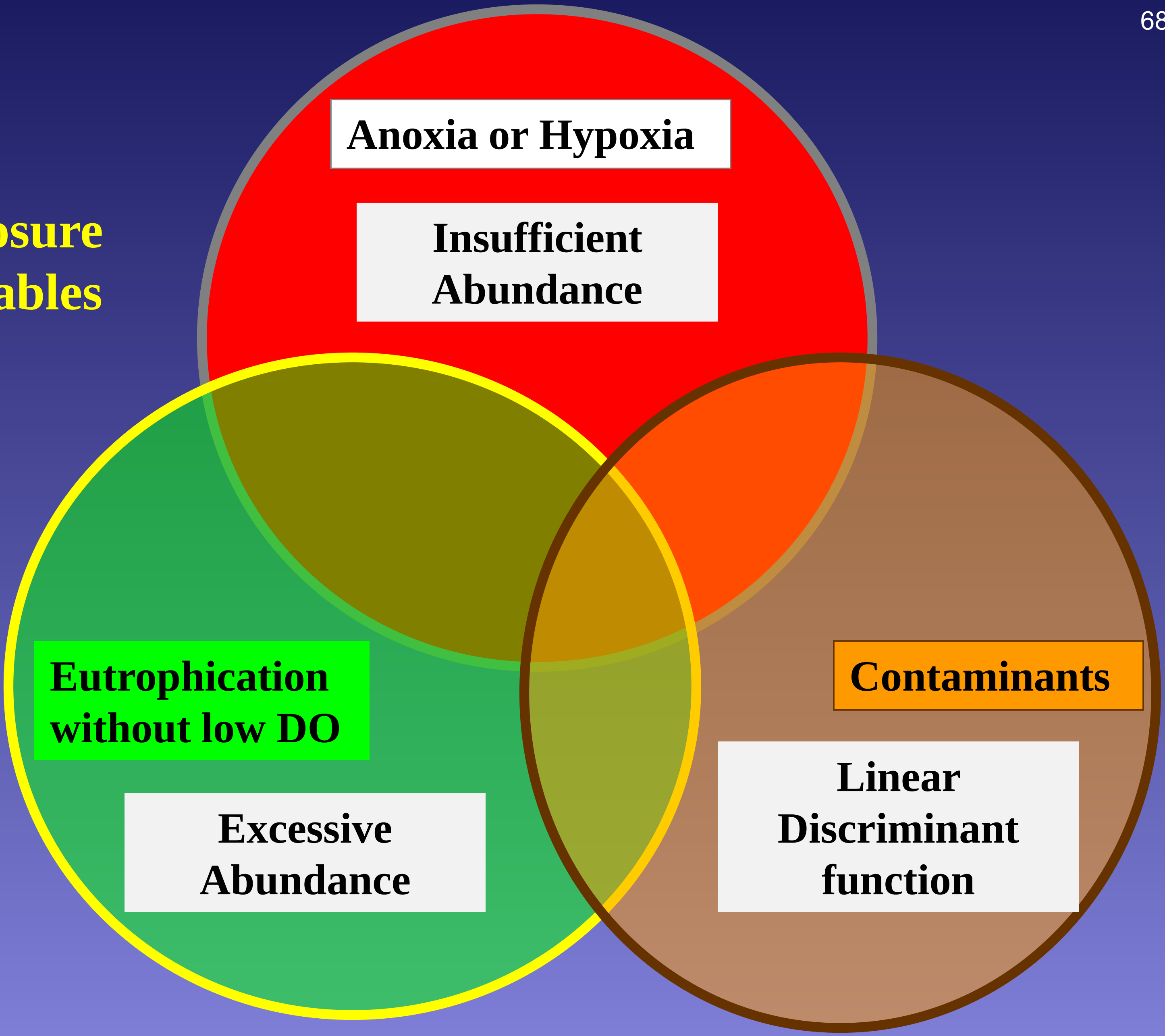
Low dissolved oxygen
Eutrophication
Sediment Contamination

(Dauer et al. 2002. EPA Technical Report)

Exposure Variables



Exposure Variables



Causes of benthic community degradation

I. Sediment contamination

Discriminant function

II. Organic enrichment (absent low DO)

Excessive abundance metric

III. Low dissolved oxygen

Insufficient abundance metric

Causes of

benthic community degradation

I. Sediment contamination

Discriminant function

OLD DOMINION UNIVERSITY

Department of Biological Sciences
College of Sciences
Norfolk, VA 23529-0456

DEVELOPMENT OF DIAGNOSTIC APPROACHES TO DETERMINE SOURCES OF ANTHROPOGENIC STRESS AFFECTING BENTHIC COMMUNITY CONDITION IN THE CHESAPEAKE BAY

Final Report

Prepared by

Principal Investigators: Daniel M. Dauer [1]
Michael F. Lane [1]
Roberto J. Llansó [2]

1 - Department of Biological Sciences
Old Dominion University

Causes of benthic community degradation

I. Sediment contamination

Linear discriminant function

63 benthic metrics

Two stress groups

Contaminant

Others

Validation rate – 85%

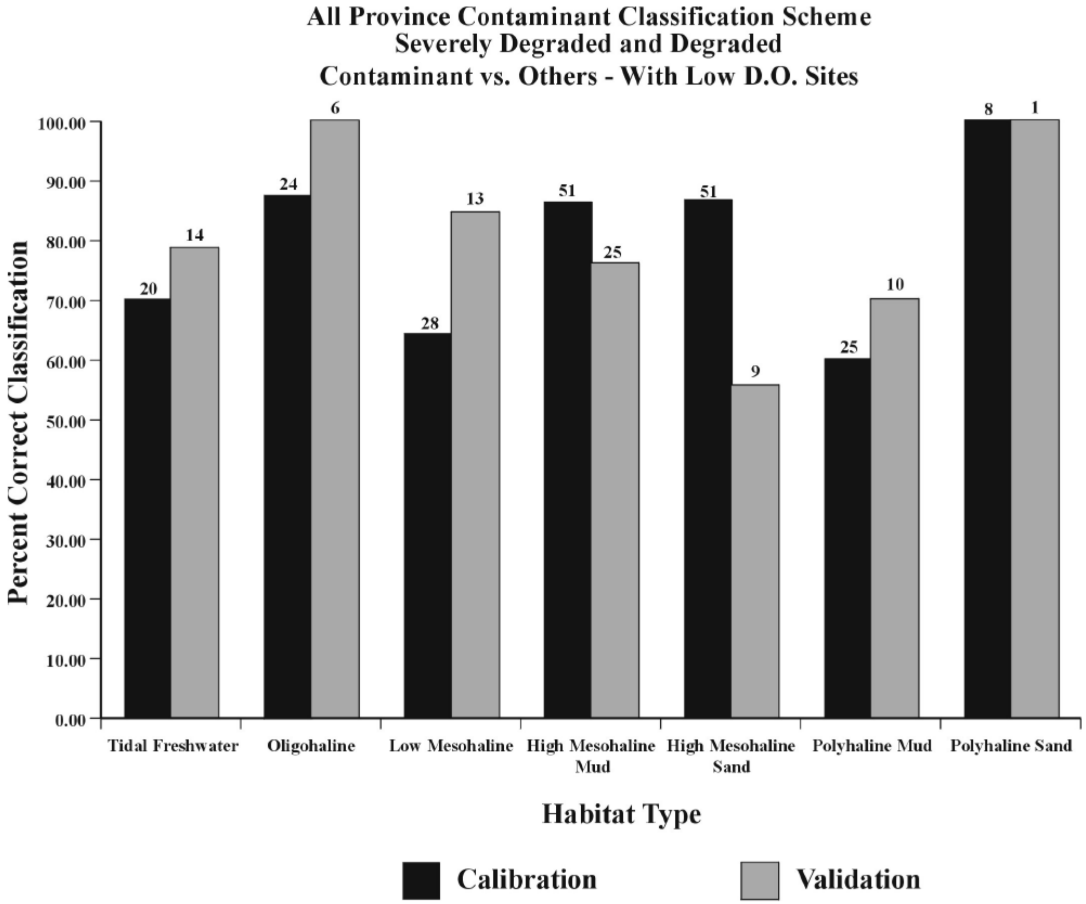


Figure 2. Discriminant function classification efficiencies for individual habitat types for the Baywide discriminant function for classifying severely degraded and degraded sites (including Low D.O. sites) into the Contaminant and Other stress groups. Numbers above the bars indicate the number of observations within each habitat type.

Table 3. Percent of the stratum placed into the sediment contaminant effect group using the contaminant discriminant function of Dauer et al. 2002 (posterior probability > 0.5). Data from 1996-2002. Elizabeth River data includes the intensive 1999 event and 25 random samples of the watershed from 2000-2002.

Stratum	N	Percentage of stratum in Contaminant Group
Lower (VA) Mainstem	175	10.9
Upper Bay Mainstem	175	17.7
MD Eastern Tributaries	175	16.6
Patuxent River	175	20.0
MD Middle Mainstem	175	17.1
MD Western Tributaries	175	24.6
Potomac River	175	31.4
James River	175	30.9
Rappahannock River	175	37.1
York River	175	38.3
Elizabeth River	275	52.4

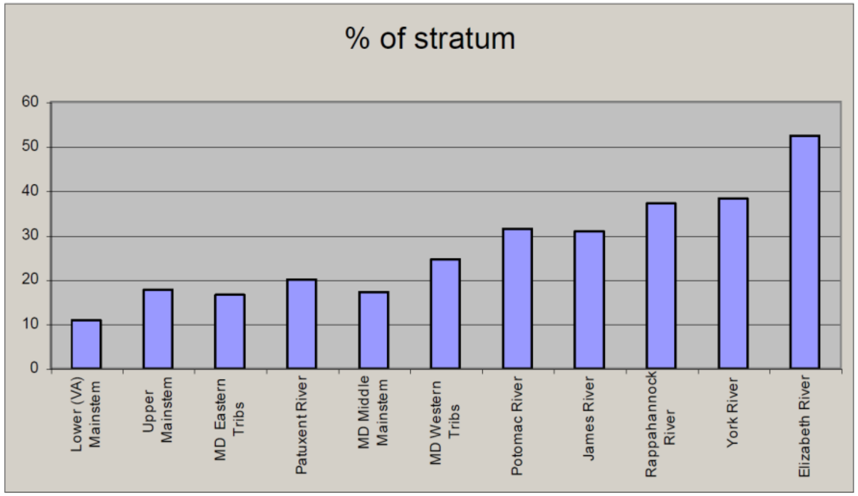


Figure 2. Percentage of stratum with a B-IBI value < 2.7 and placed into the Contaminant Group with a posterior probability > 0.5.

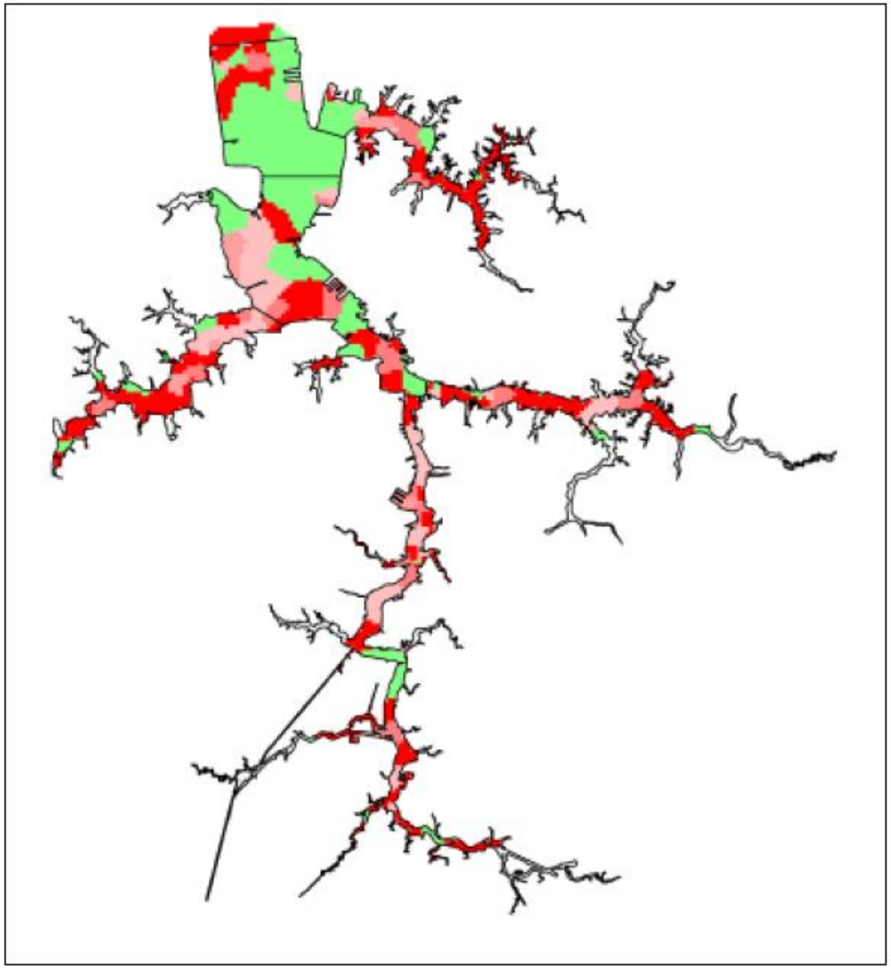
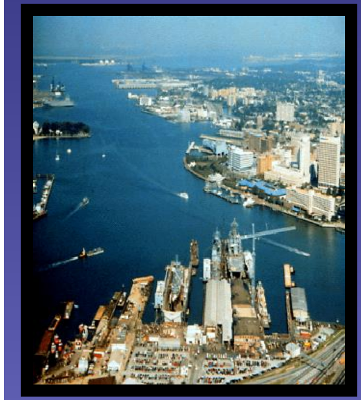


Figure 5. Diagnostic discriminant tool results and an interpolation fitting algorithm used here to classify the Elizabeth River watershed benthic communities into categories distinguished by the type of stress experienced by those communities. Red shading indicates degraded benthic communities stressed by toxic contamination (posterior probability in Contaminant Group > 0.5), with higher color intensity indicating higher probabilities of contaminant effects (>0.5 to <0.7; >=0.7 to <0.9; >=0.9). Salmon shading indicates degraded benthic communities stressed by other sources (posterior probability in Contaminant Group <=0.5). Green indicates good benthic community condition.



Causes of benthic community degradation

I. Sediment contamination

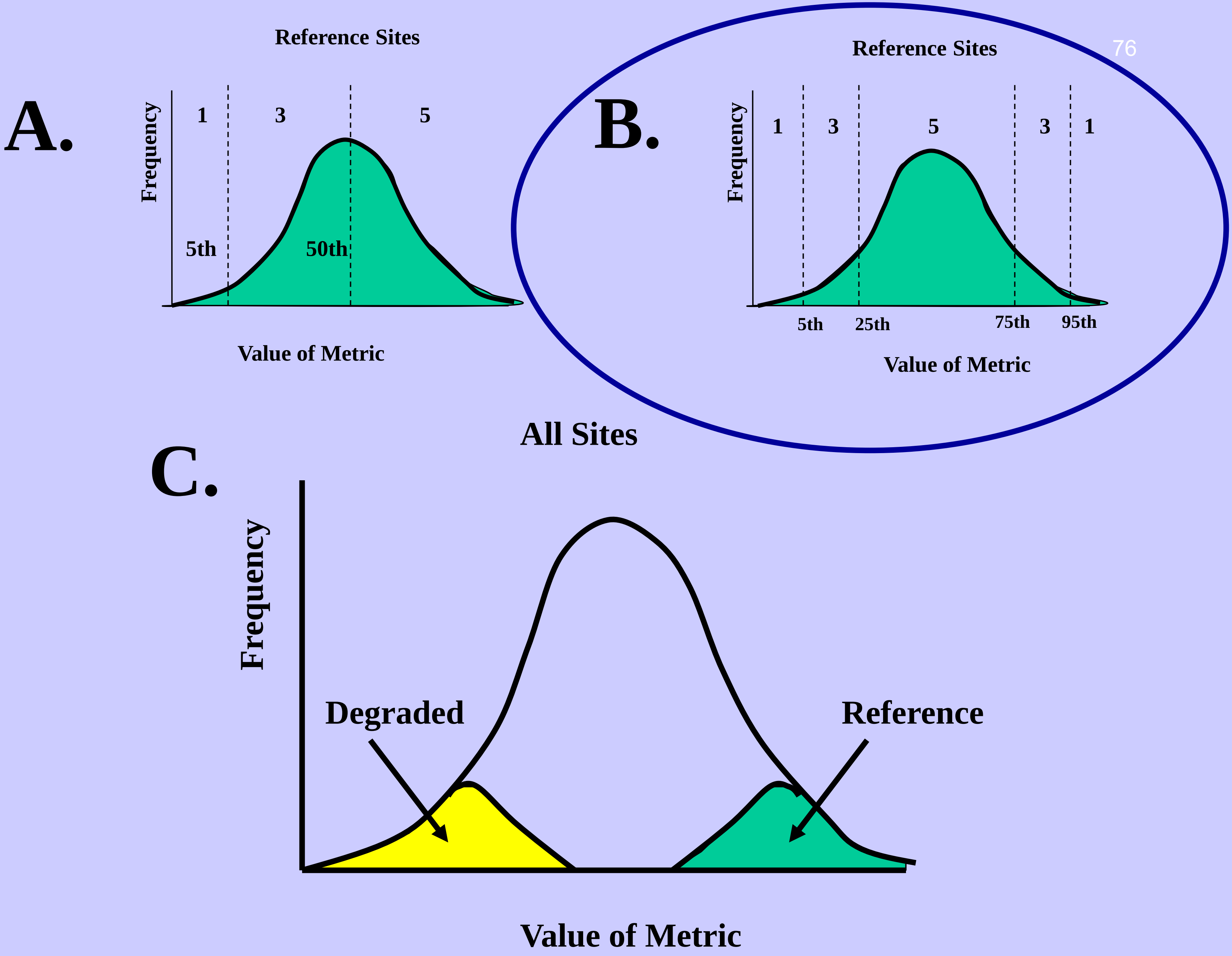
Discriminant function

II. Organic enrichment (absent low DO)

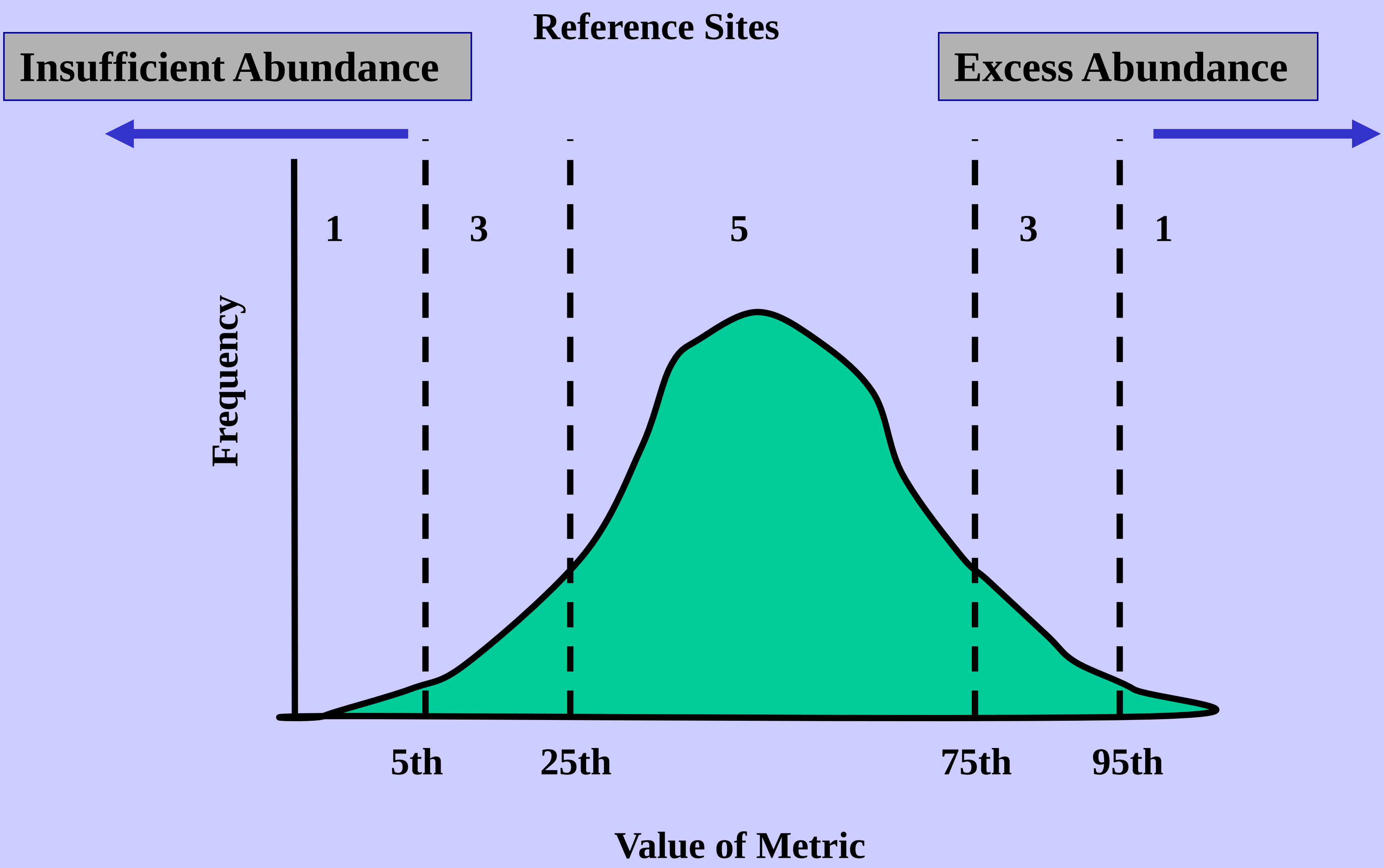
Excessive abundance metric

III. Low dissolved oxygen

Insufficient abundance metric

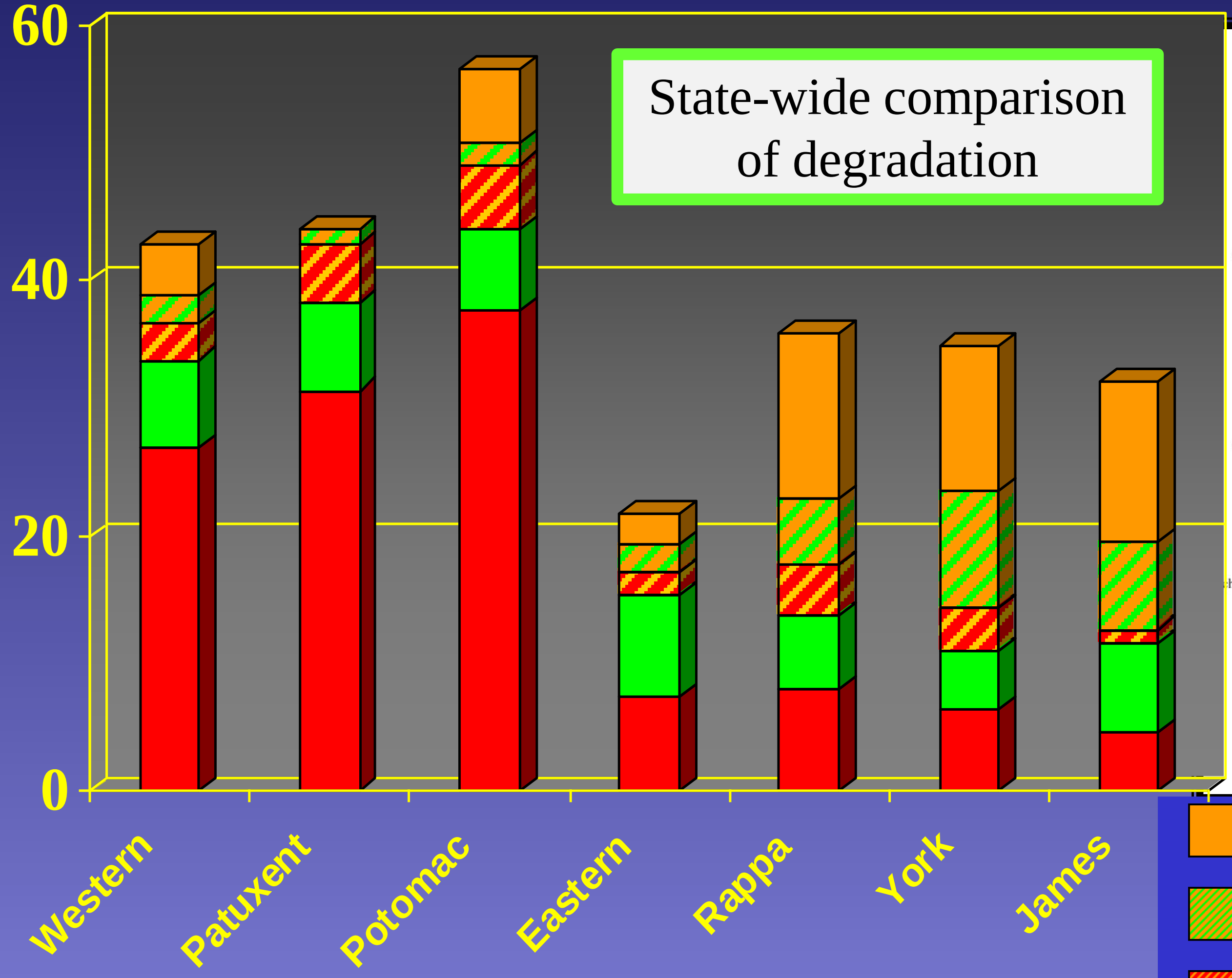

A.
Reference Sites
Frequency
1
3
5
5th
50th
Value of Metric
B.
Reference Sites
Frequency
1
3
5
3
1
5th
25th
75th
95th
Value of Metric
All Sites
C.
Frequency
Degraded
Reference
Value of Metric

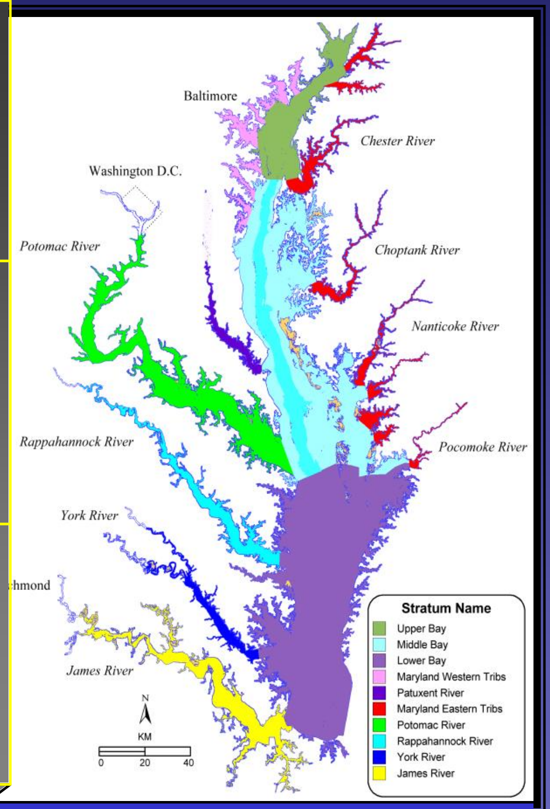
Index of Biotic Integrity (IBI)



Degradation Categories

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





Contaminant (Cont)

Cont & Excessive Abundance

Cont & Insufficient Abundance

Excessive Abundance

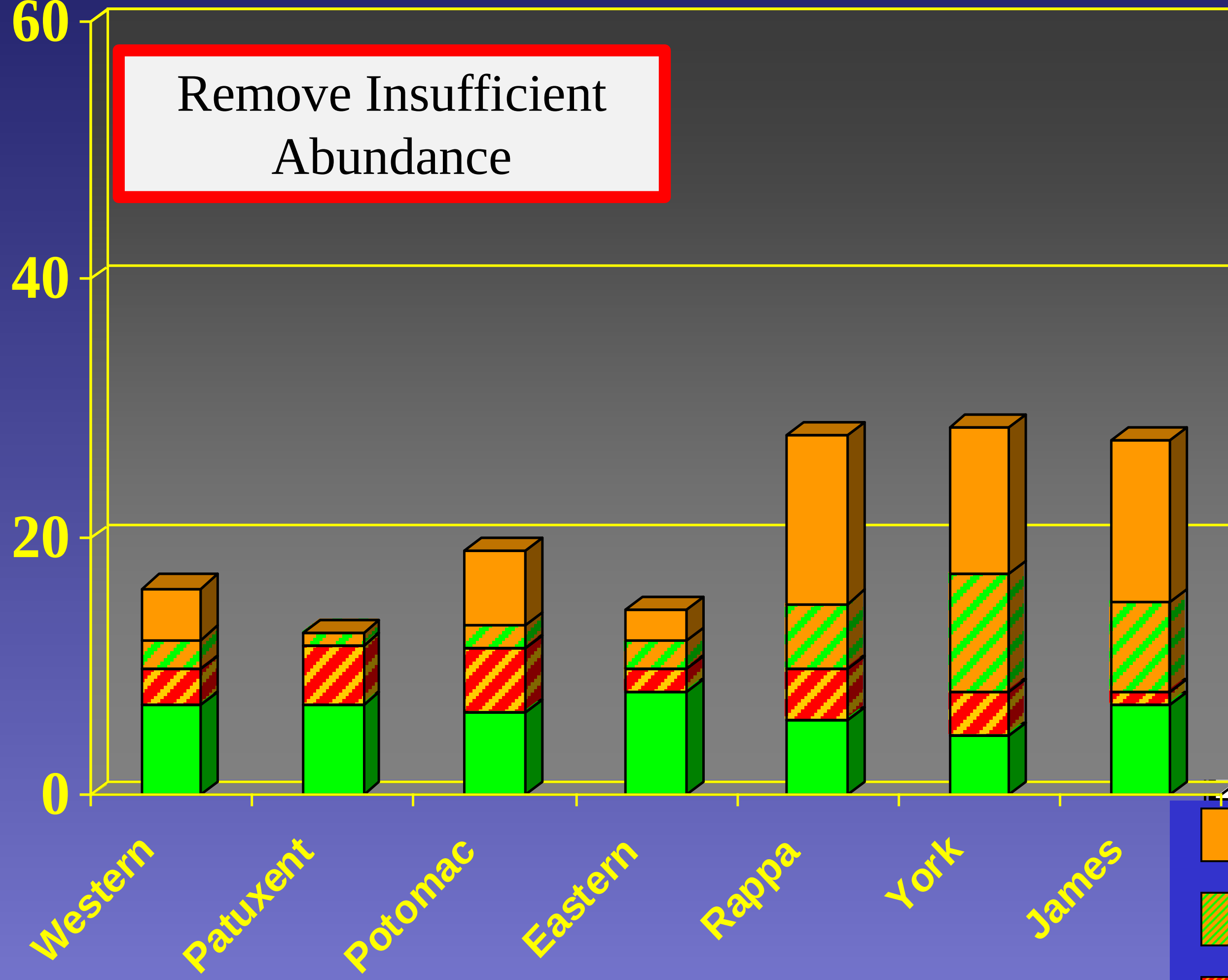
Insufficient Abundance

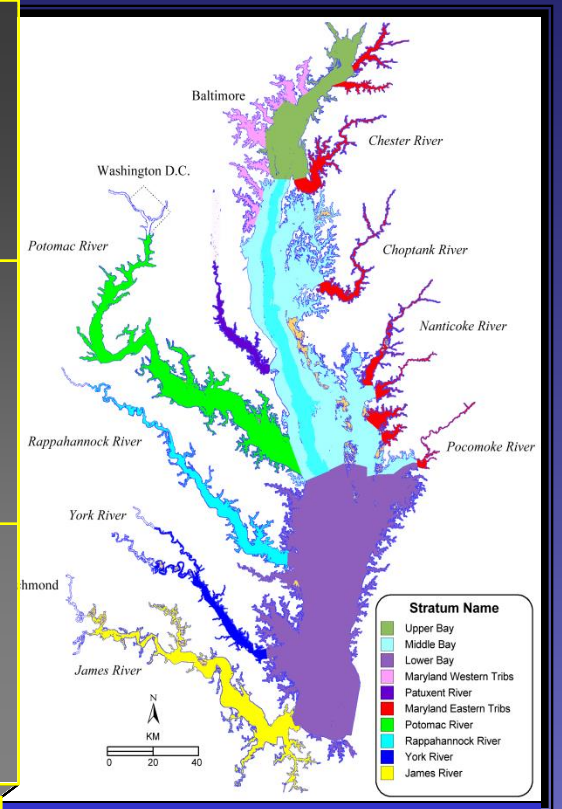
Tributary strata

Degradation Categories

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

Remove Insufficient Abundance





Contaminant (Cont)

Cont & Excessive Abundance

Cont & Insufficient Abundance

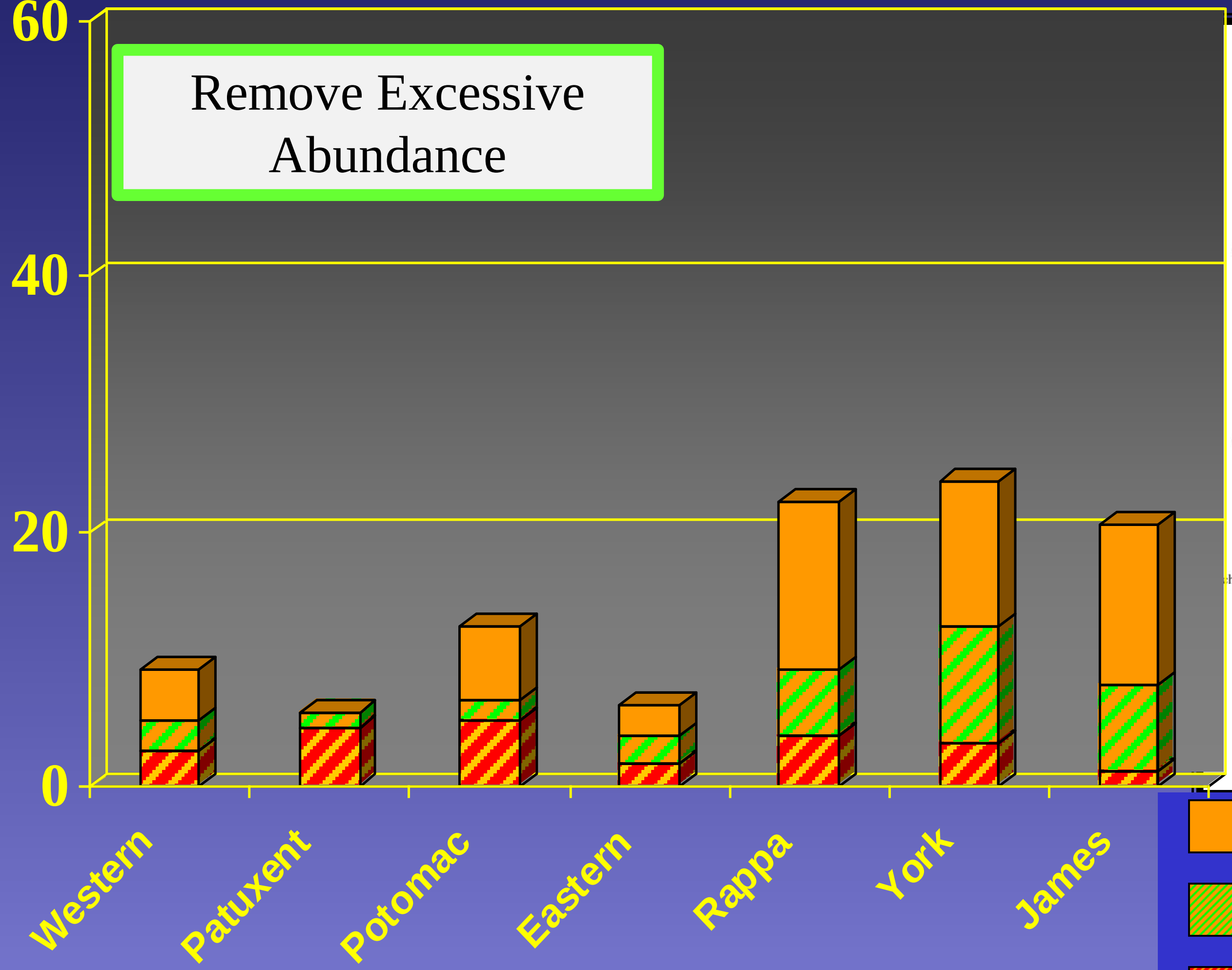
Excessive Abundance

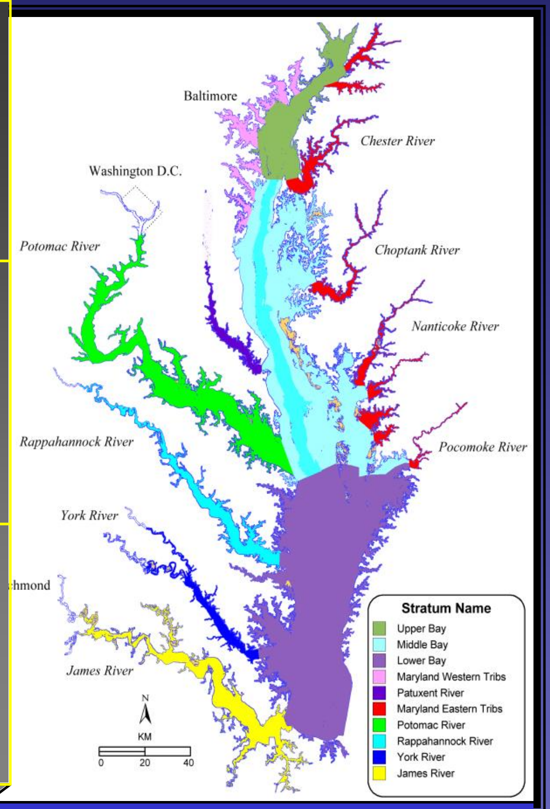
Insufficient Abundance

Tributary strata

Degradation Categories

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



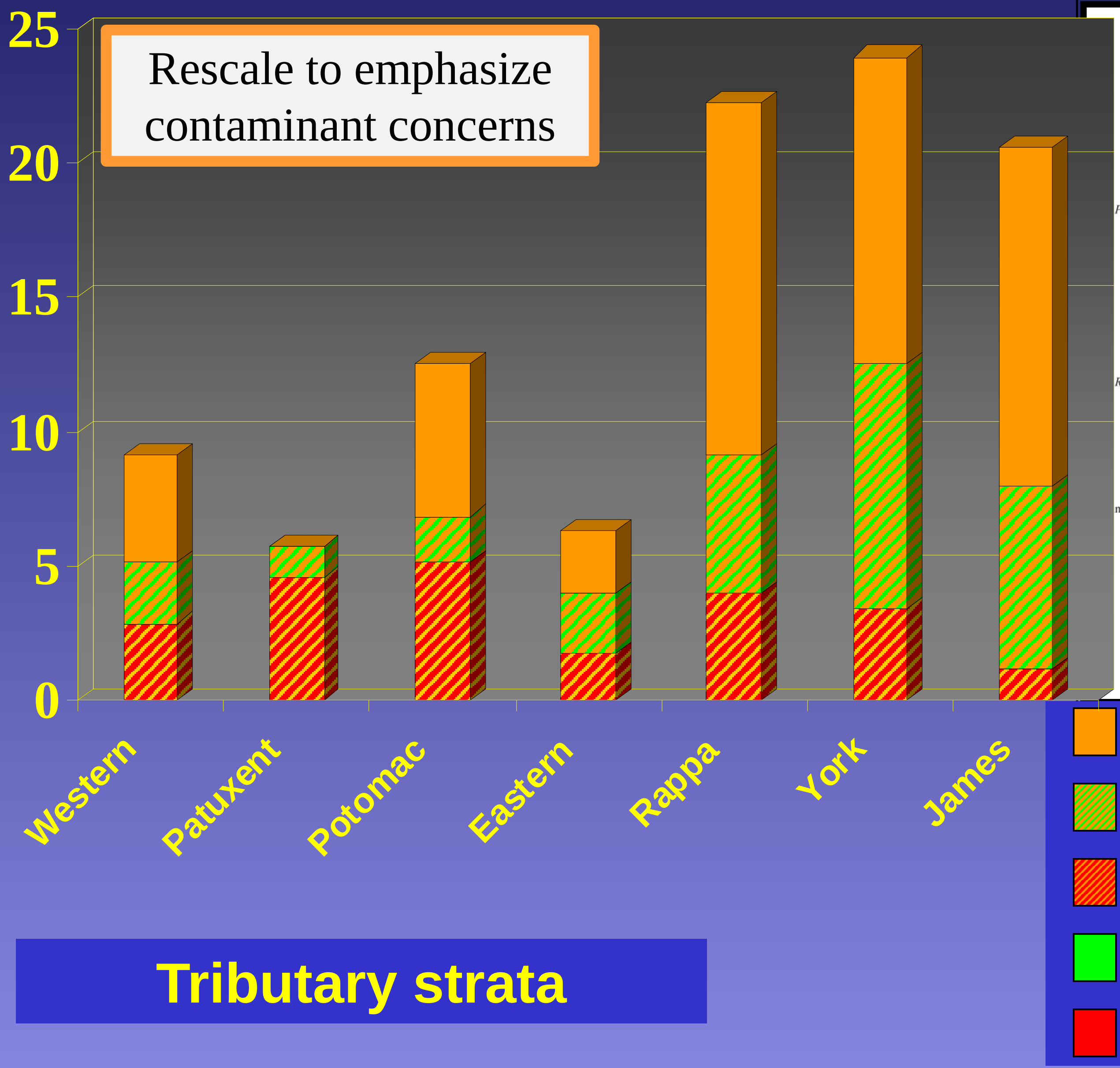


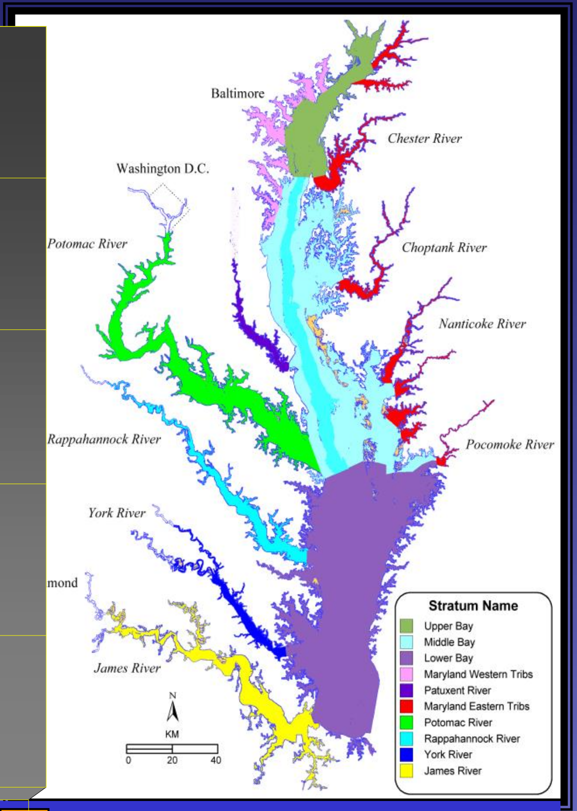
- Contaminant (Cont)
- Cont & Excessive Abundance
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

Tributary strata

Degradation Categories

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



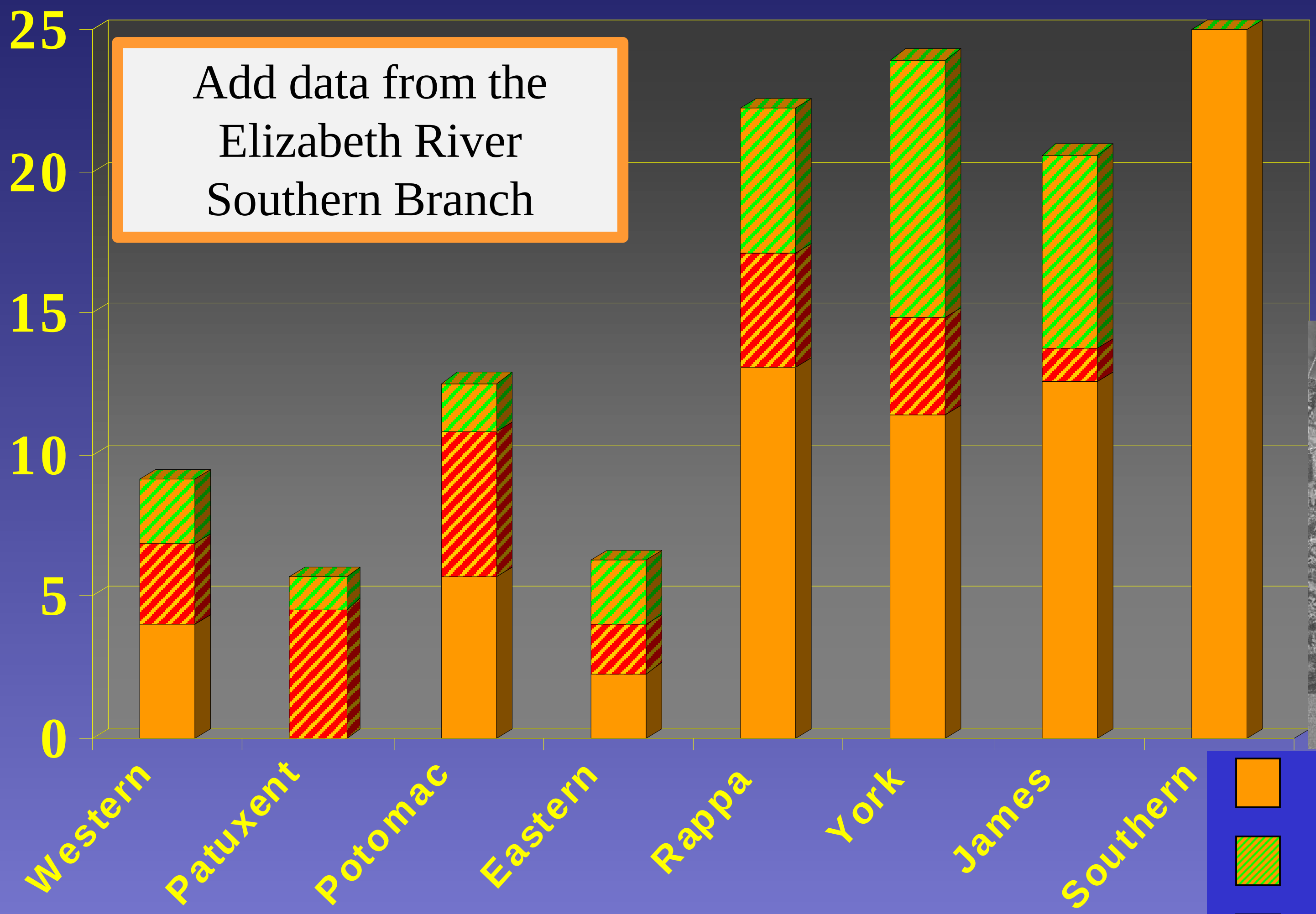


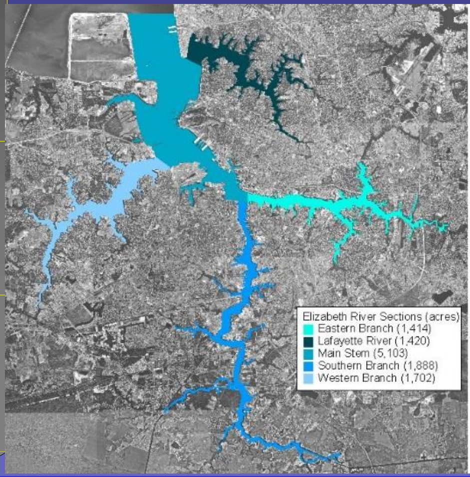
Tributary strata

Degradation Categories

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

Add data from the Elizabeth River Southern Branch

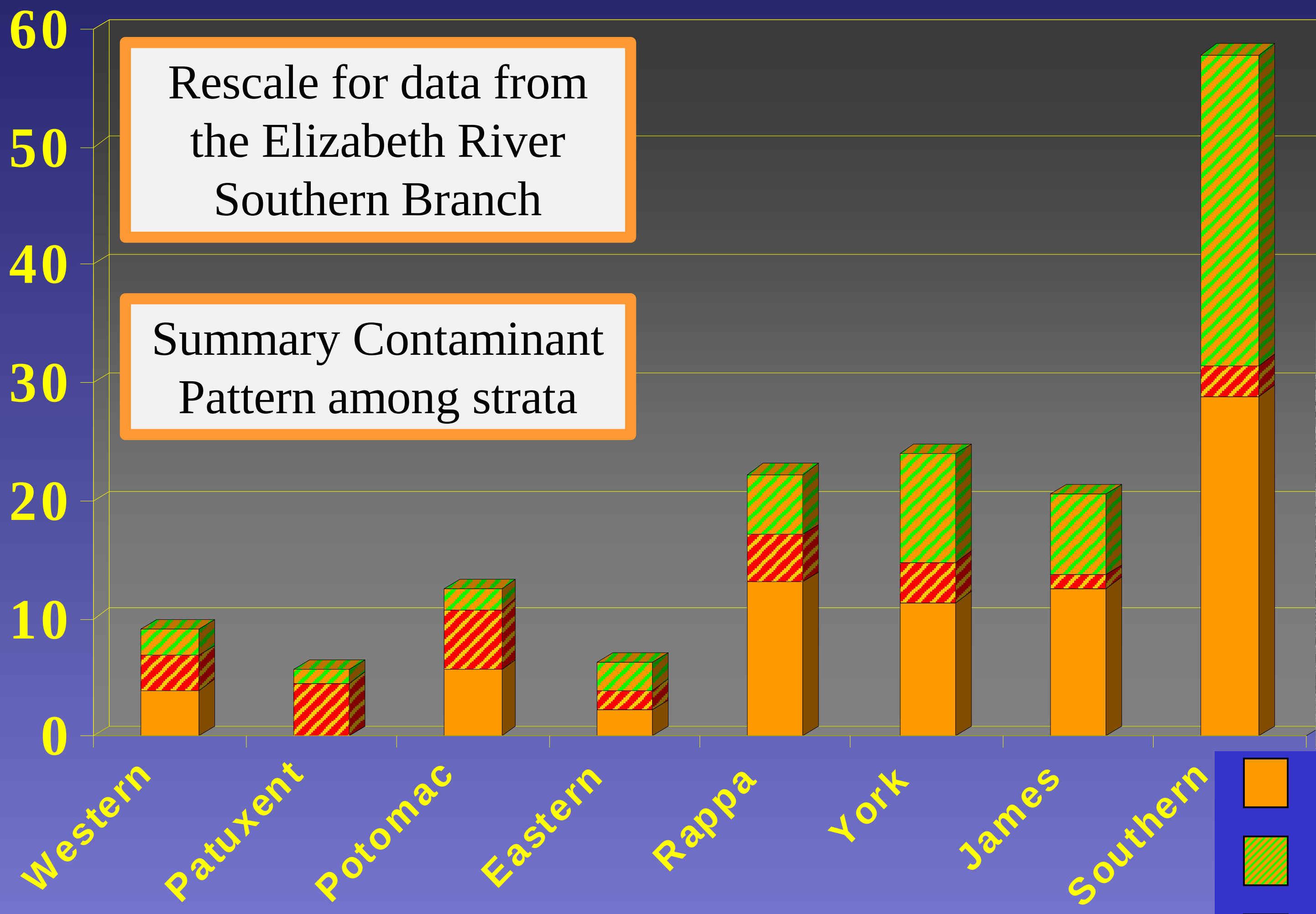


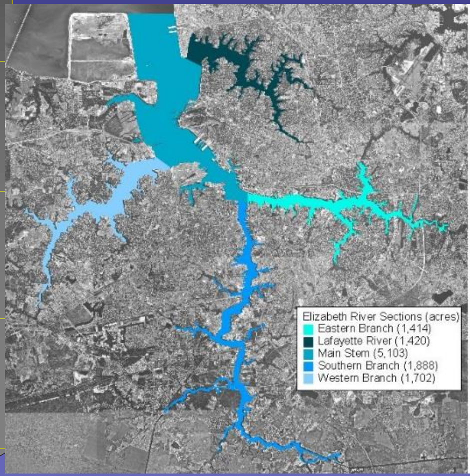


Tributary strata

Degradation Categories

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

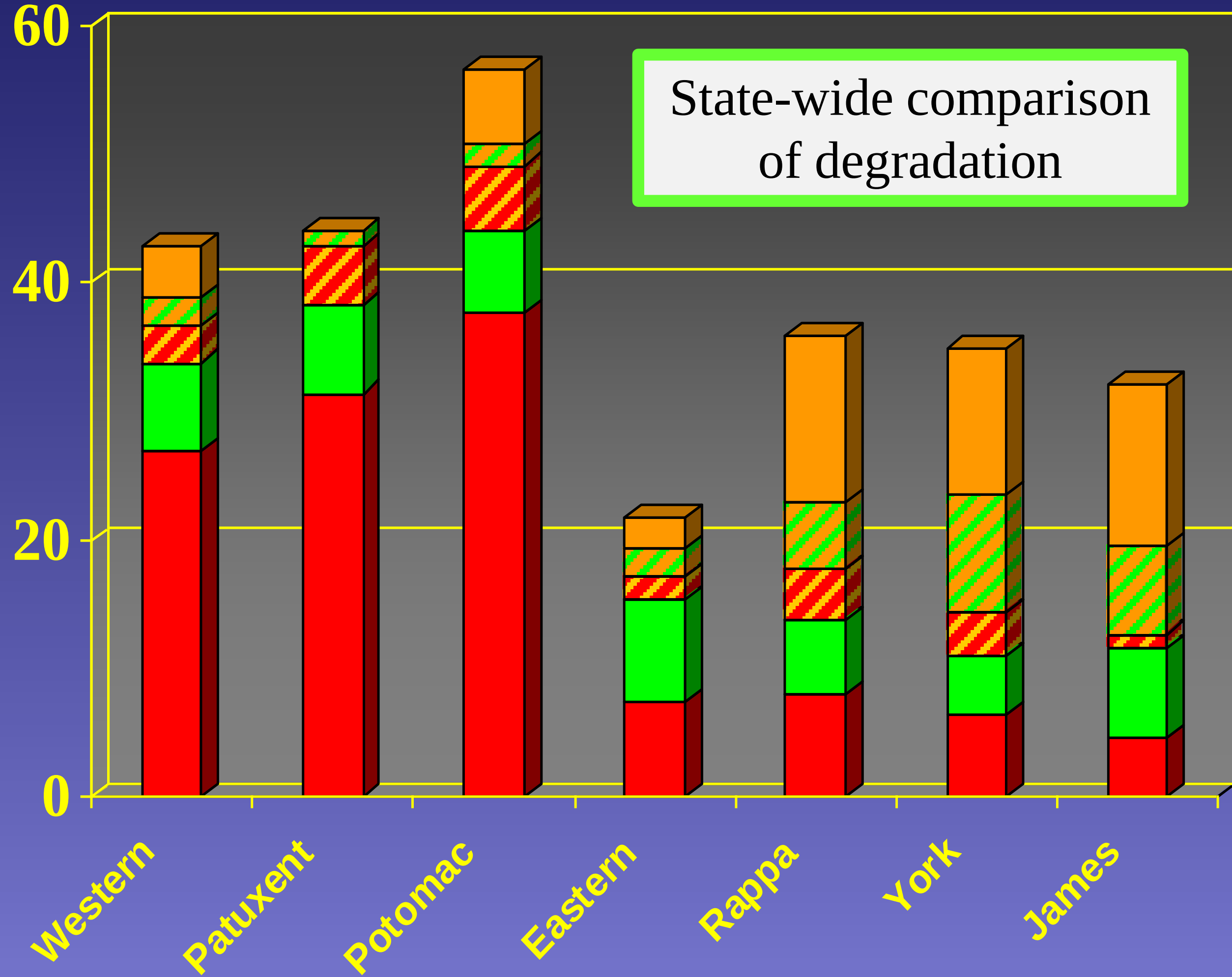


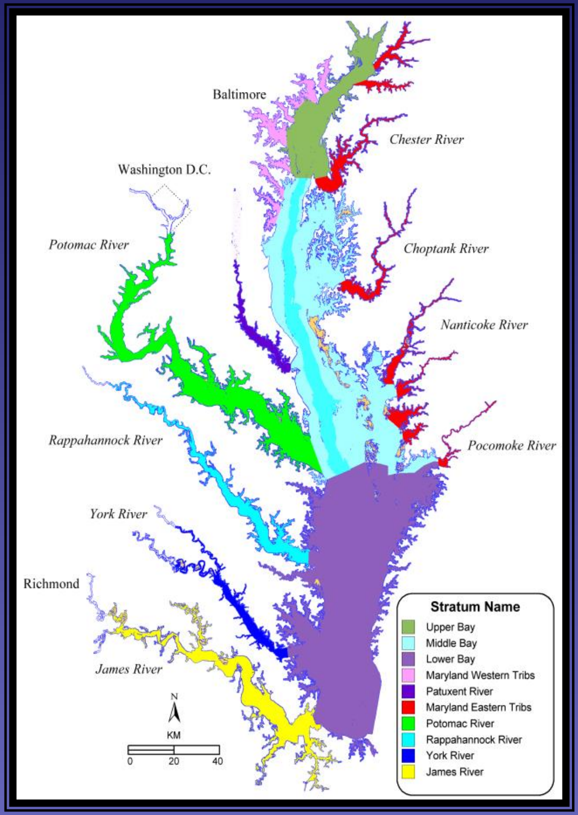


Tributary strata

Degradation Categories

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

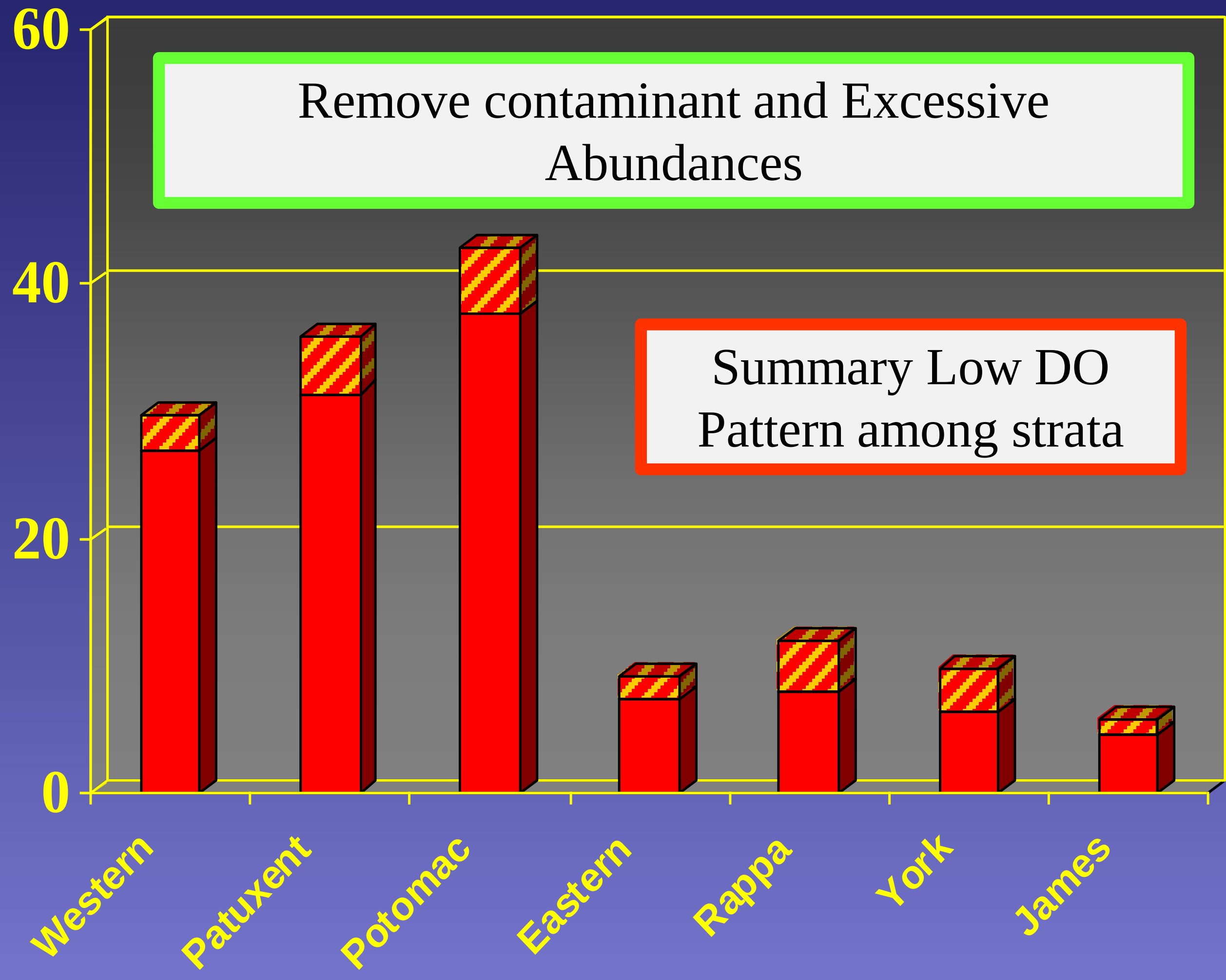


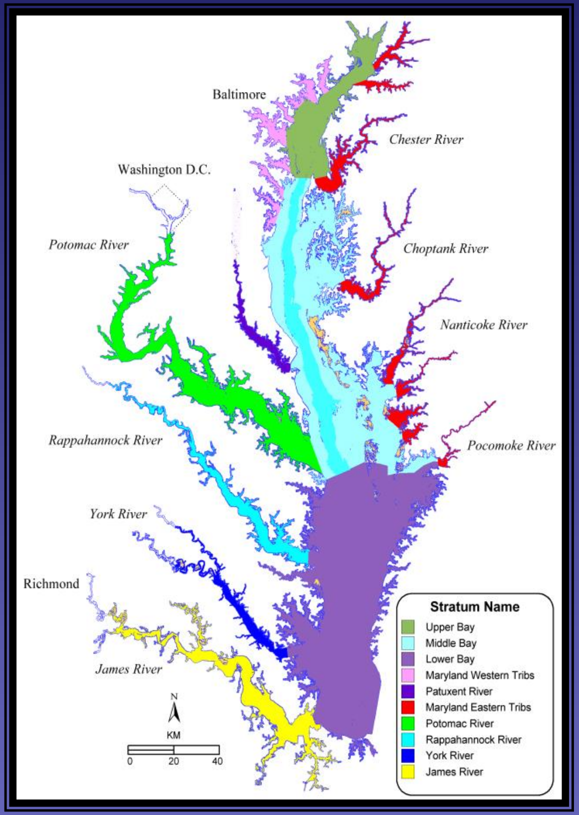


Tributary strata

Degradation Categories

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





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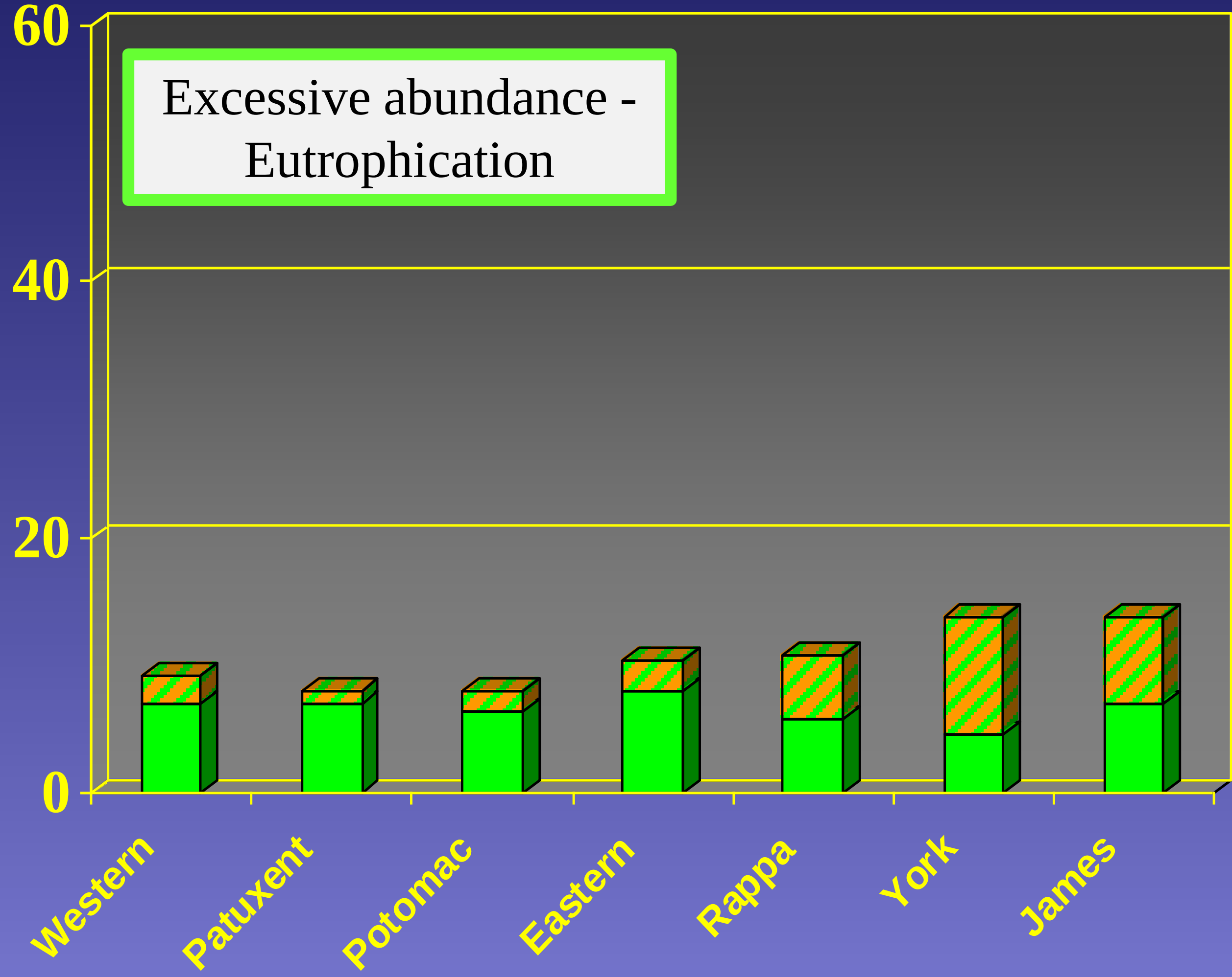
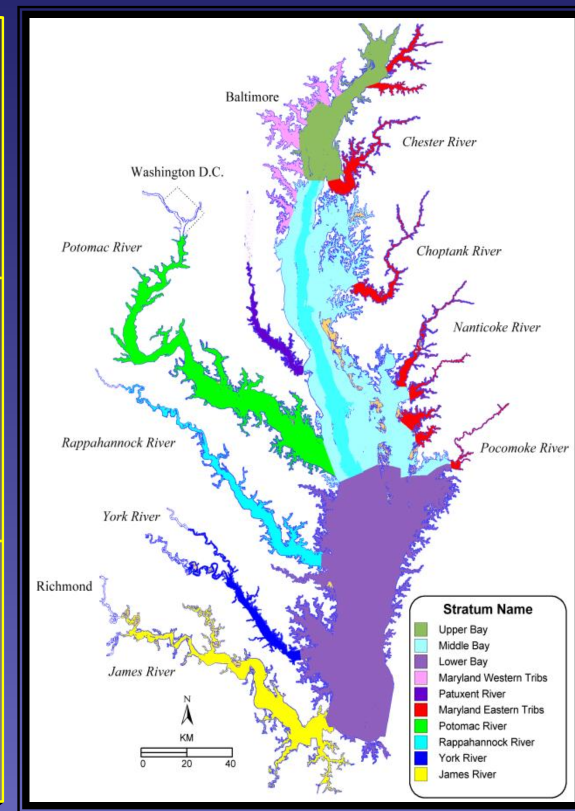
- Cont & Insufficient Abundance
- Excessive Abundance
- Insufficient Abundance

Tributary strata

Degradation Categories

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





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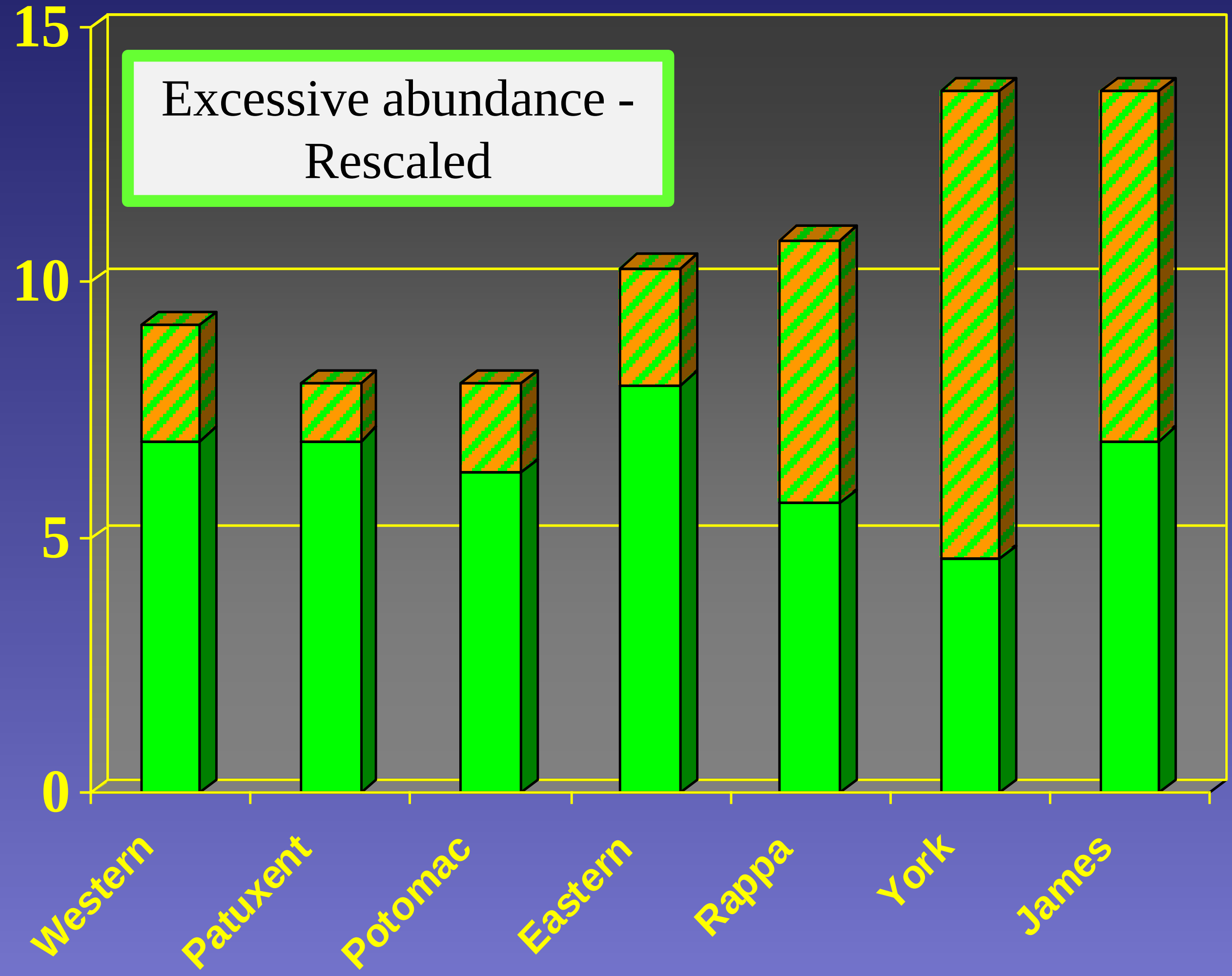
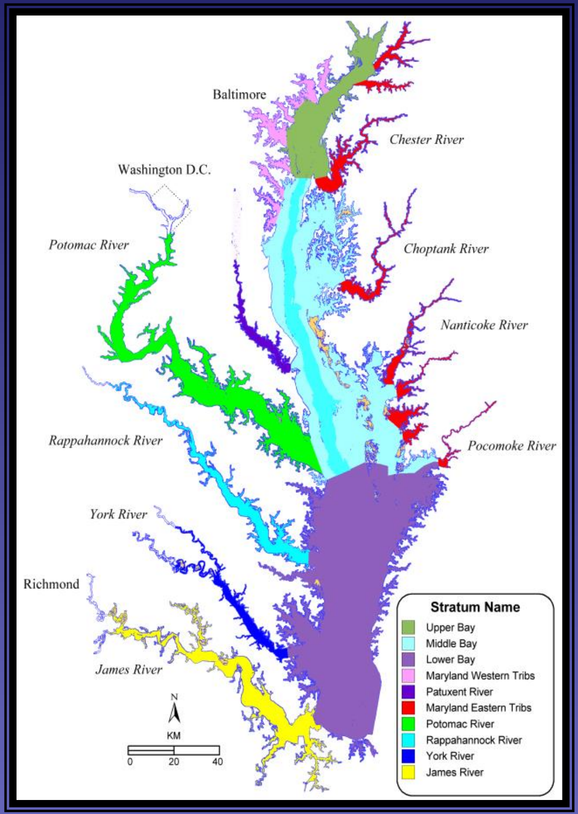
- Insufficient Abundance

Tributary strata

Degradation Categories

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



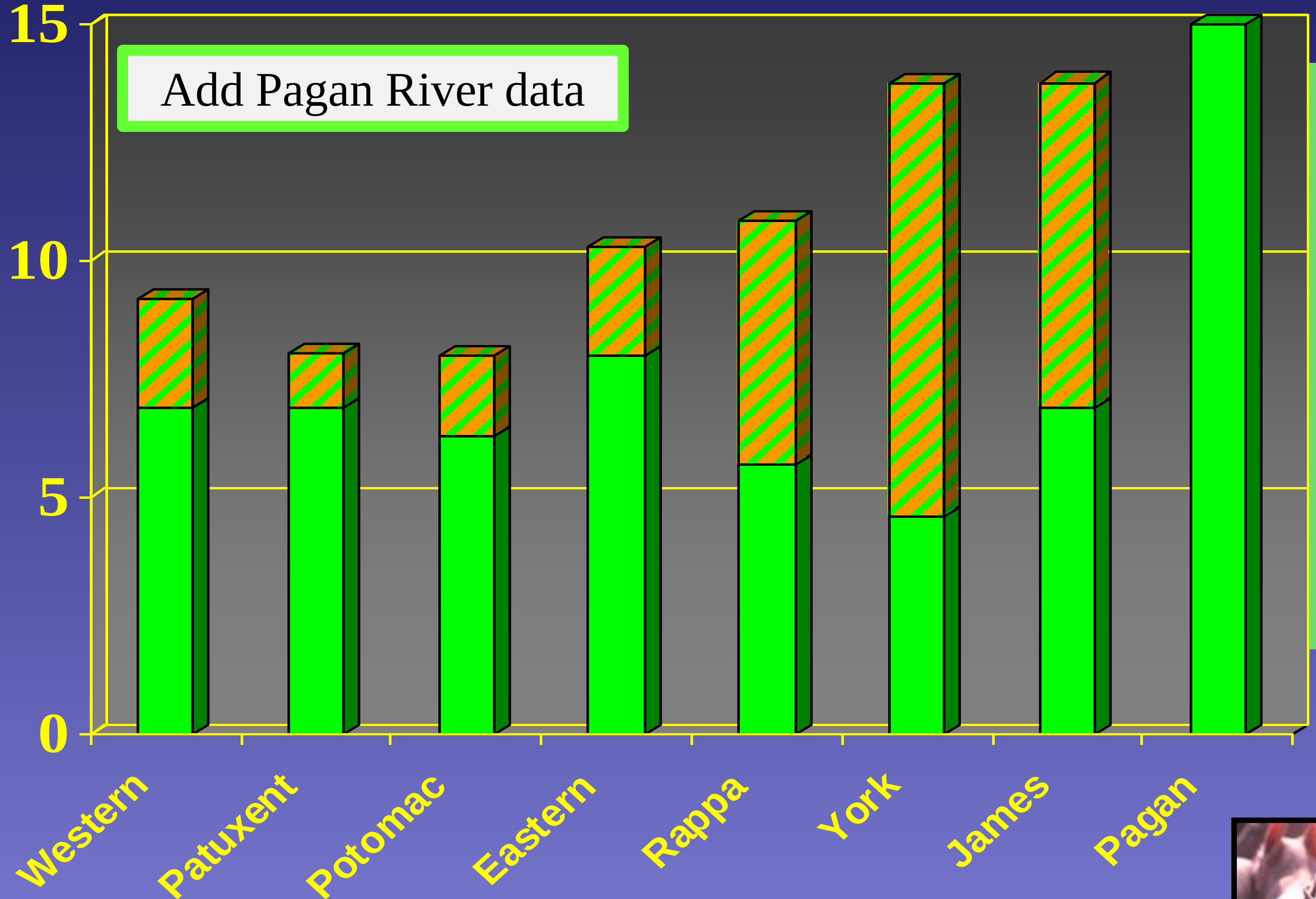


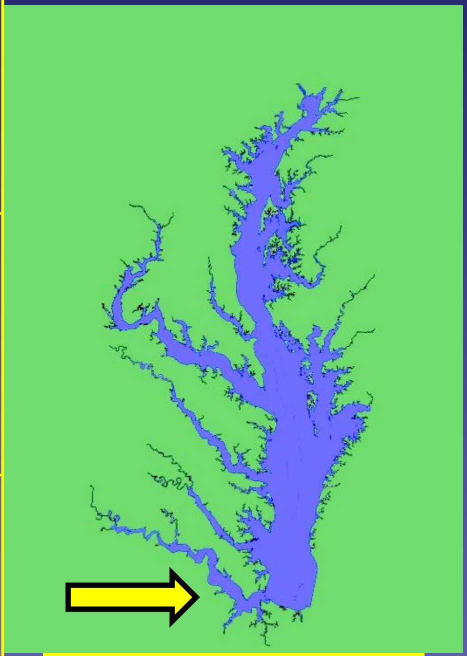
Contaminant (Cont)
Cont & Excessive Abundance
Cont & Insufficient Abundance
Excessive Abundance
Insufficient Abundance

Tributary strata

Degradation Categories

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



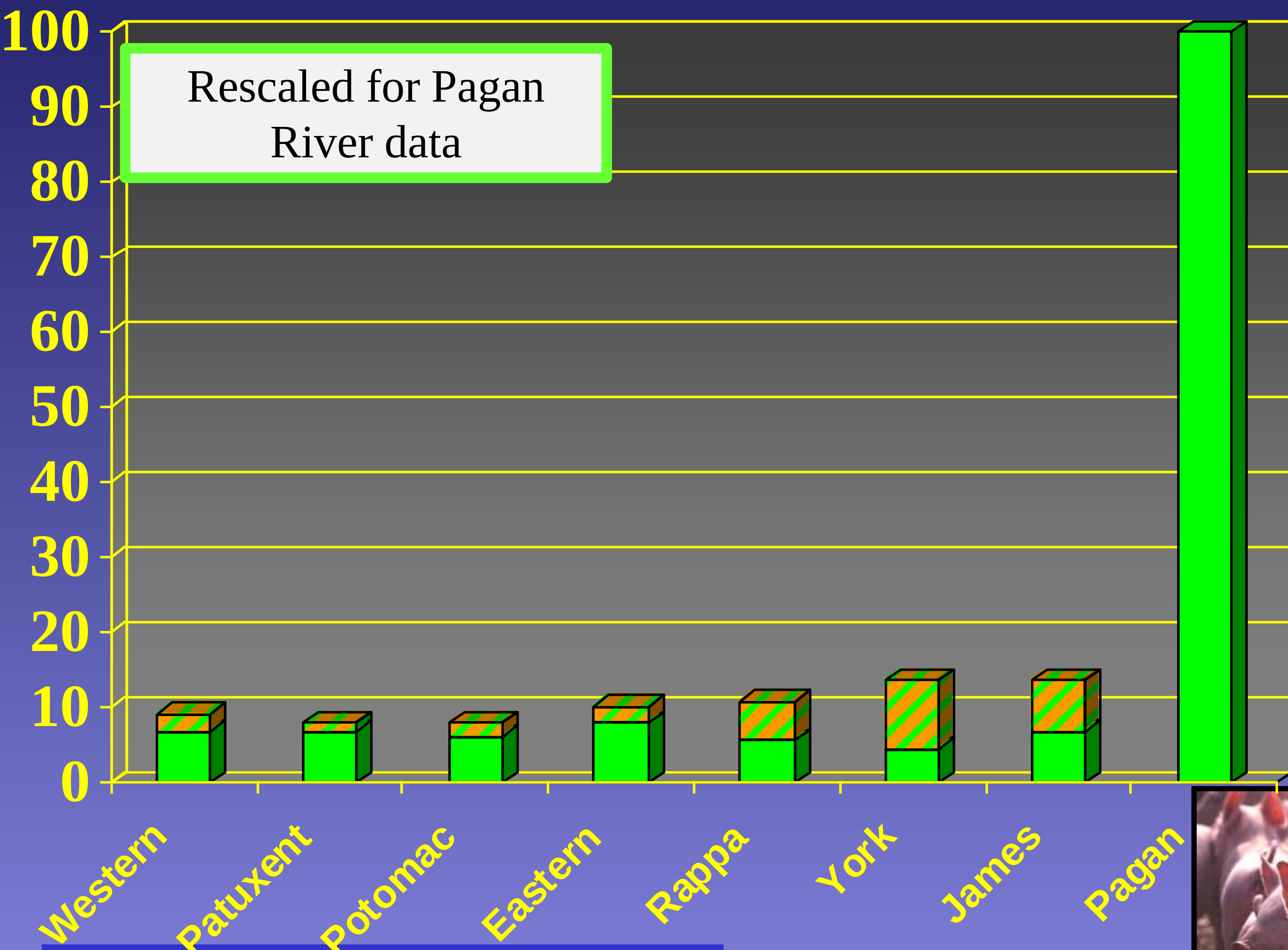


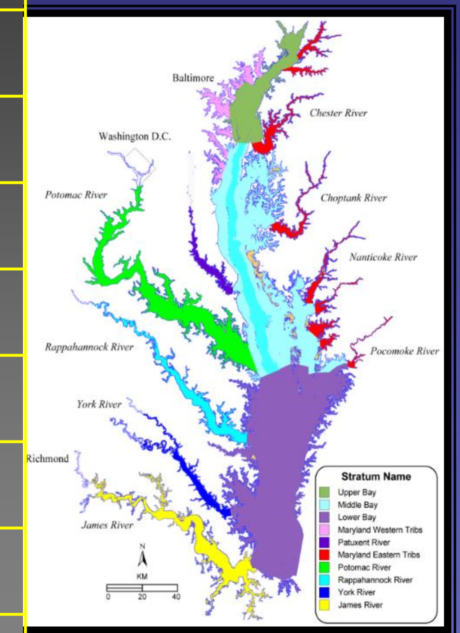
Pagan River

Tributary strata

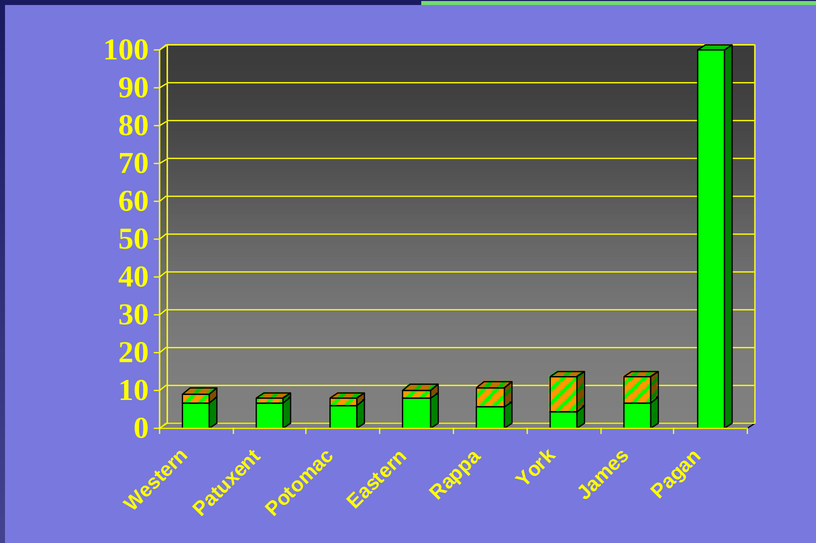
Degradation Categories

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





Tributary strata



Pagan River prior to 1996

TN annual mean **-1.8** mg/L
(summer mean - **3.5** mg/L)

TP annual mean - **0.8** mg/L
(summer mean **1.3** mg/L)

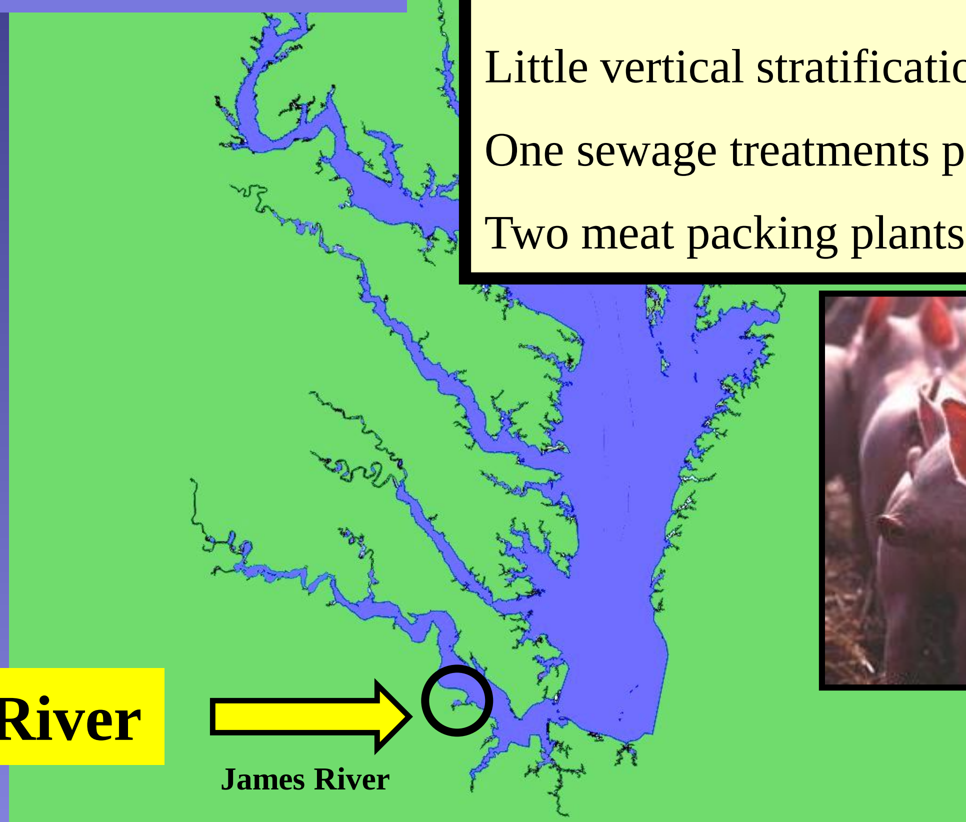
Chlorophyll a levels **30 - 140**µg/L
(summer mean **100** µg/L)

Secchi depth 0.4m

Little vertical stratification

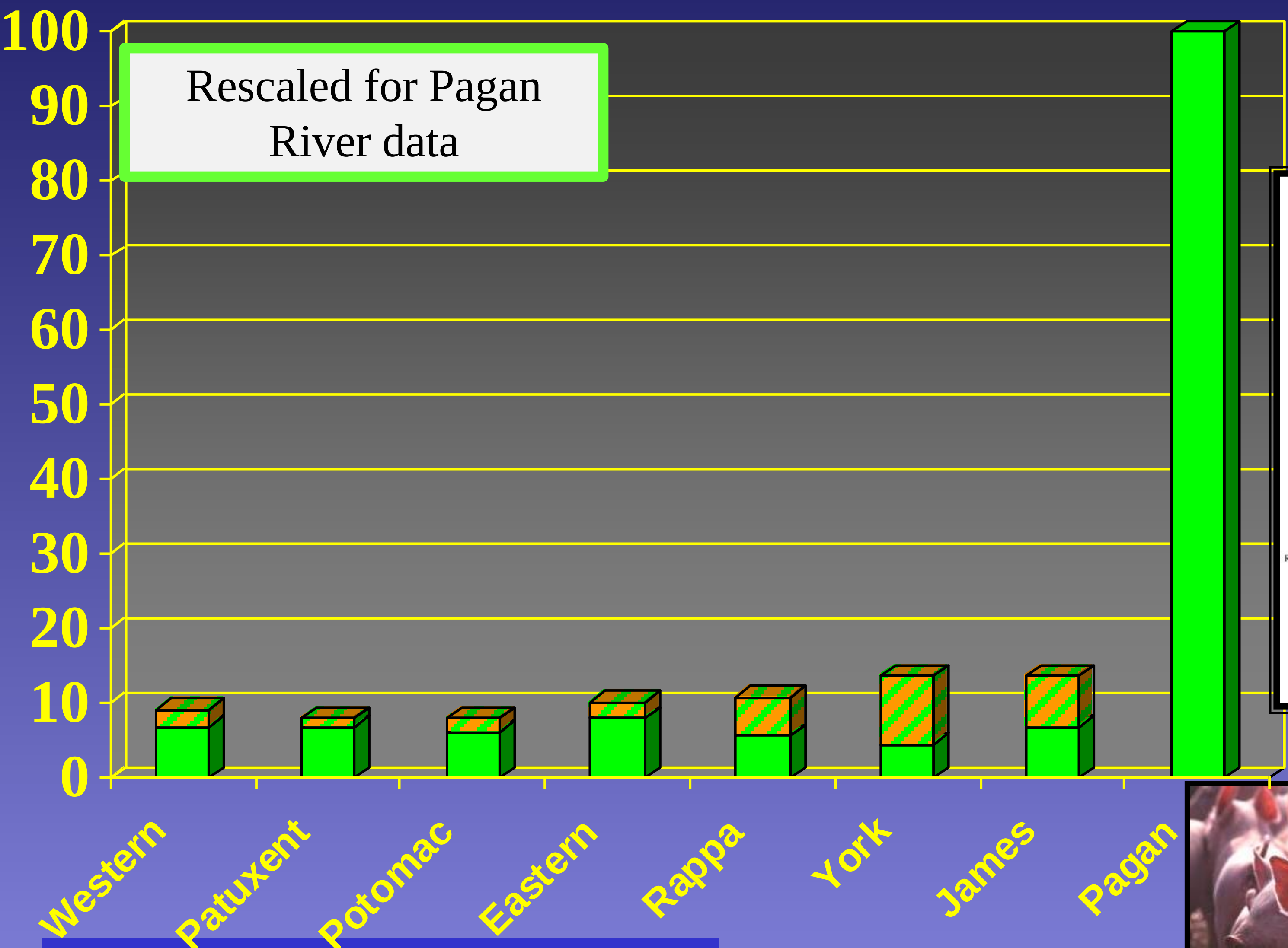
One sewage treatments plant

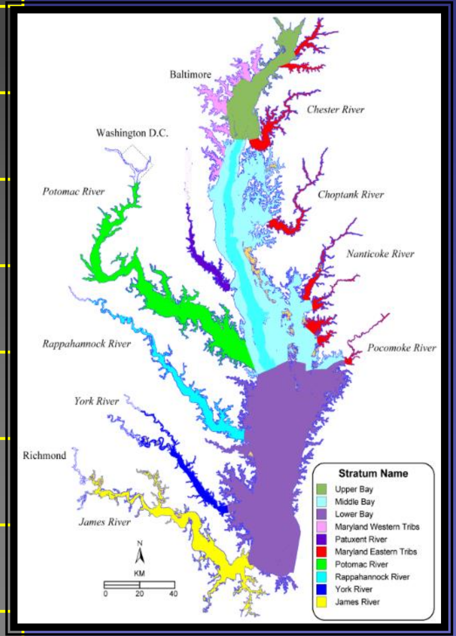
Two meat packing plants in Smithfield



Degradation Categories

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



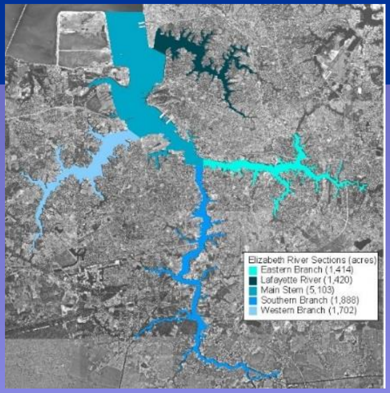


Tributary strata

Diagnostic approaches to causes of degradation

Summary

1. Sediment contamination
   - Linear discriminant function
2. Moderate eutrophication
   - Single metric (excessive abundance)
3. Low dissolved oxygen
   - Single metric (insufficient abundance)



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

Low dissolved oxygen
Eutrophication
Sediment Contamination

(Dauer et al. 2002. EPA Technical Report)

(6) Impaired waters designations of Maryland DNR and Virginia DEQ 303d

(Llansó et al. 2009)

(6) Impaired waters designations of Maryland DNR and Virginia DEQ 303d

(Llansó et al. 2009)

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Assessing ecological integrity for impaired waters decisions in Chesapeake Bay, USA

Roberto J. Llansó [a,*], Daniel M. Dauer [b], Jon H. Vølstad [a,c]

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[b] Department of Biological Sciences, Old Dominion University, Norfolk, Virginia 23529, USA
[c] Institute of Marine Research, P.O. Box 1870 Nordnes, 5817 Bergen, Norway

ARTICLE INFO

Keywords:
Ecological integrity
Benthic community condition
Impaired waters assessment
Biological criteria
Chesapeake Bay

ABSTRACT

To meet the requirements of the Clean Water Act, the States of Maryland and
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method to 1430 probability-based benthic samples in 85 Chesapeake Bay se
ments were considered impaired for benthic community condition. The final
considers benthic condition in combination with key stressors such as dis
contaminants.

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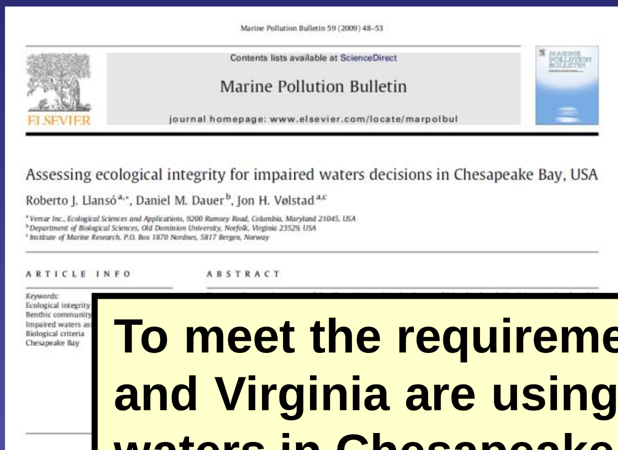
Years 2000-2004
1,430 samples
85 segments

(6) Impaired waters designations of Maryland DNR and Virginia DEQ 303d

(Llansó et al. 2009)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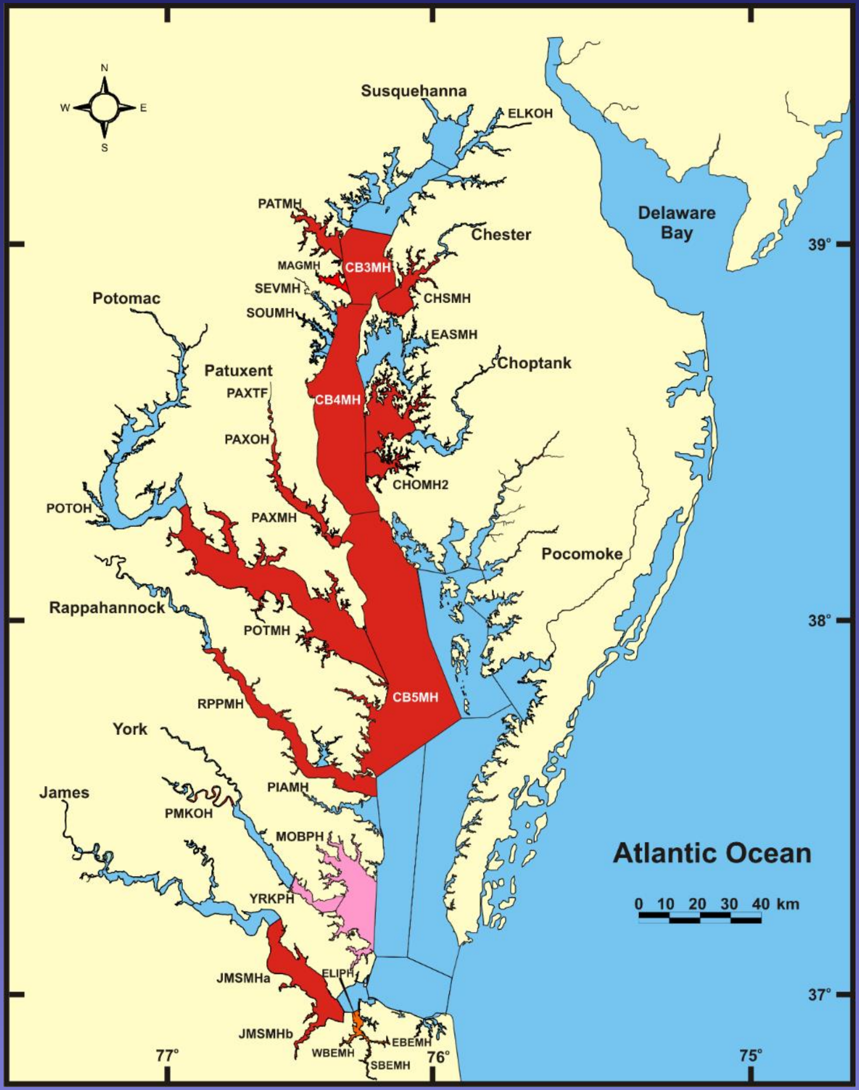
1. **The impaired waters decision approach combines multiple benthic habitat-dependent indices in a Bay segment (equivalent to water bodies) with a statistical test of impairment.**
2. **The method takes into consideration uncertainty in reference conditions, sampling variability, multiple habitats, and sample size.**
3. **Twenty-two segments were considered impaired for benthic community condition.**

(6) Impaired waters designations of Maryland DNR and Virginia DEQ 303d (Llansó et al. 2009)

303D Assessment 2000-2004

Impaired Segment

Impaired but BIBI ≥ 3.0



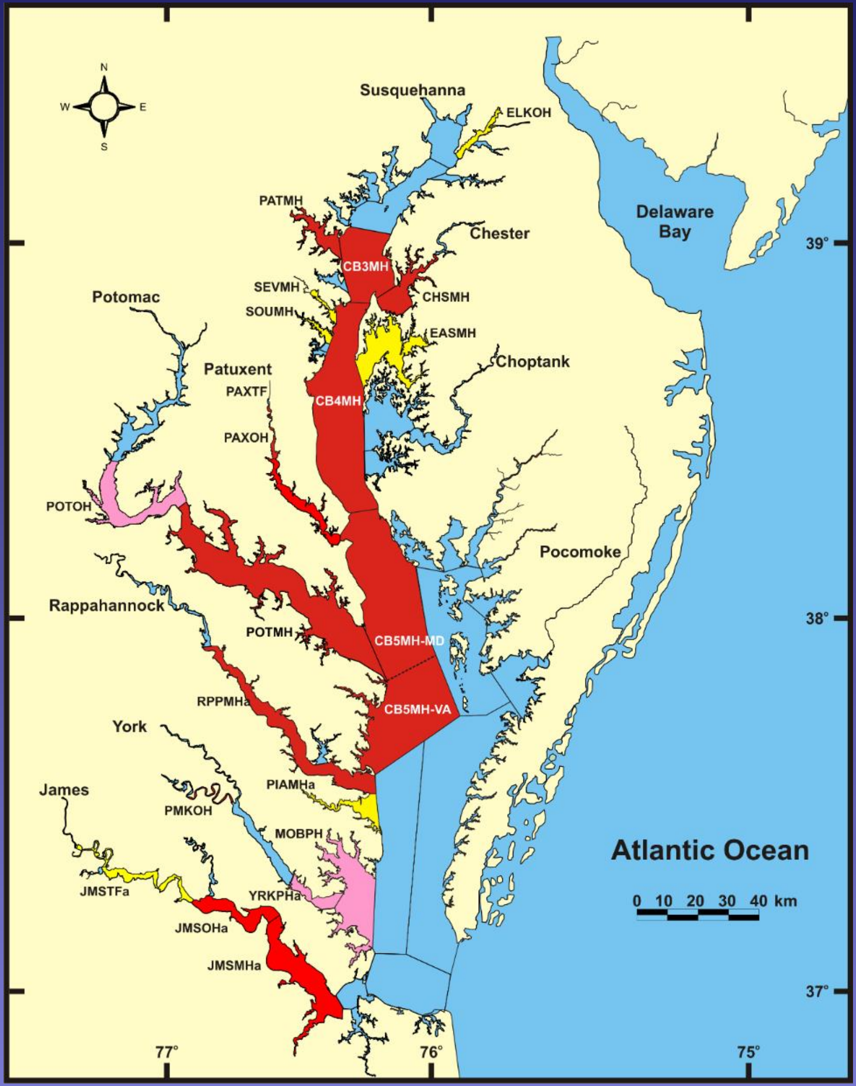
(6) Impaired waters designations of Maryland DNR and Virginia DEQ 303d (Llansó et al. 2009)

303D Assessment 2009-2014

Impaired Segment

Impaired but BIBI ≥ 3.0

New impaired segment



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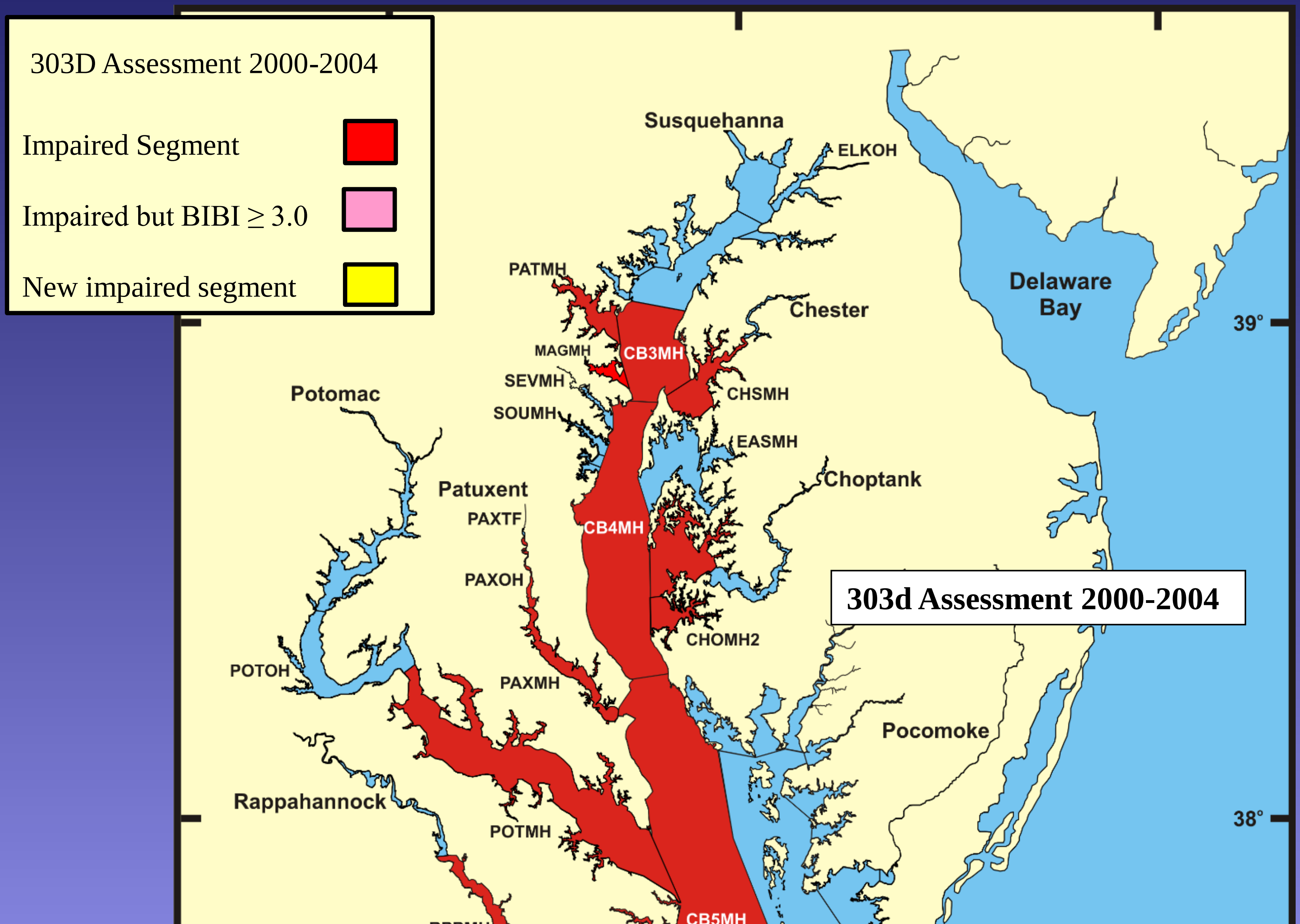

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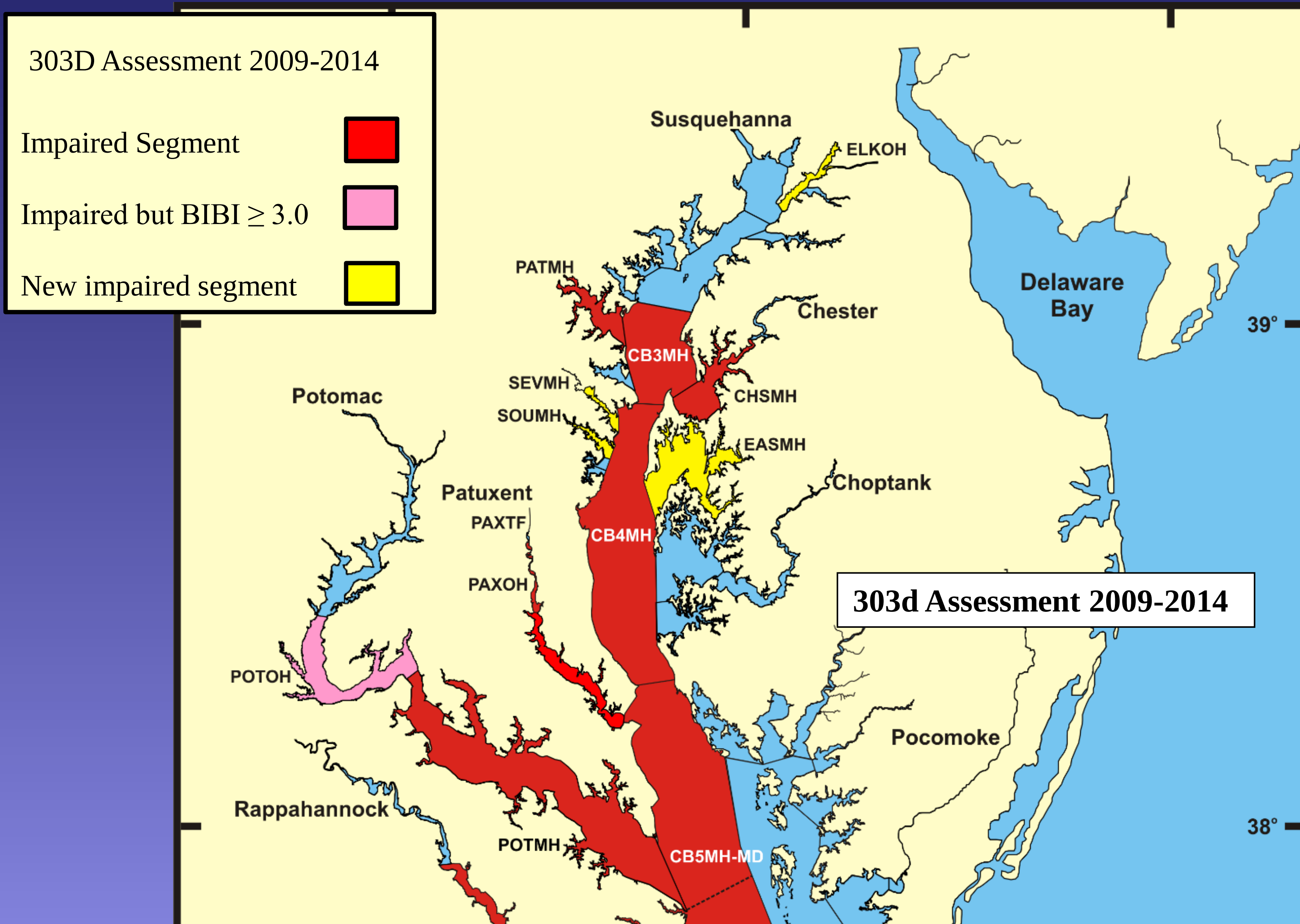

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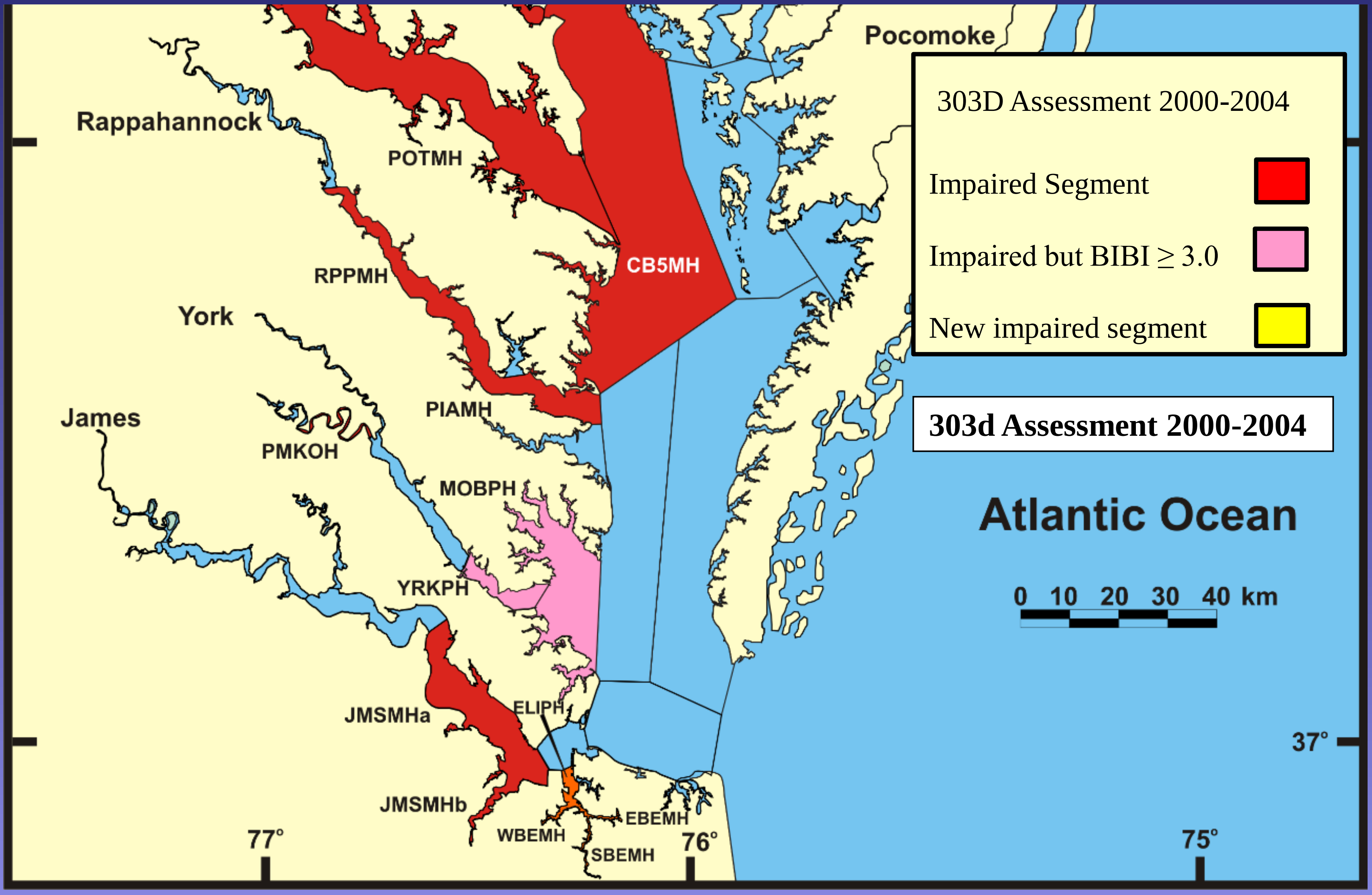

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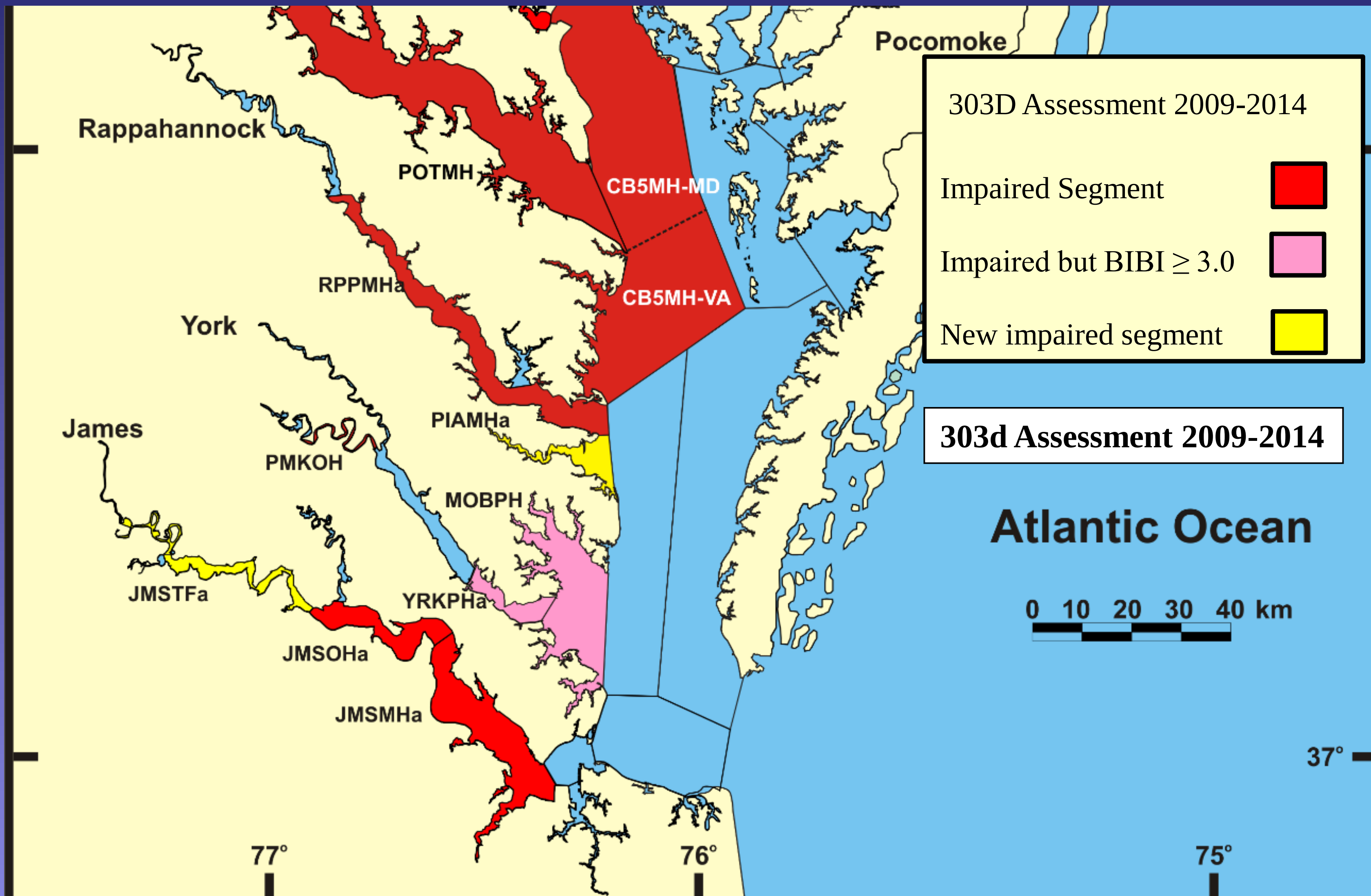

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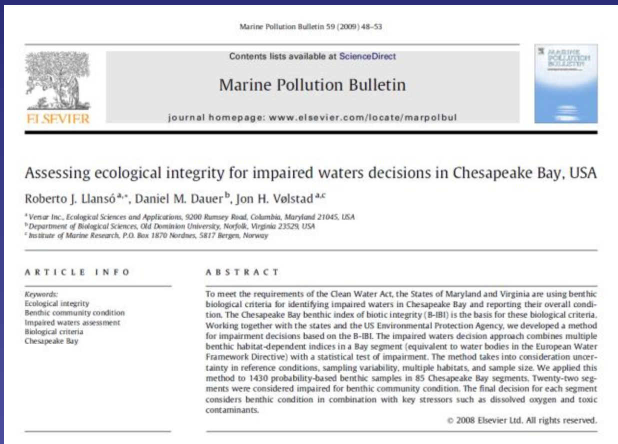
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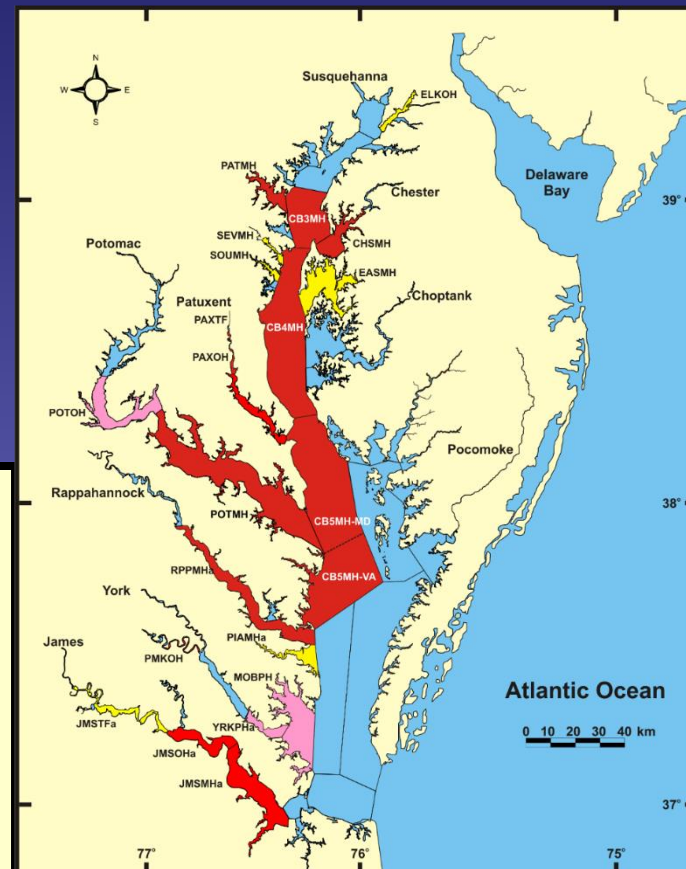

23 impaired segments in 2009-2014
22 segments in 2000-2004

15 impaired segments in common

The previous five impaired segments of the Elizabeth River watershed are not listed – inadequate sample size.

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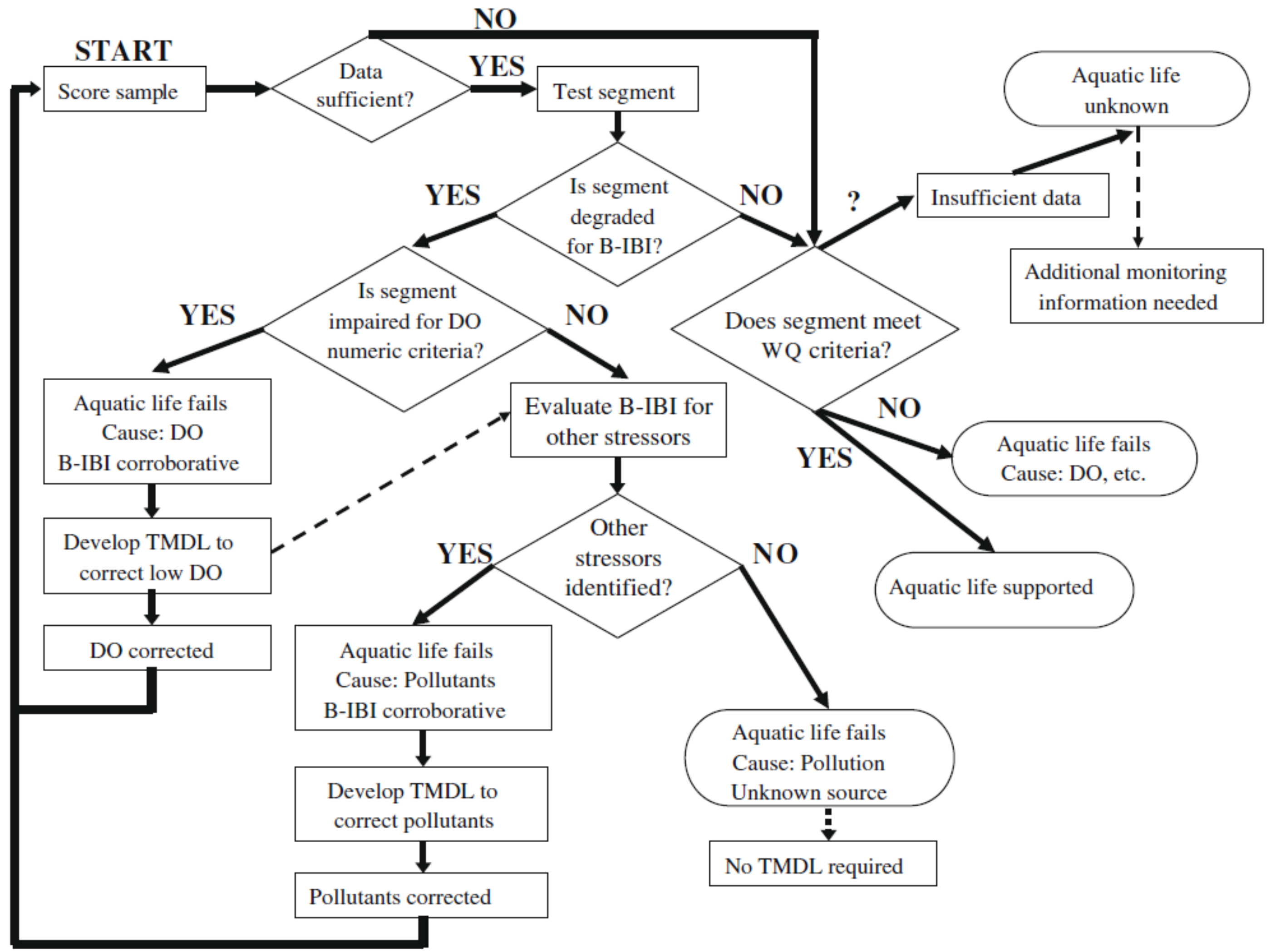

Fig. 1. Proposed decision process for assessing impaired waters in Chesapeake Bay.

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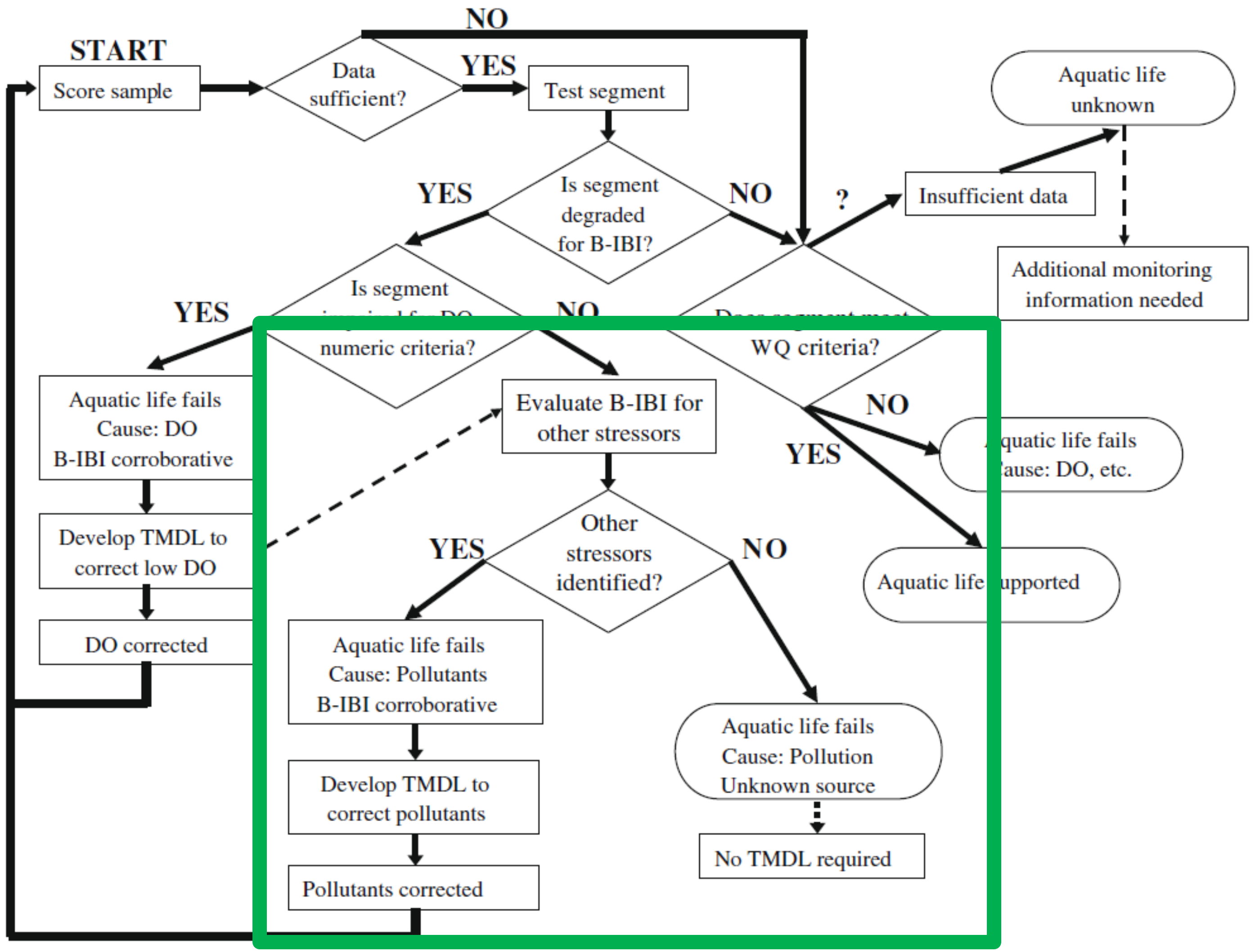

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Causes of

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I. Sediment contamination

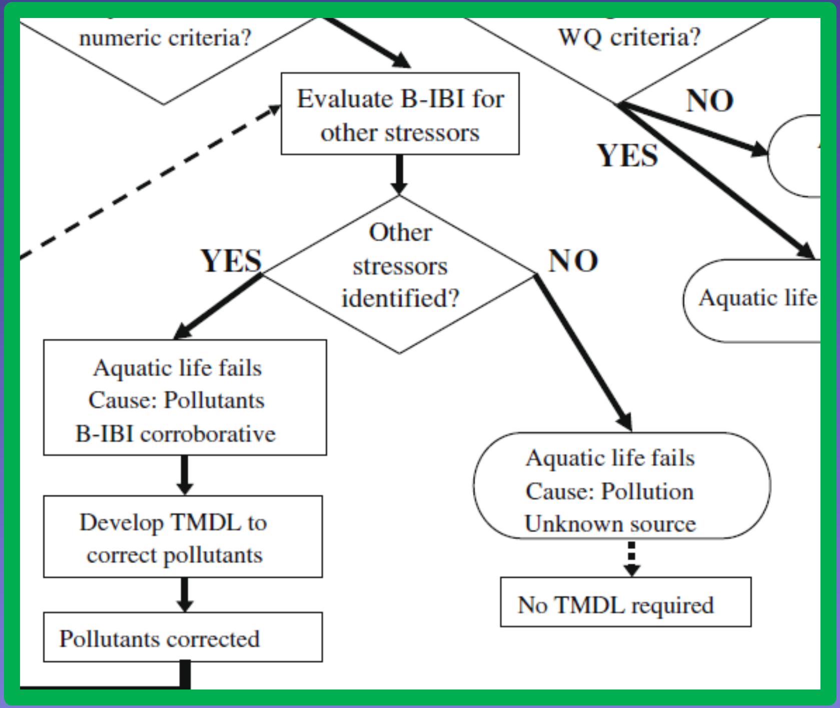
Discriminant function

II. Organic enrichment (absent low DO)

Excessive abundance metric

III. Low dissolved oxygen

Insufficient abundance metric



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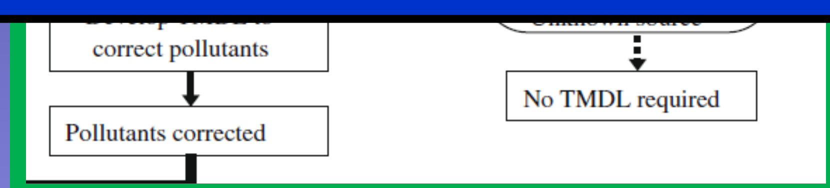

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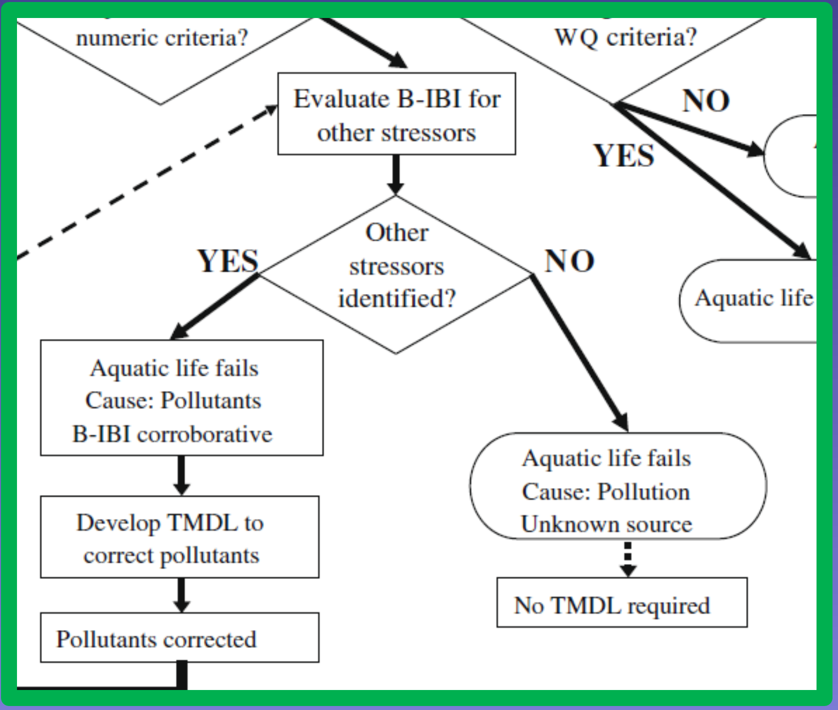
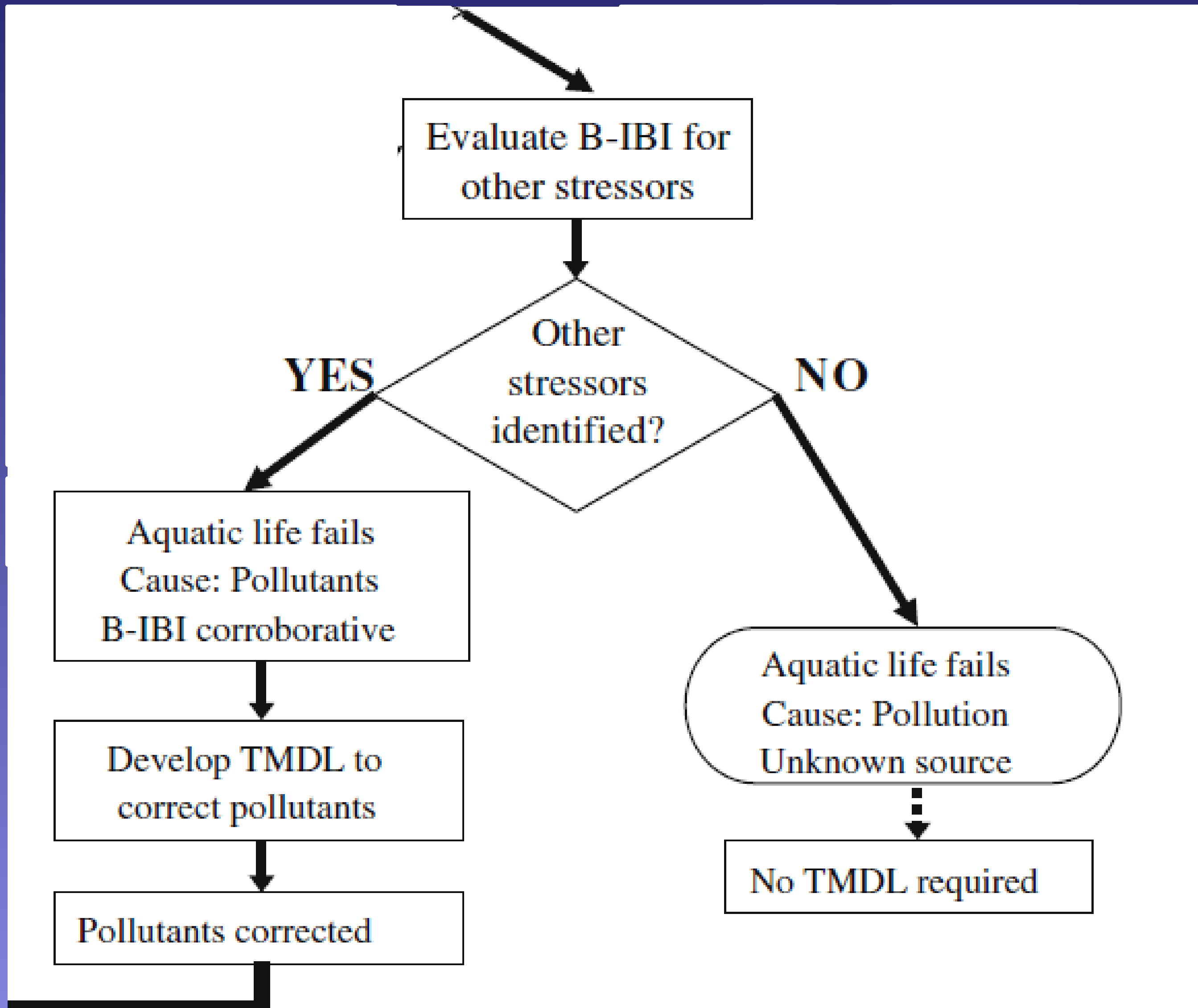


Assessing ecological integrity for impaired waters decisions in Chesapeake Bay, USA

Roberto J. Llansó[a,*], Daniel M. Dauer[b], Jon H. Vølstad[a,c]

Marine Pollution Bulletin 59 (2009) 48–53



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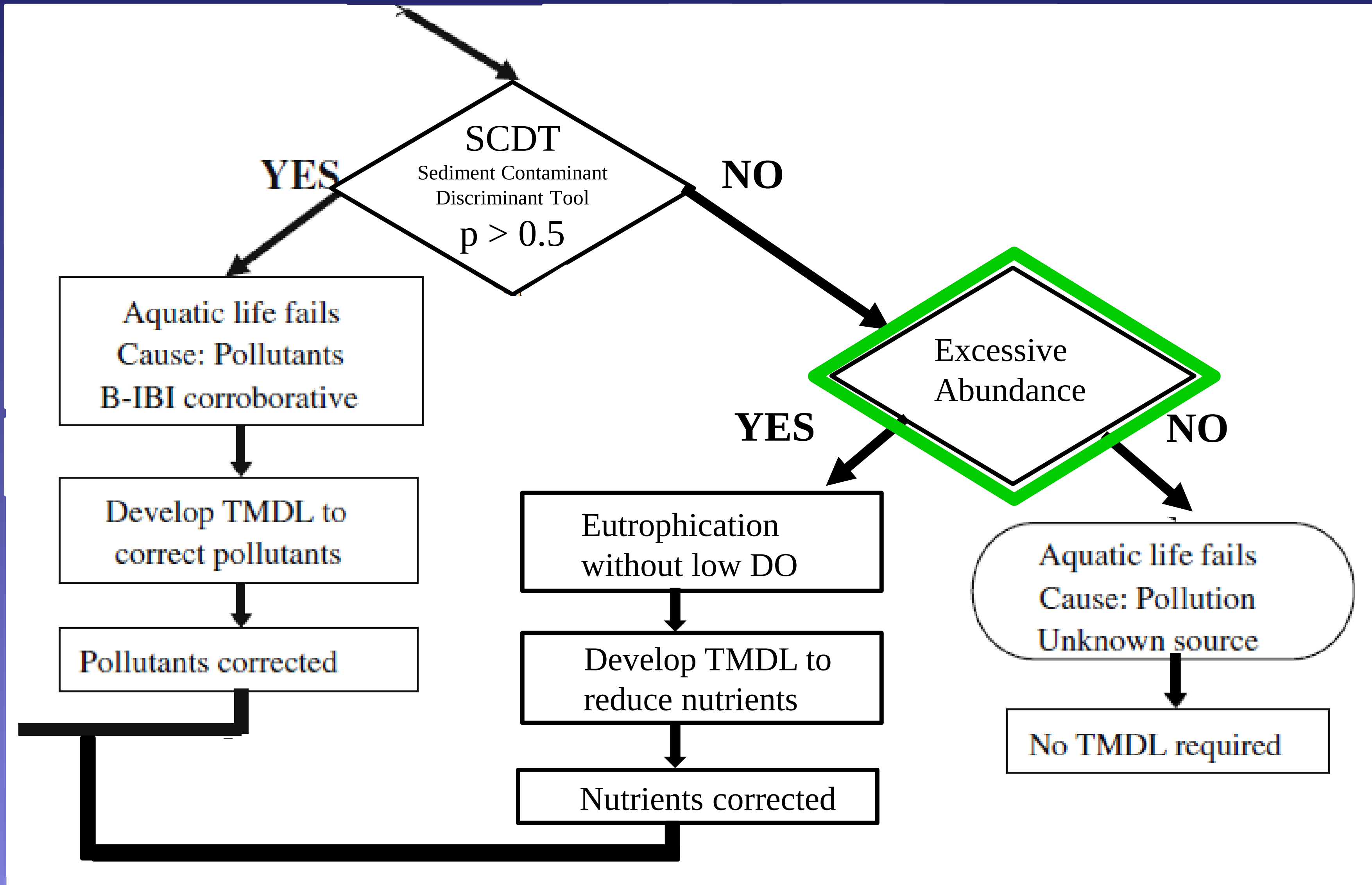

Assessing ecological integrity for impaired waters decisions in Chesapeake Bay, USA

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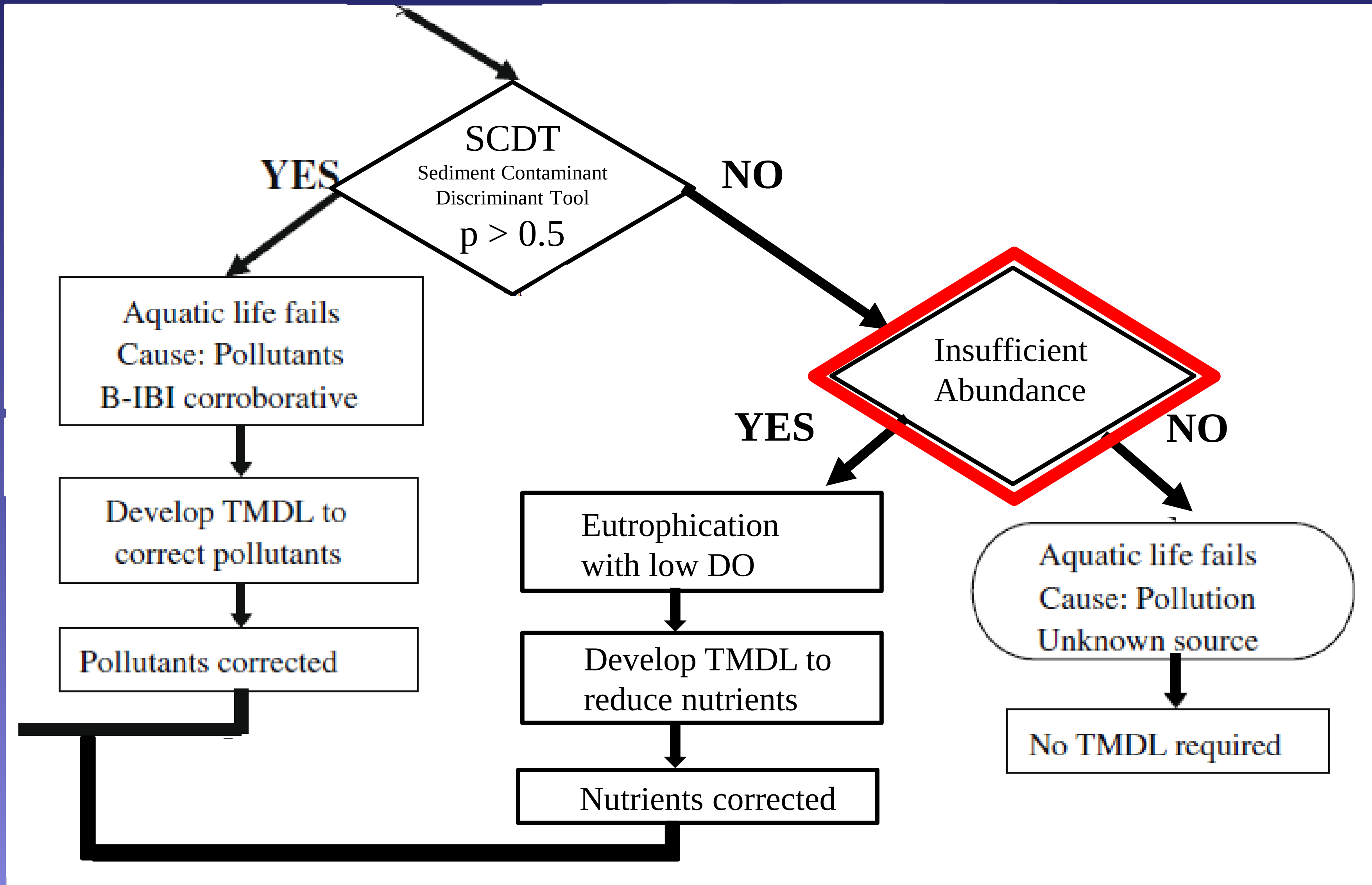


(6) Impaired waters designations of Maryland DNR and Virginia DEQ 303d (Llansó et al. 2003)

Summary

1. Water body test developed

2. Compares recent benthic samples with original reference sample

3. Combines different habitats

4. Diagnostic approaches can be applied

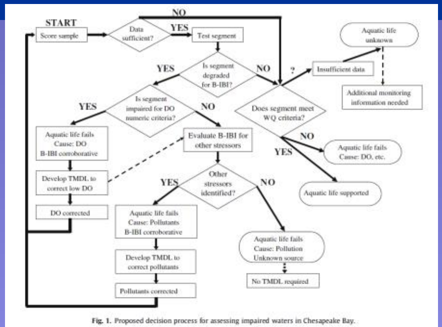
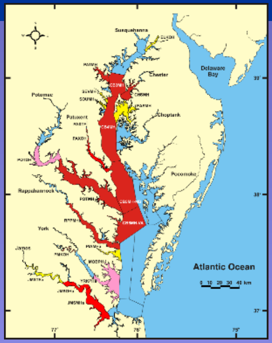


Fig. 1. Proposed decision process for assessing impaired waters in Chesapeake Bay.



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

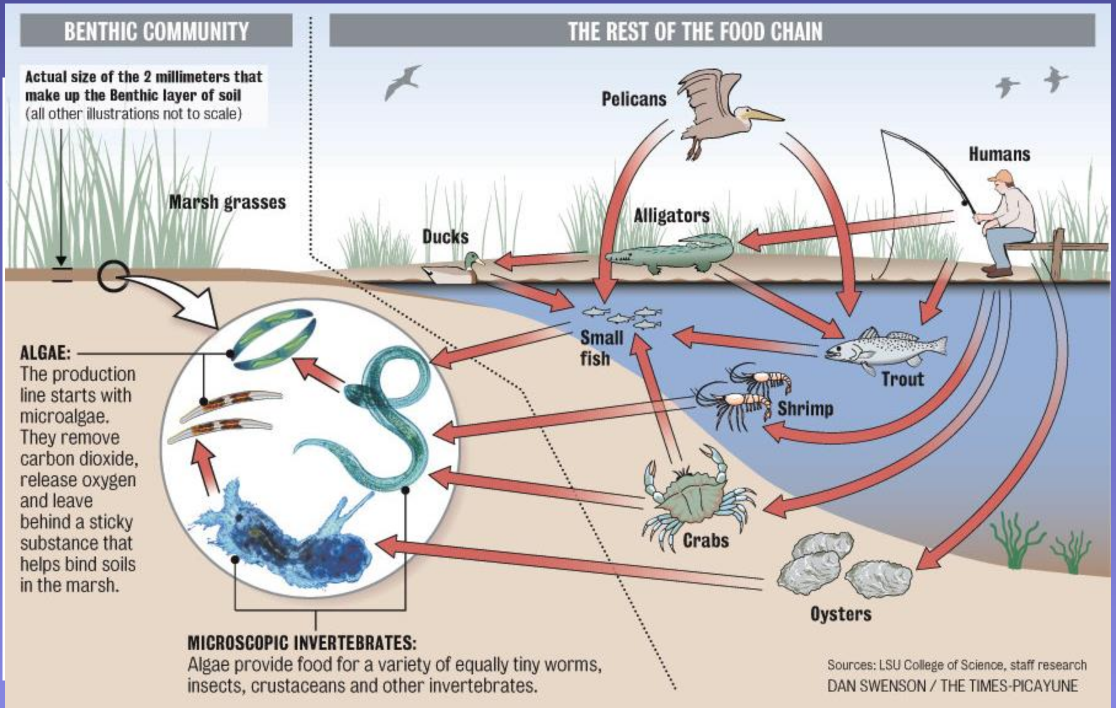
Low dissolved oxygen
Eutrophication
Sediment Contamination

(Dauer et al. 2002. EPA Technical Report)

(6) Impaired waters designations of Maryland DNR and Virginia DEQ

303d (Llansó et al. 2003)

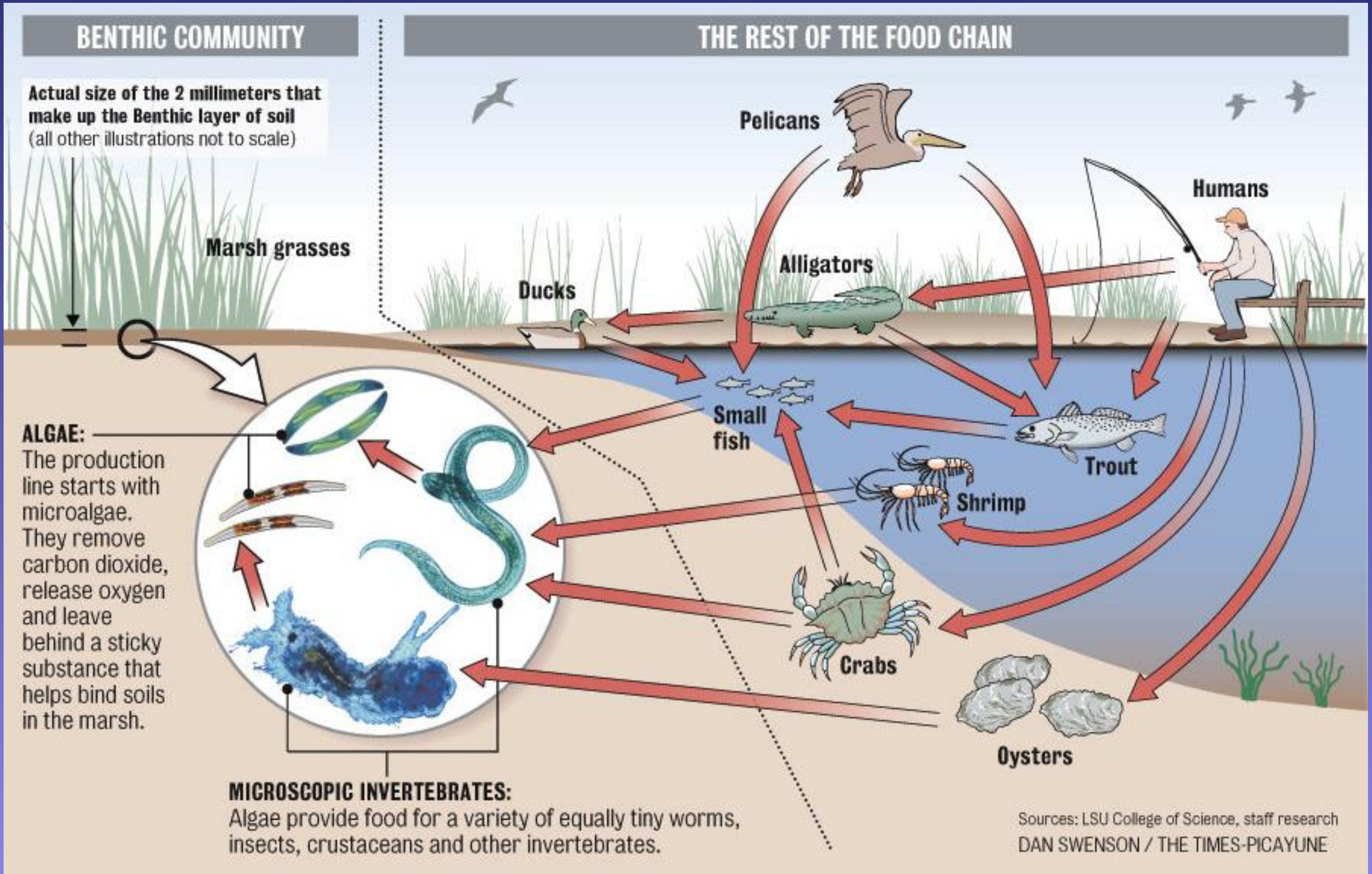
(7) Functional metric/index approach



(7) Functional metric/index approach

Benthic secondary productivity

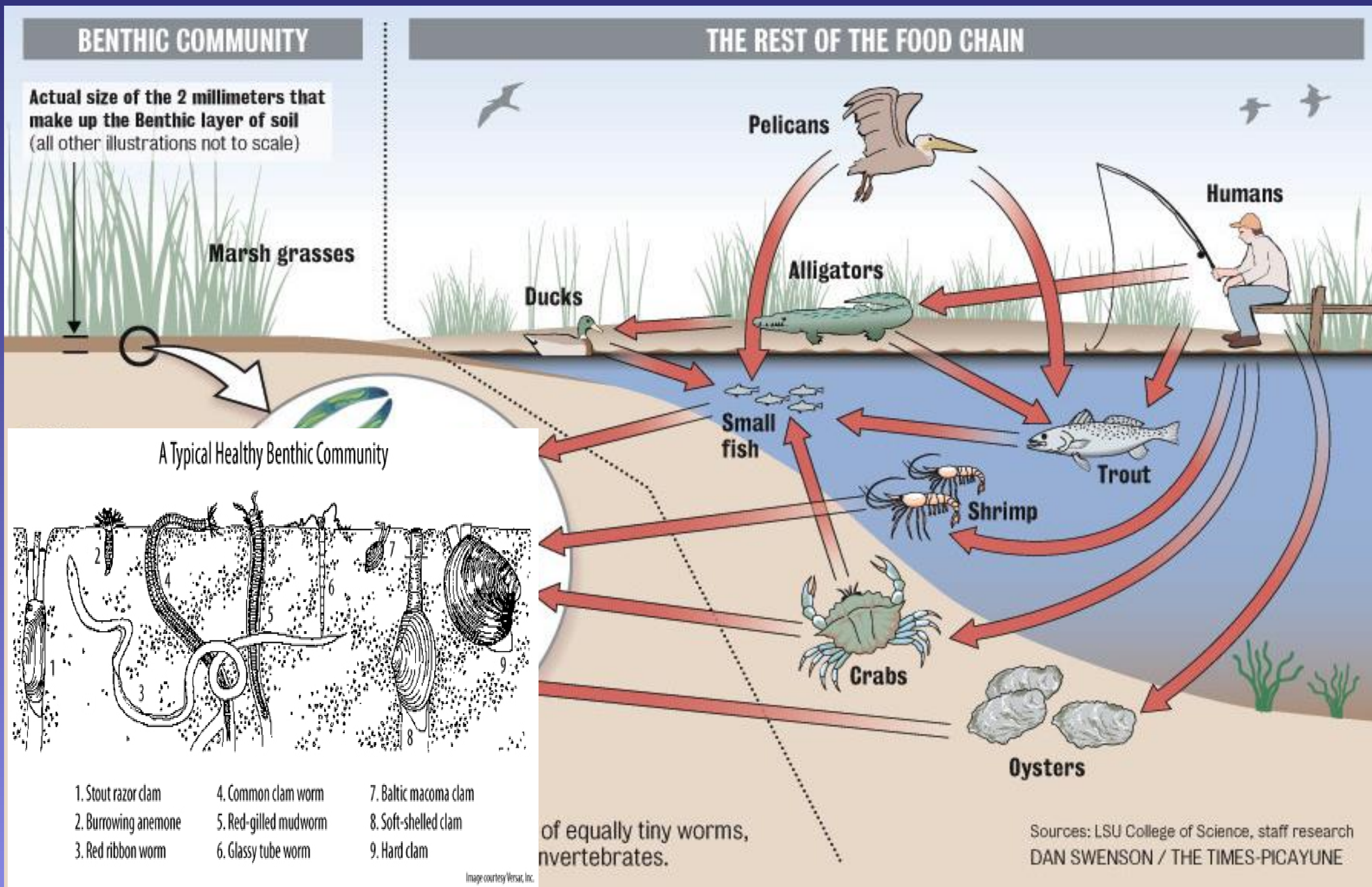
Dauer et al. 2011. VADEQ Technical Report.



(7) Functional metric/index approach

Benthic secondary productivity

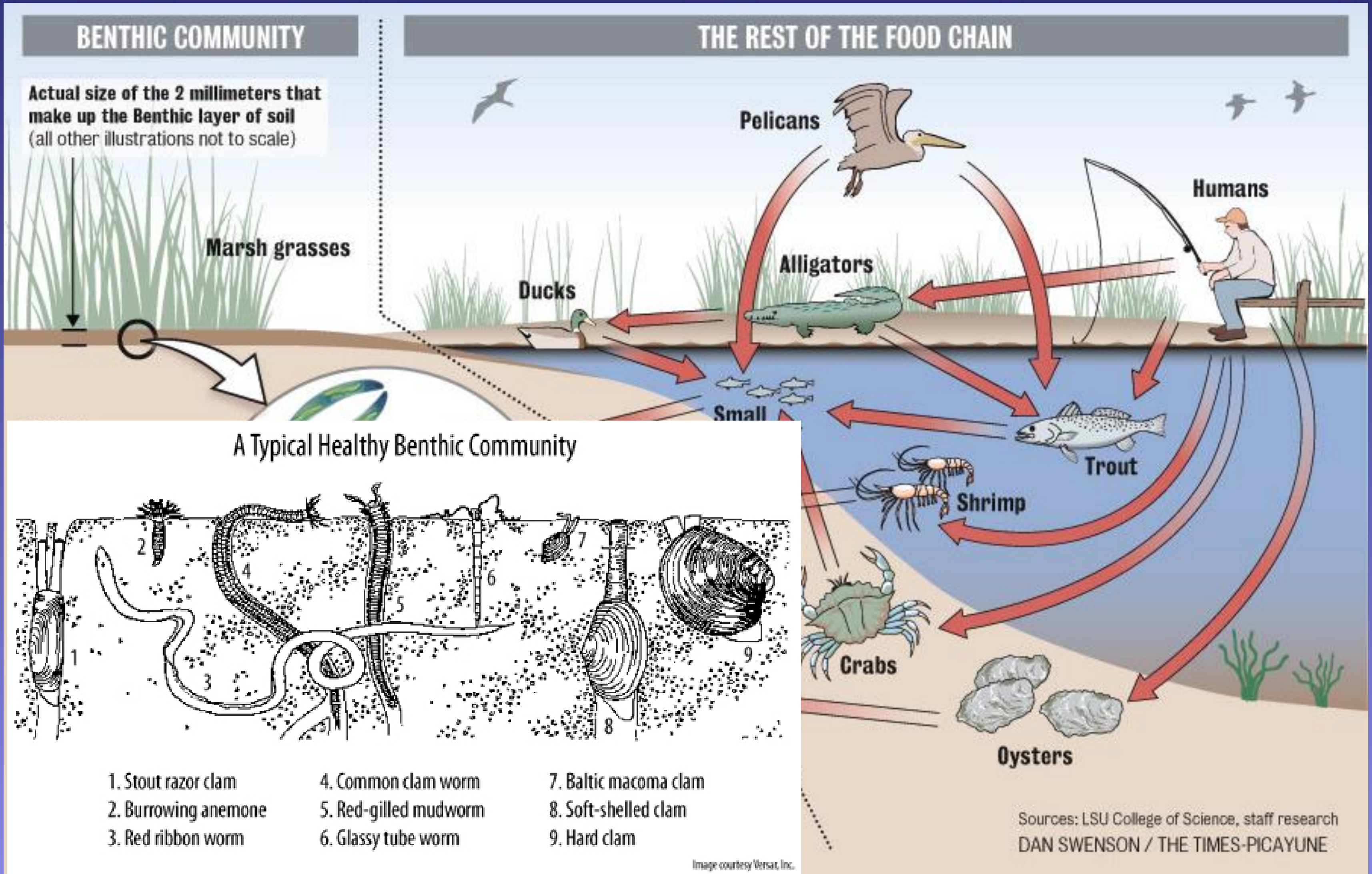
Dauer et al. 2011. VADEQ Technical Report.



(7) Functional metric/index approach

Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report.



(7) Functional metric/index approach

Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report.

Preliminary evaluations of secondary productivity estimates as indicators of the ecological value of the benthos to higher trophic levels in Chesapeake Bay

Prepared by

Principal Investigators:

Daniel M. Dauer[1]
Michael F. Lane[1]
Roberto J. Llansó[2]
Robert Diaz[3]

Submitted to:

Virginia Department of Environmental Quality
629 East Main Street
Richmond, Virginia 23230

December, 2011

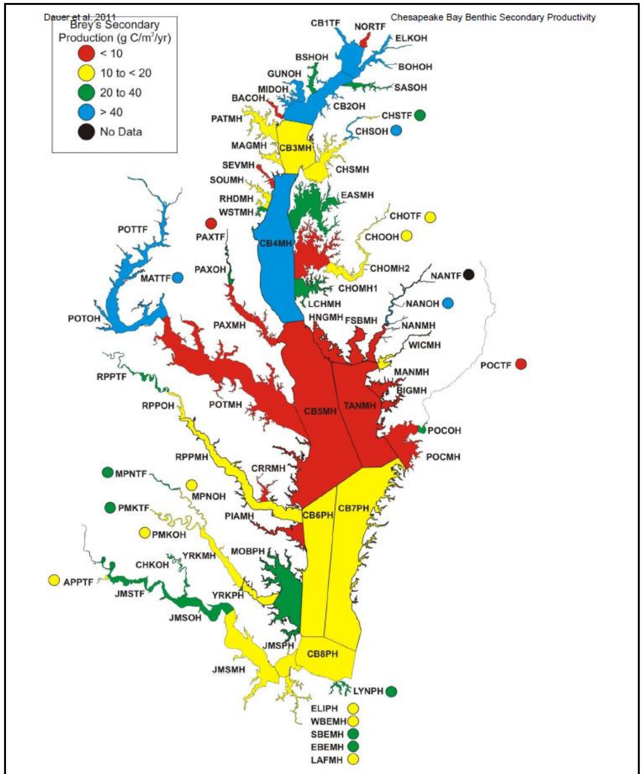


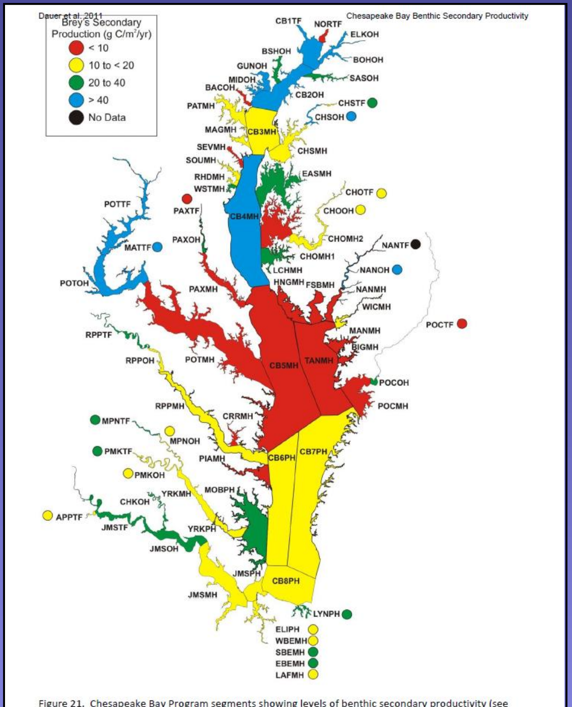
Figure 21. Chesapeake Bay Program segments showing levels of benthic secondary productivity (see insert at top).

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Sturdivant et al. 2014. Estuaries and Coasts

- Production equation matters
- Estuarine pattern of benthic secondary production
- Low dissolved oxygen effects
- Contaminant effects
- Trophic transfer challenges
    - Susceptibility to predation
    - Microbial sinks



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(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Sturdivant et al. 2014. Estuaries and Coasts

Production equation matters

Dauer et al. 2011 Chesapeake Bay Benthic Secondary Productivity

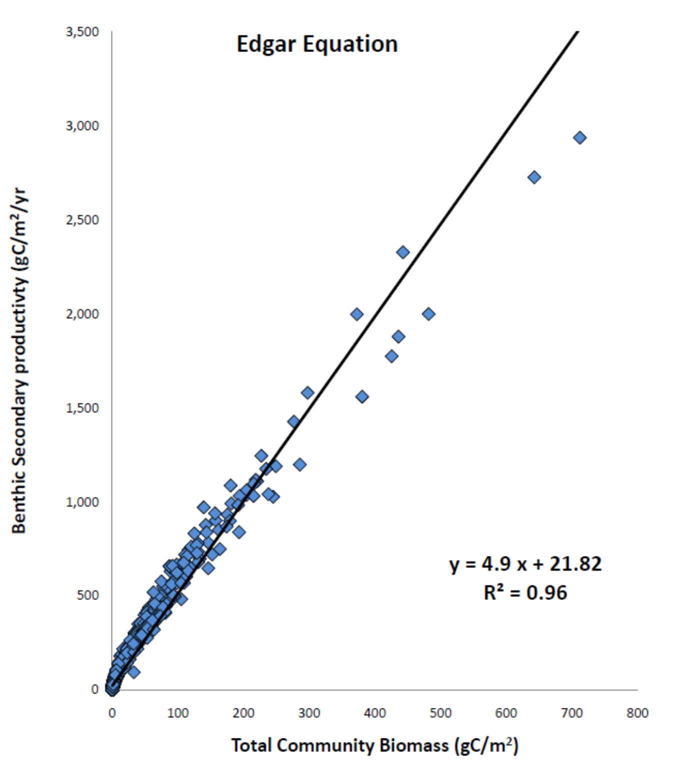

Figure 2. Benthic Secondary Productivity as a function of Total Community Biomass using the Edgar equation. Equation applied for each species and summed.

Dauer et al. 2011 Chesapeake Bay Benthic Secondary Productivity

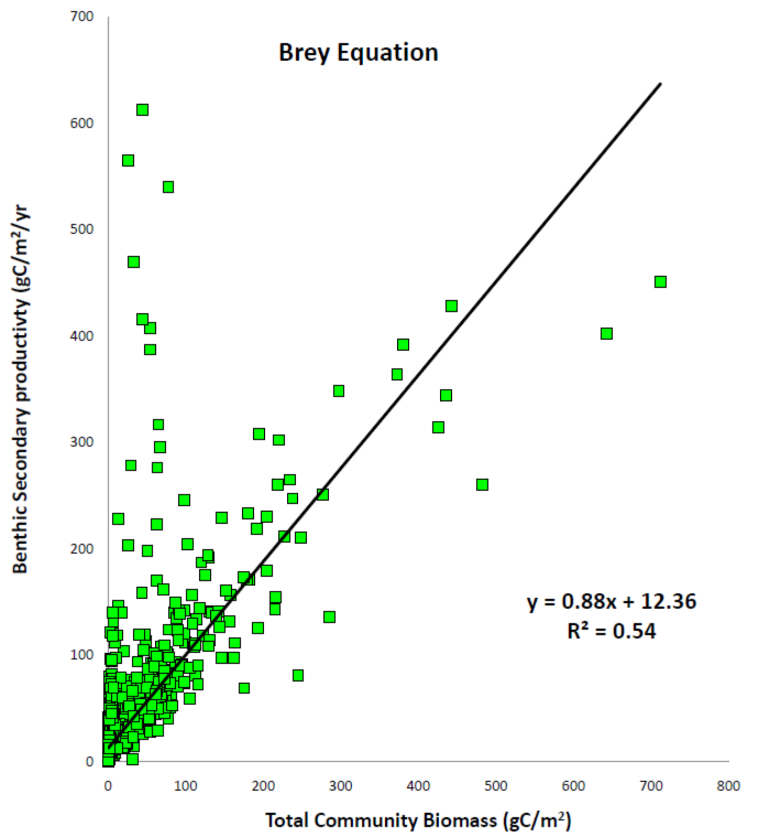

Figure 3. Benthic Secondary Productivity as a function of Total Community Biomass using the Brey equation. Equation applied for each species and summed.

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report
Sturdivant et al. 2014. Estuaries and Coasts

Production equation matters

Edgar (1990)

$$P = 0.0049 \times B^{0.80} T^{0.89}$$

P - per sample daily macrobenthic production
B - per sample standing crop biomass (mg AFDW)
T - water temperature in C

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Sturdivant et al. 2014. Estuaries and Coasts

Production equation matters

Brey's (2001)

$$\log_{10}(P/B) = 7.947 - 2.294 \times \log_{10}(w) - (2409.856 \times 1/T) + (0.168 \times 1/D) + (0.194 \times Subtid) + (0.180 \times InfEpi) + (0.174 \times Tax1) - (0.188 \times Tax2) + (0.330 \times Tax3) + (582.851 \times \log_{10}(w) \times 1/T)$$

w - mean body mass per individual expressed in kJ

D sample depth in meters

T - temperature in K and several discrete (dummy) variables which took the following form:

Dummy variables

Subtid increases the P/B ratio with a a depth of > 1 meter

InfEpi is set to 1 if the organism is infaunal also resulting in an increase in the P/B ratio

Tax1, *Tax2* and *Tax3* are dummy variables that identify specific taxon effects - (1) annelid or crustacean; (2) echinoderm or (3) an insect, respectively, and 0 if otherwise.

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Sturdivant et al. 2014. Estuaries and Coasts

- Production equation matters
- Estuarine pattern of benthic
- Low dissolved oxygen effec
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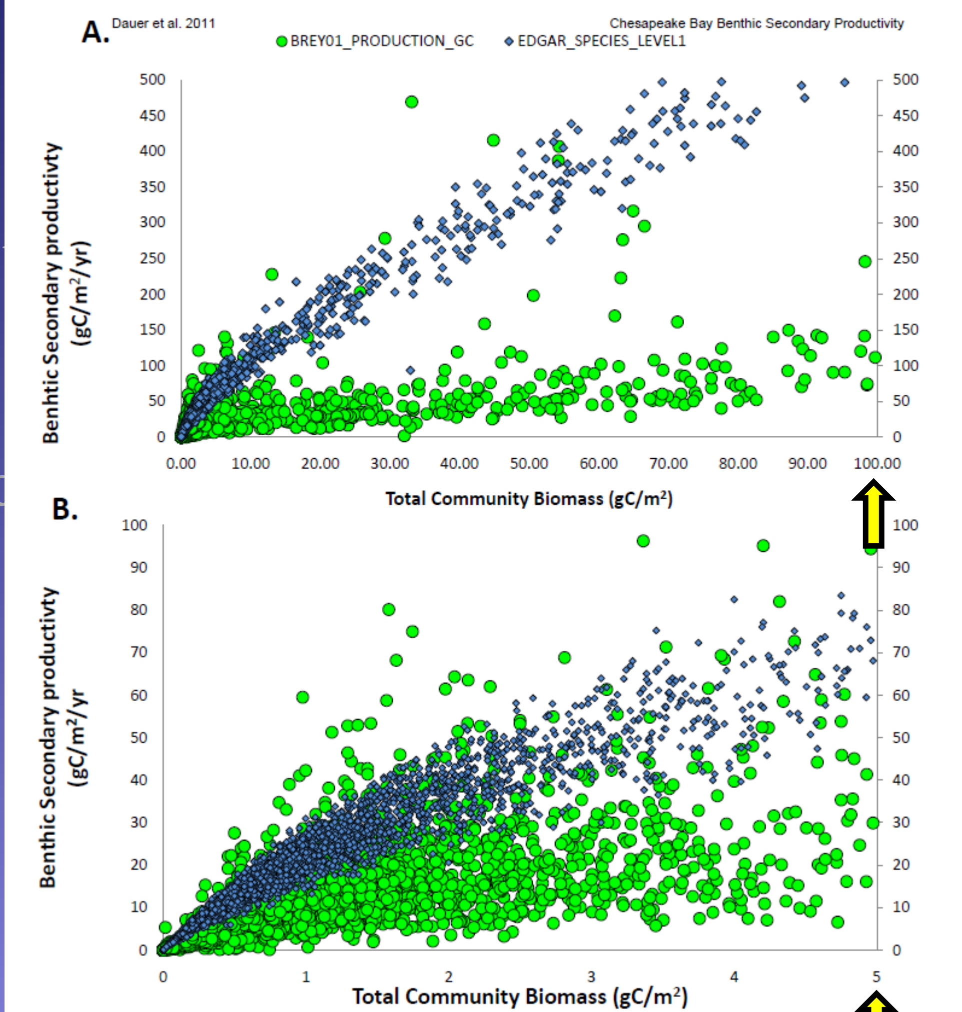


Figure 4. Benthic Secondary Productivity as a function of Total Community Biomass compar[ing] Edgar's equation versus Brey's. Equation applied for each species and summed. A. Biomass values to 100 gC/m^2 Biomass. B. Biomass axis limited to ≤ 5 $gC/m^2/yr$.

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report
Sturdivant et al. 2014. Estuaries and Coasts

Production equation matters

Estuarine pattern of benthic secondary production

Low dissolved oxygen effects

Contaminant effects

Trophic transfer challenges

- Susceptibility to predation
- Microbial sinks

indicates one standard error. All random data from 1996 -2009 n = 3,919.

(7) Functional metric/index approach - Benthic secondary productivity

Estuarine pattern of benthic secondary production

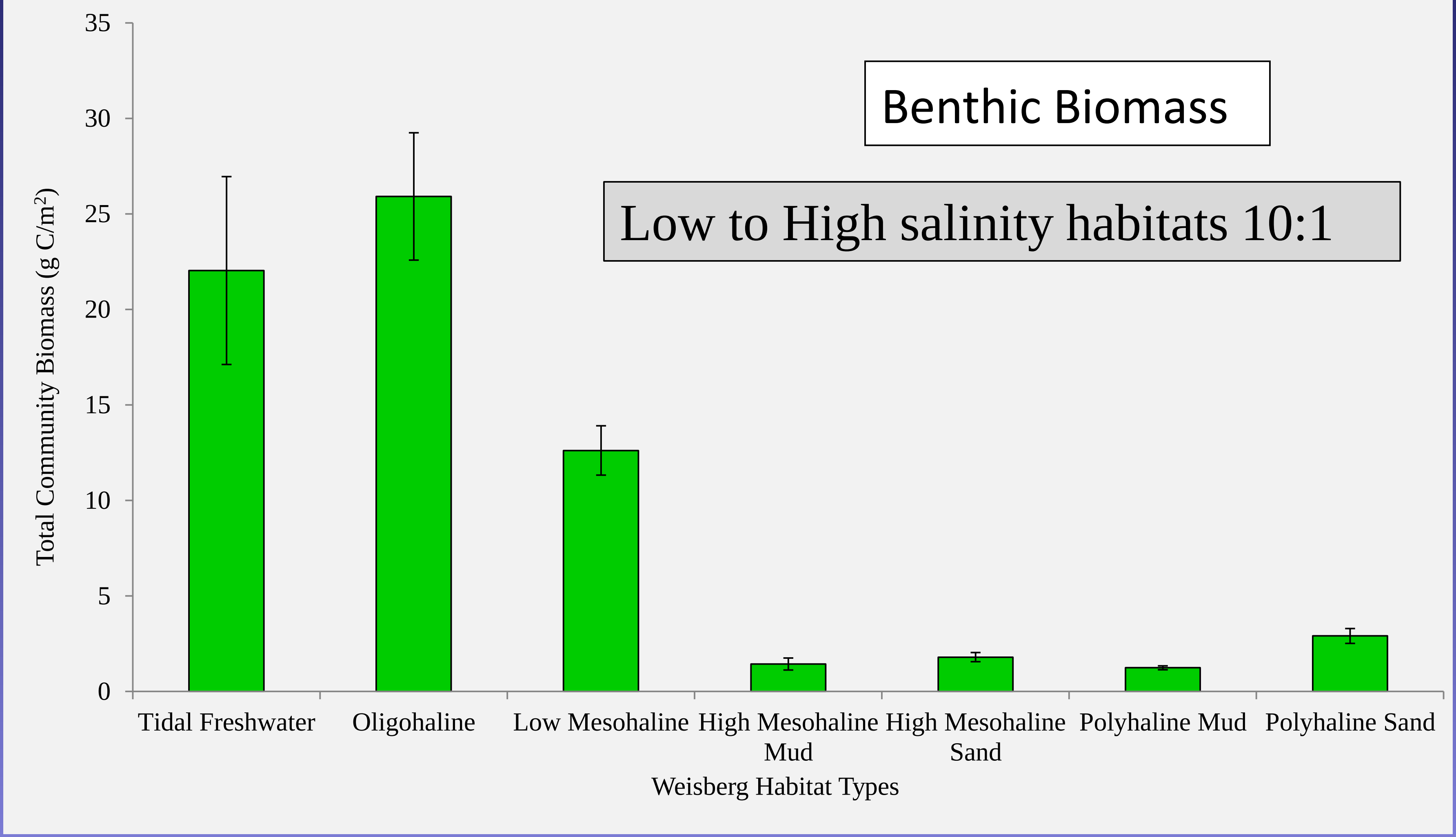


Figure 6. Mean standing stock biomass (gC/m²) by the habitat types of Weisberg et al. (1997). Bar indicates one standard error. All random data from 1996 -2009 n = 3,919.

(7) Functional metric/index approach - Benthic secondary productivity

Estuarine pattern of benthic secondary production

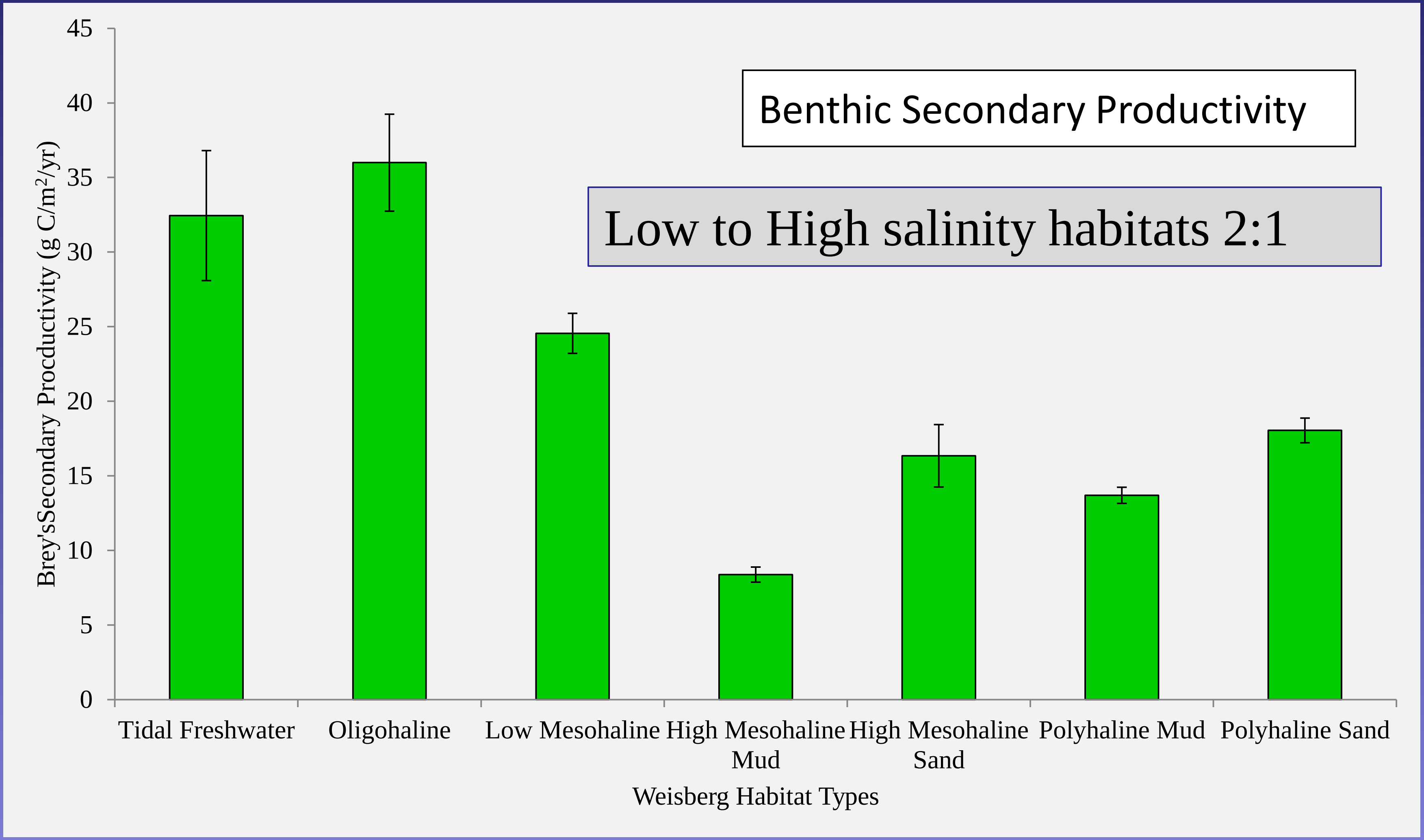


Figure 5. Mean secondary production (gC/m²/yr) by the habitat types of Weisberg et al. (1997). Bar indicates one standard error. All random data from 1996 -2009 n = 3,919.

(7) Functional metric/index approach - Benthic secondary productivity

Estuarine pattern of benthic secondary production

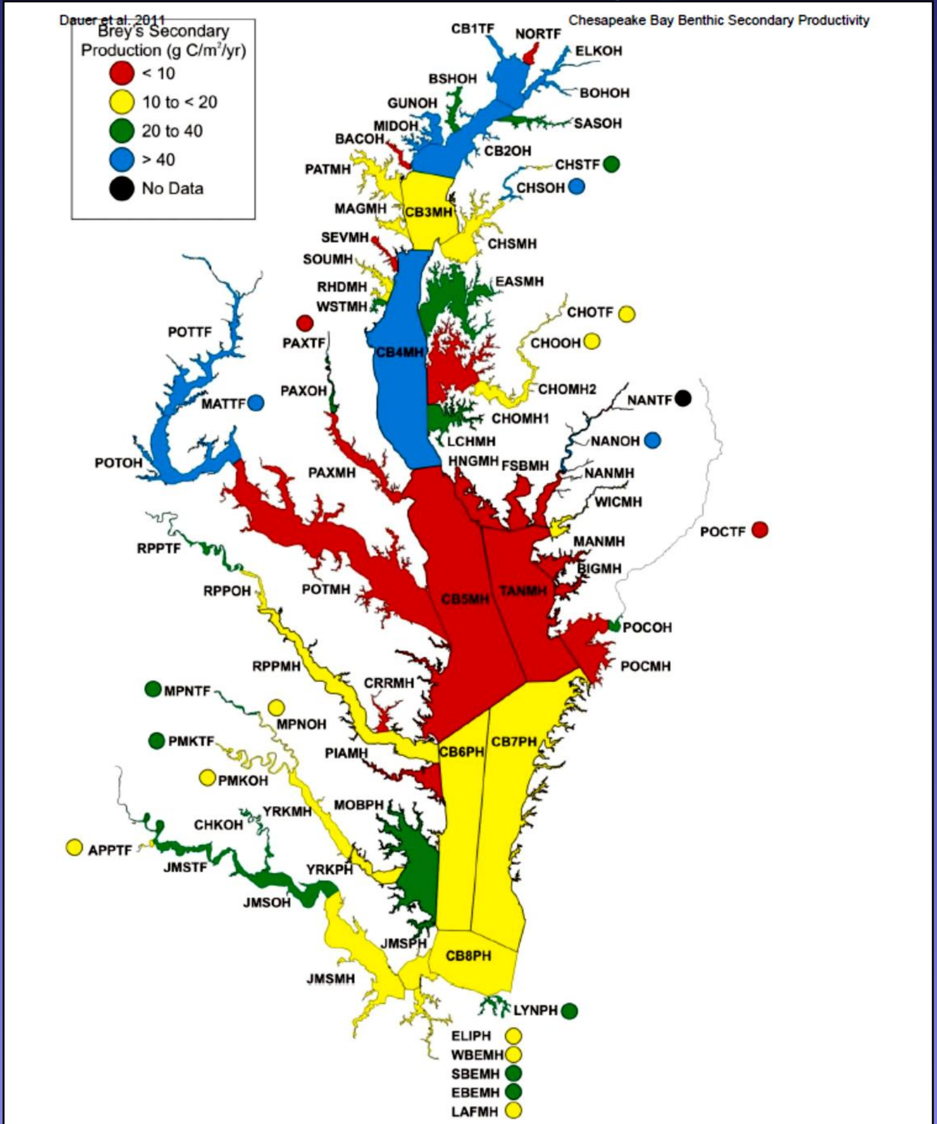
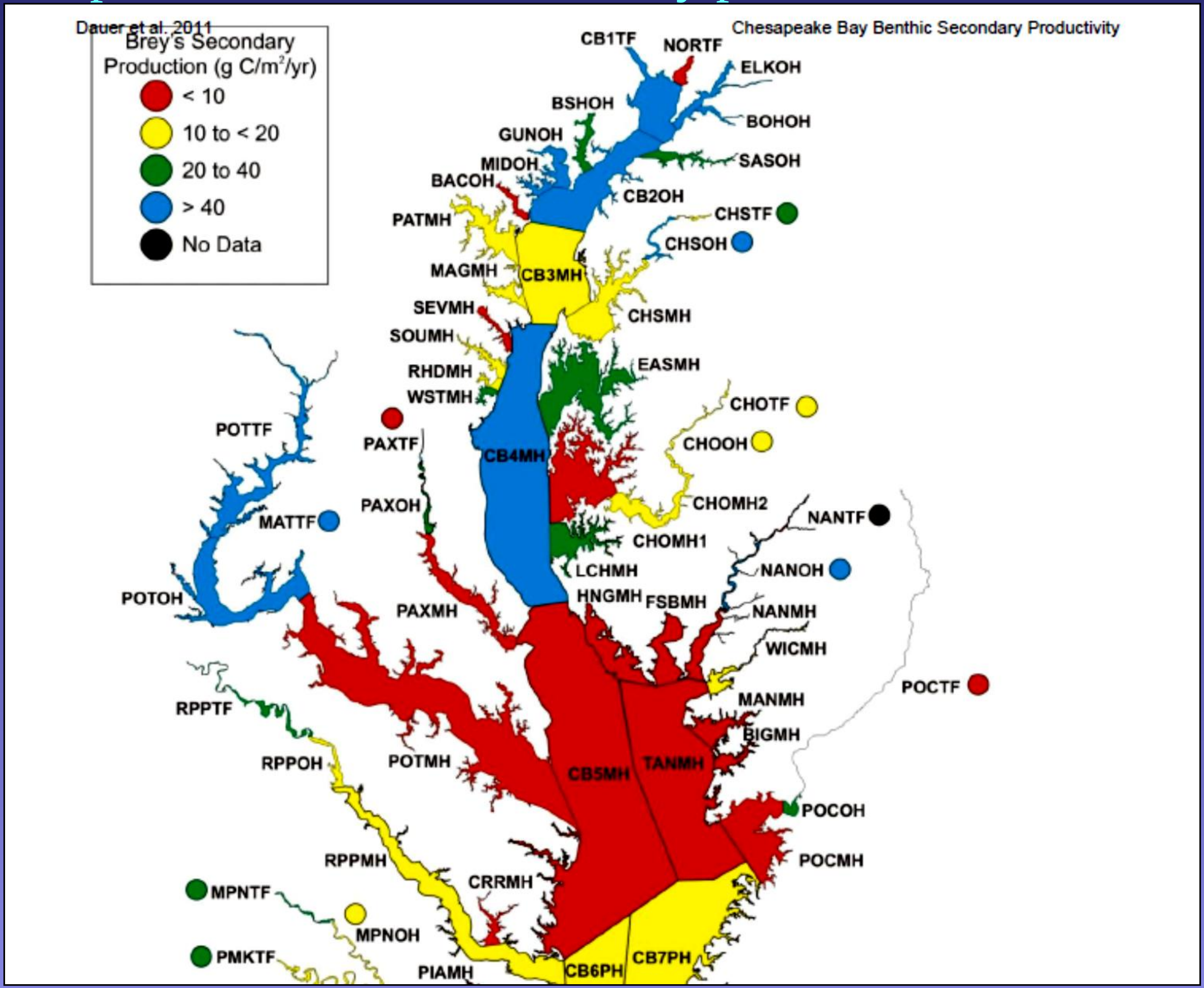


Figure 21. Chesapeake Bay Program segments showing levels of benthic secondary productivity (see

(7) Functional metric/index approach - Benthic secondary productivity

Estuarine pattern of benthic secondary production



(7) Functional metric/index approach - Benthic secondary productivity

Estuarine pattern of benthic secondary production

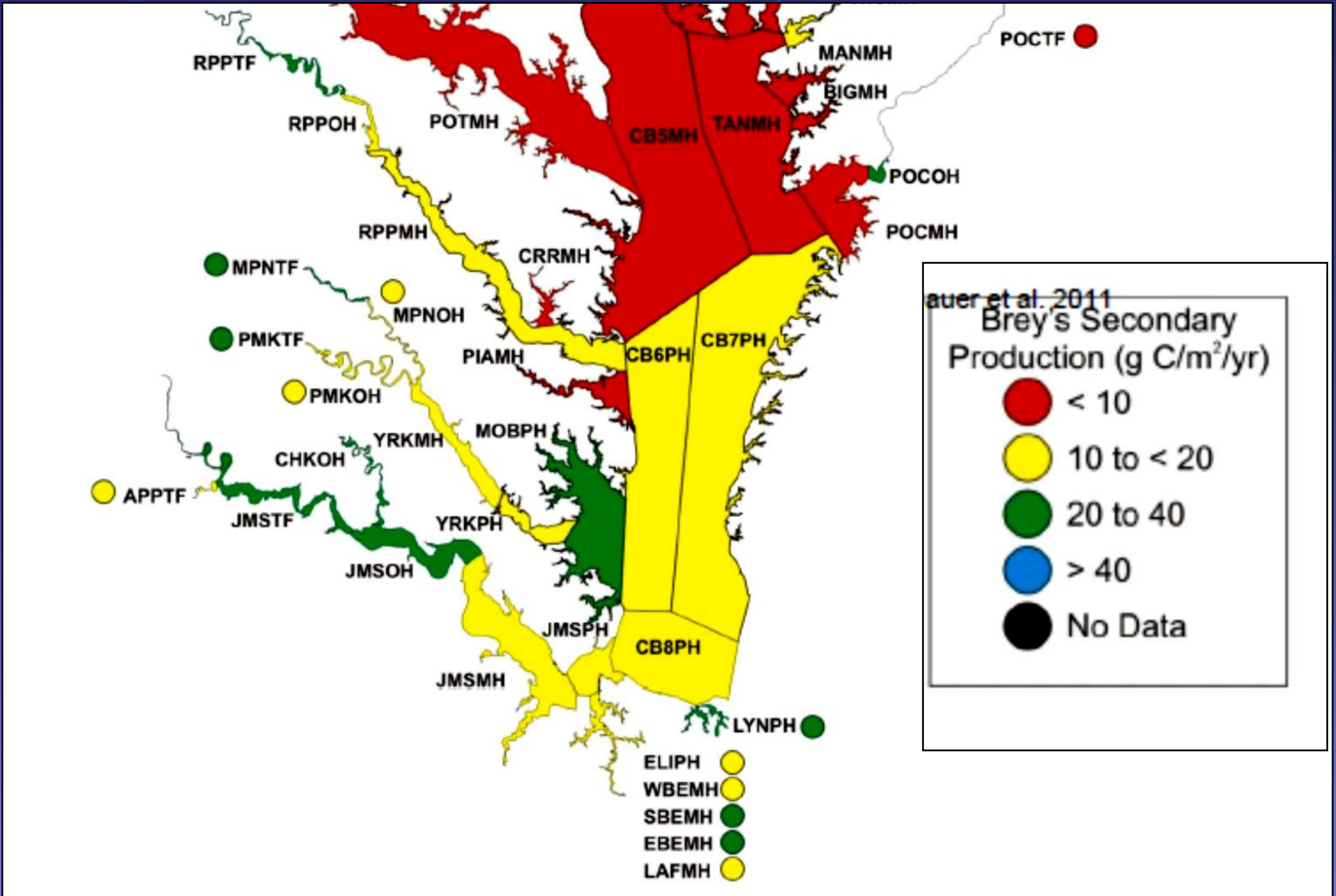


Figure 21. Chesapeake Bay Program segments showing levels of benthic secondary productivity (see insert at top).

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Sturdivant et al. 2014. Estuaries and Coasts

- Production equation matters
- Estuarine pattern of benthic secondary production
- Low dissolved oxygen effects
- Contaminant effects
- Trophic transfer challenges
    - Susceptibility to predation
    - Microbial sinks

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report
Sturdivant et al. 2014. Estuaries and Coasts

➡ Low dissolved oxygen effects

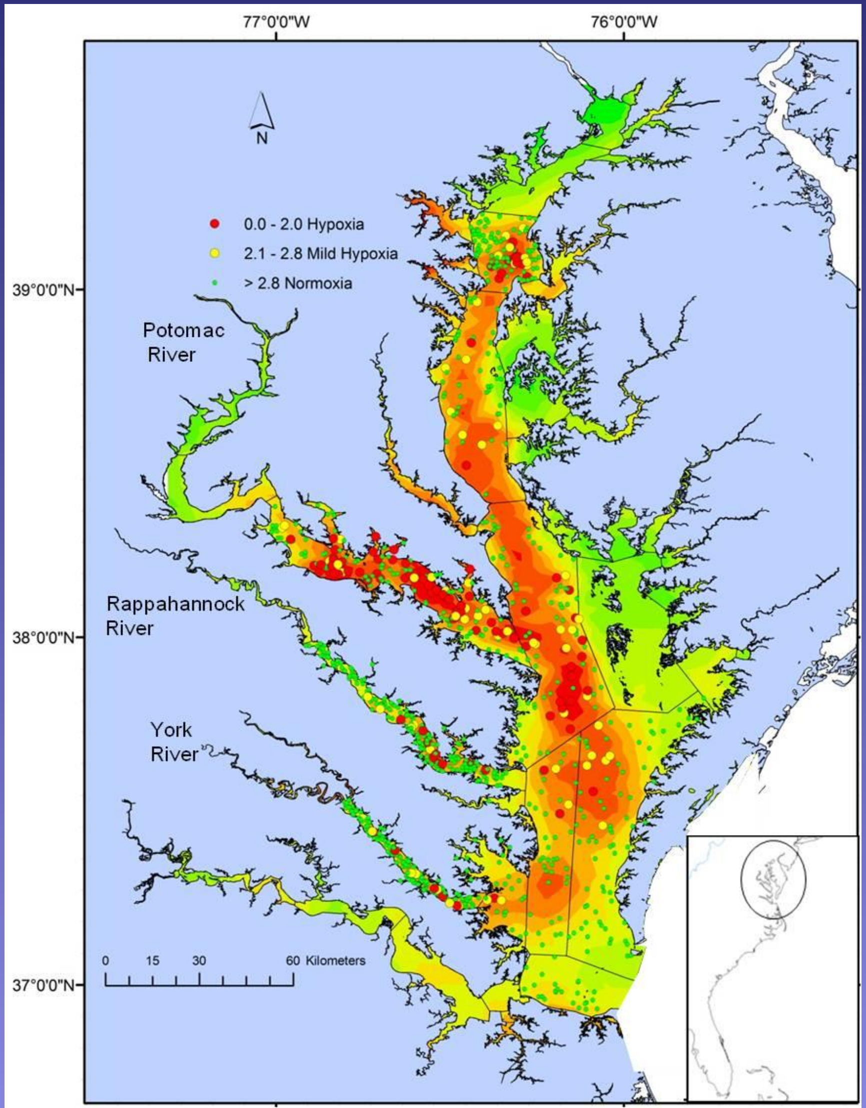
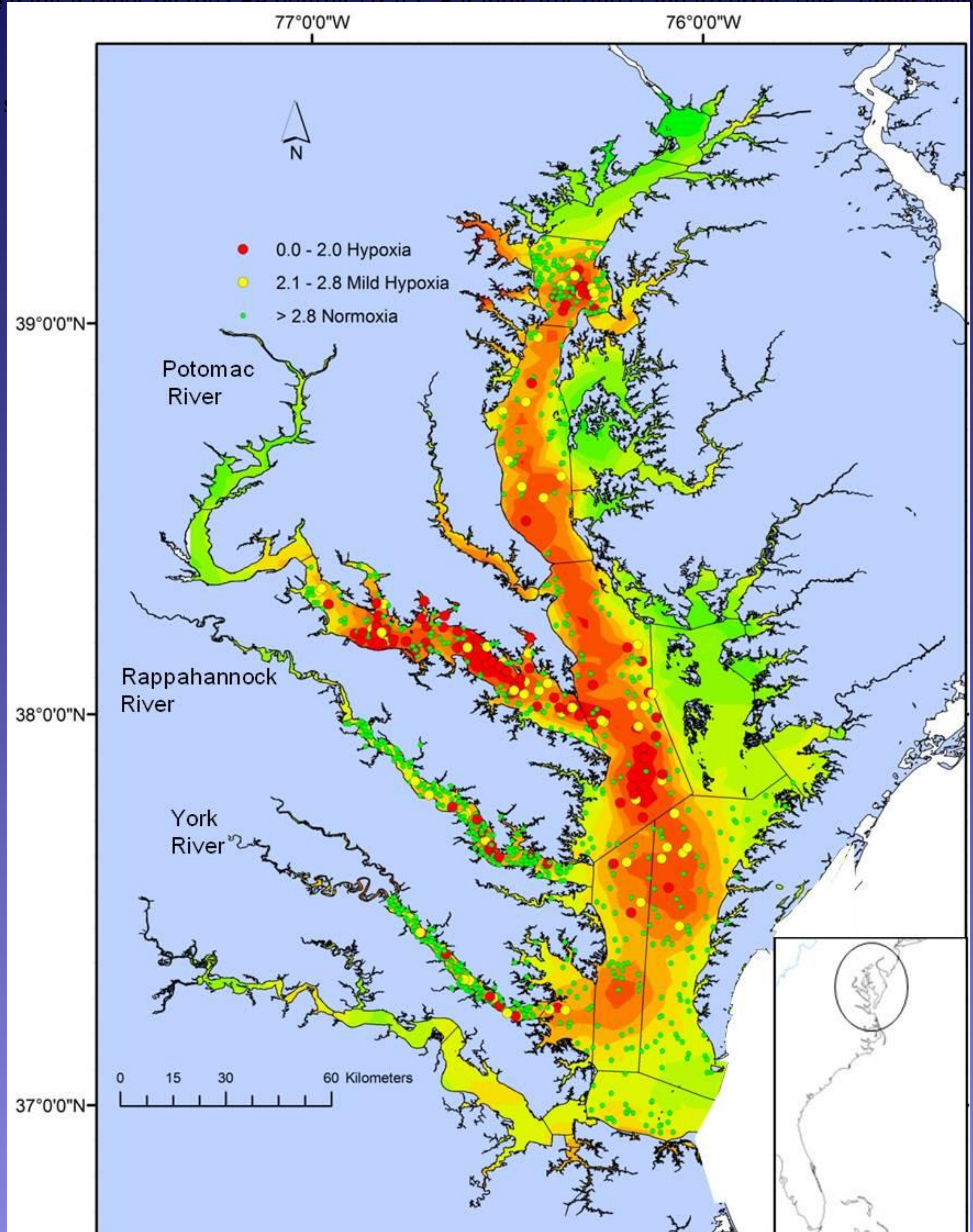


Figure 14. Mean community abundance by the **CBP benthic strata. Bar indicates one standard error. UPB – Upper Mainstem, MWT – Maryland Western Tributari**

Figure 15. Mean B-IBI by the ... stem, MWT – Maryland Western Tributarie

Figure 16. Mean species per s

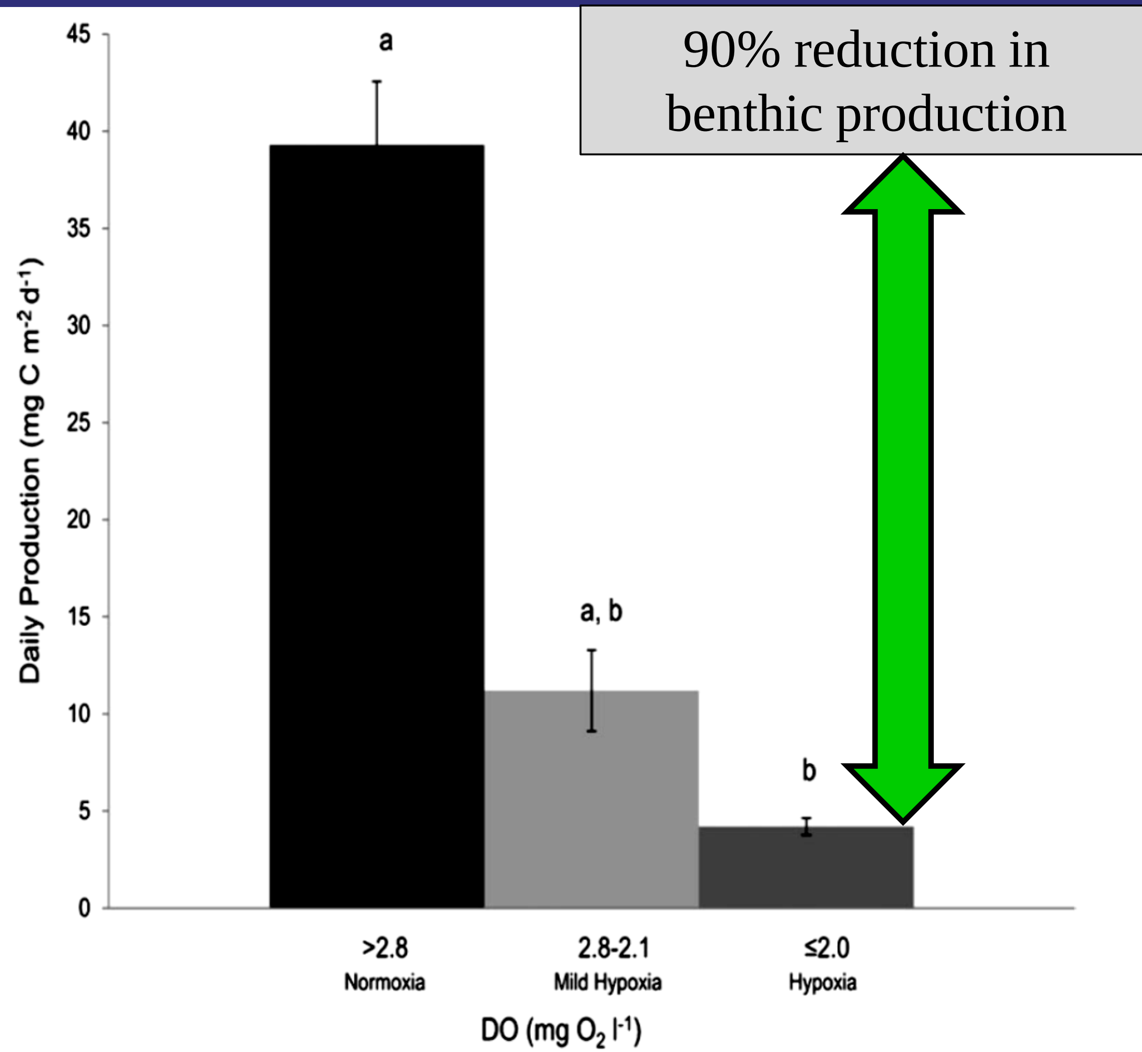


(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Sturdivant et al. 2014. Estuaries and Coasts

Fig. 3 Relationship between mean daily macrobenthic production and dissolved oxygen concentration in Chesapeake Bay. Letter differences represent significance ($df=26$, $F=27.97$, $p<0.0005$). Normoxic areas have significantly higher daily macrobenthic production than hypoxic areas. Error bars represent ±1 SE



(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

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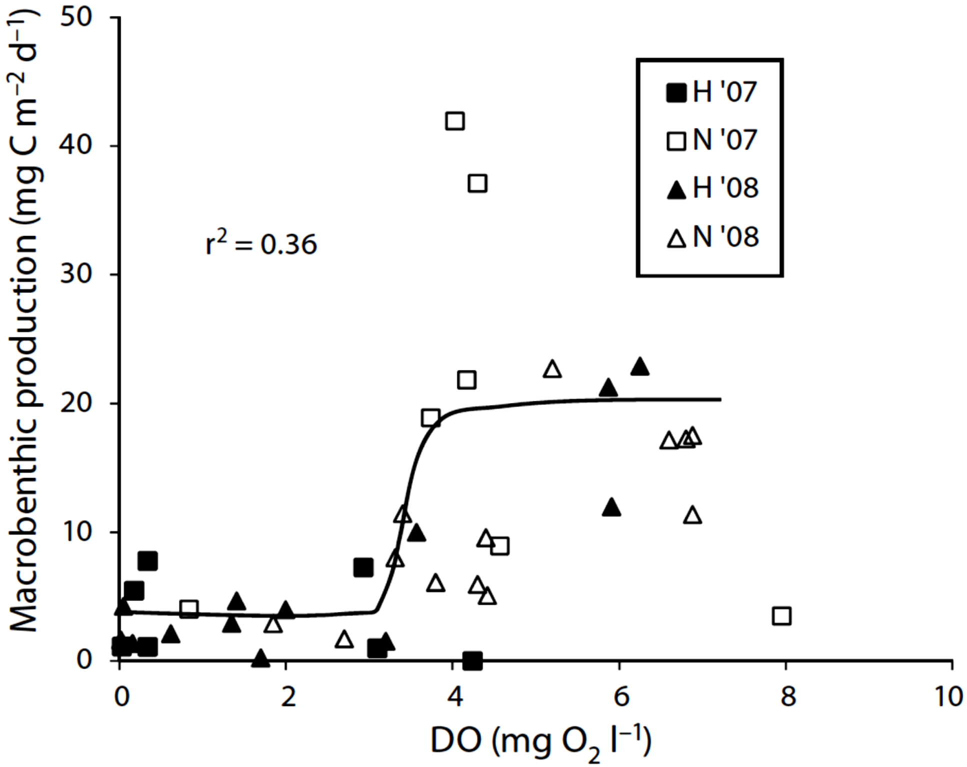


Fig. 4. Dissolved oxygen concentration and daily macrobenthic production for the continuously monitored hypoxic and normoxic sites in 2007 and 2008. There was a sigmoid relationship between DO and daily macrobenthic production (df = 39, $F = 10.31$, p = 0.0003). Squares represent 2007 data; triangles represent 2008 data. Solid symbols indicate the hypoxic (H) sites, and hollow symbols the normoxic (N) sites

Sigmoid DO – benthic production relationship

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Sturdivant et al. 2014. Estuaries and Coasts

Low dissolved oxygen effects

Table 3 Comparison of oxygen condition and mean daily macrobenthic production

(*a*) *By phylum* (±*1SE*)

	n	Mollusca	Annelida	Arthropoda
		$p=0.002$	$p<0.0005$	$p<0.0005$
Normoxia	924	40.8 (4.4) a	9.6 (0.4) a	3.2 (0.3) a
Mild hypoxia	64	6.5 (3.1) a,b	3.7 (0.4) b	0.7 (0.2) b
Hypoxia	101	3.0 (2.5) b	2.5 (0.4) b	0.2 (0.1) b

Taxocene patterns
(Used Edgar's equation)

(*b*) *By class* (±*1SE*)

	n	Bivalvia	Gastropoda	Polychaetea	Oligochaetea	Amphipoda	Isopoda
		$p=0.003$	ns	$p<0.0005$	$p=0.027$	$p=0.013$	$p<0.0005$
Normoxia	924	39.9 (4.4) a	0.8 (0.3)	7.7 (0.3) a	1.8 (0.3) a	1.5 (0.2) a	0.5 (0.1)
Mild hypoxia	64	6.2 (3.1) a,b	0.3 (0.1)	3.4 (0.4) b	0.3 (0.1) a,b	0.5 (0.2) a,b	0.1 (0.0)
Hypoxia	101	2.9 (2.5) b	0.1 (0.0)	2.4 (0.4) b	0.1 (0.0) b	0.1 (0.0) b	0.0 (0.0)

Letter differences denote significance

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Sturdivant et al. 2014. Estuaries and Coasts

Low dissolved oxygen effects

Table 6. Compilation of the major hypoxia resistant species collected at the 4 continuously monitored sites: in 2007, hypoxic Site 18 (hyp) and normoxic Site 25 (norm); in 2008, hypoxic Site 11 (hyp) and normoxic Site 12 (norm). Values in the table represent the percentage of macrobenthic production contributed by each species by site; abundances are in parentheses and dash denotes no data. For taxon group: A = annelid, B = bivalve

Taxon (group)	Hypoxia LT_{50} (h)	Site 18 (hyp)	Site 25 (norm)	Site 11 (hyp)	Site 12 (norm)	Polychaete tolerance
Heteromastus filiformis (A)	168–312	–	0.1 (32)	3.3 (12)	0.1 (1)	Rosenberg (1972), Warren (1976), Kravitz (1983)
Loimia medusa (A)	72–113	0.8 (2)	1.8 (3)	–	1.2 (1)	Breitburg et al. (2003)
Macoma balthica (B)	212–1658	2.1 (2)	–	–	–	Aller et al. (1983), Brafield & Newell (1961), Hines & Comtois (1985)
Nereis succinea (A)	62–84	0.8 (1)	0.1 (1)	27.5 (20)	28.7 (17)	Fauchald & Jumars (1979), Kravitz (1983), Hines & Comtois (1985), Fong (1991), Sagasti et al. (2001)
Paraprionospio pinnata (A)	–	77.5 (48)	47 (79)	52.2 (52)	33.6 (50)	Dauer et al. (1981), Kravitz (1983), Schaffner (1987)
Streblospio benedicti (A)	43	1.3 (2)	1.4 (11)	3.6 (12)	3.5 (19)	Dauer et al. (1981), Hines & Comtois (1985), Kravitz (1983), Llansó (1991)
Tubificoides spp. (A)	720	1.3 (3)	–	–	0.3 (3)	Tevesz et al. (1980), Hines & Comtois (1985), Giere et al. (1999)

(7) Functional metric/index approach - Benthic secondary productivity

Low dissolved oxygen effects

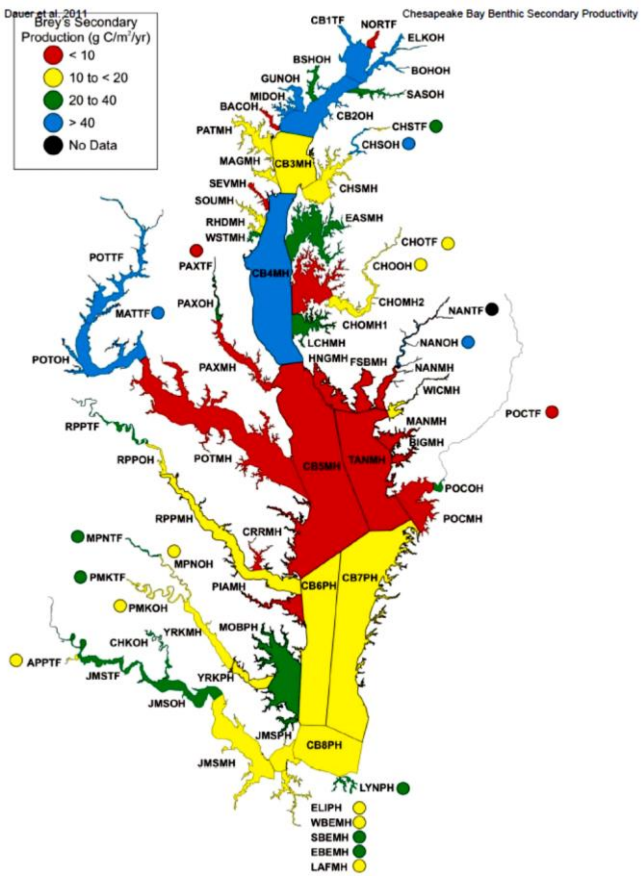


Figure 21. Chesapeake Bay Program segments showing levels of benthic secondary productivity (see insert at top).

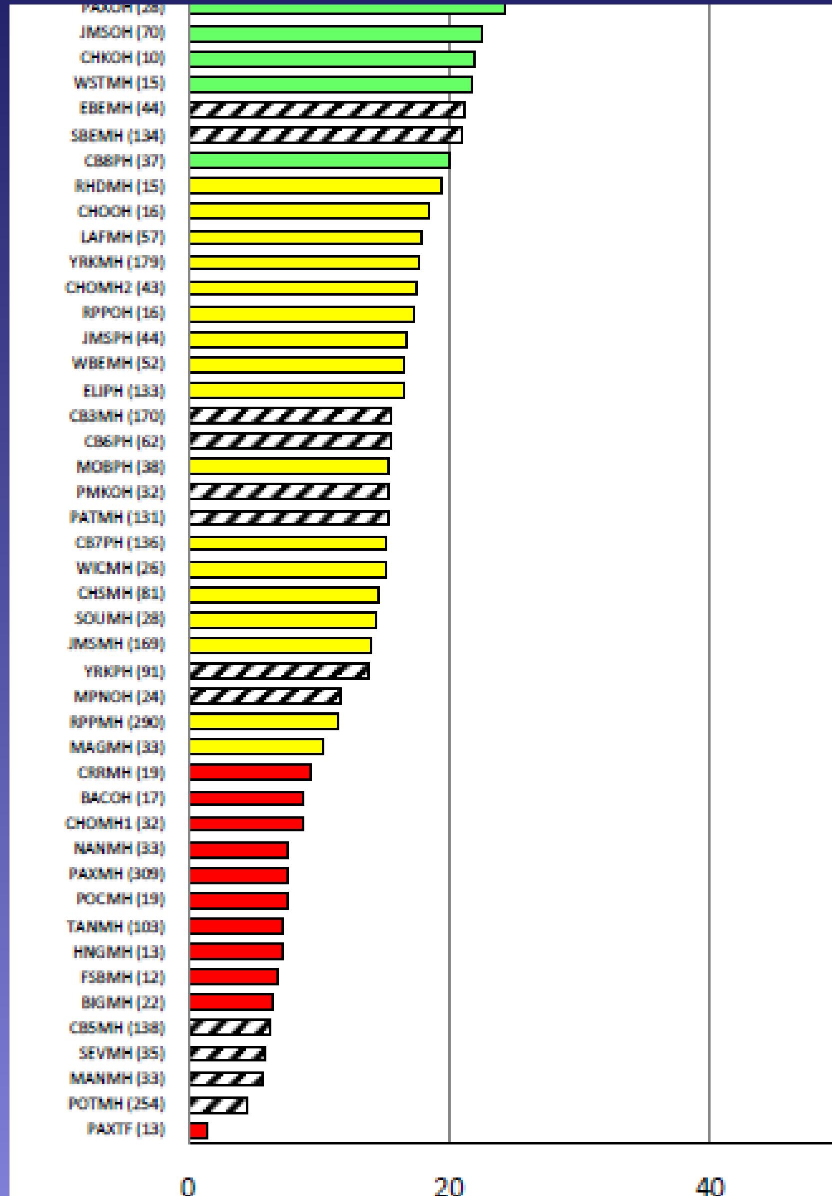
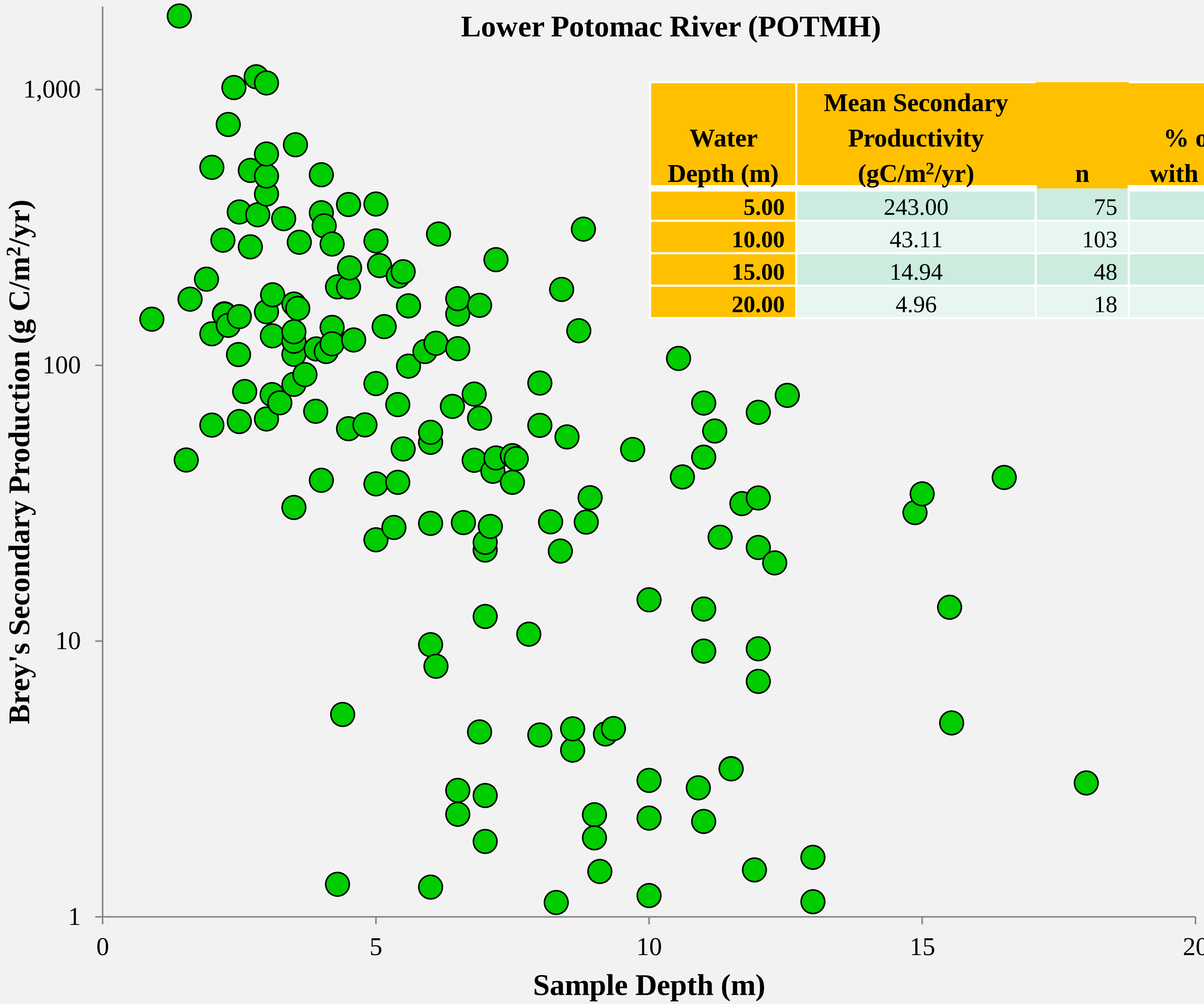


Figure 27. CBP segments and low dissolved oxygen. S

Lower Potomac River (POTMH)

Water Depth (m)	Mean Secondary Productivity ($gC/m^2/yr$)	n	% of samples with no benthos
5.00	243.00	75	8.0
10.00	43.11	103	39.8
15.00	14.94	48	41.7
20.00	4.96	18	72.2



(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report
Sturdivant et al. 2014. Estuaries and Coasts

Production equation matters
Estuarine pattern of benthic secondary production
Low dissolved oxygen effects
Contaminant effects
Trophic transfer challenges
- Susceptibility to predation
- Microbial sinks

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

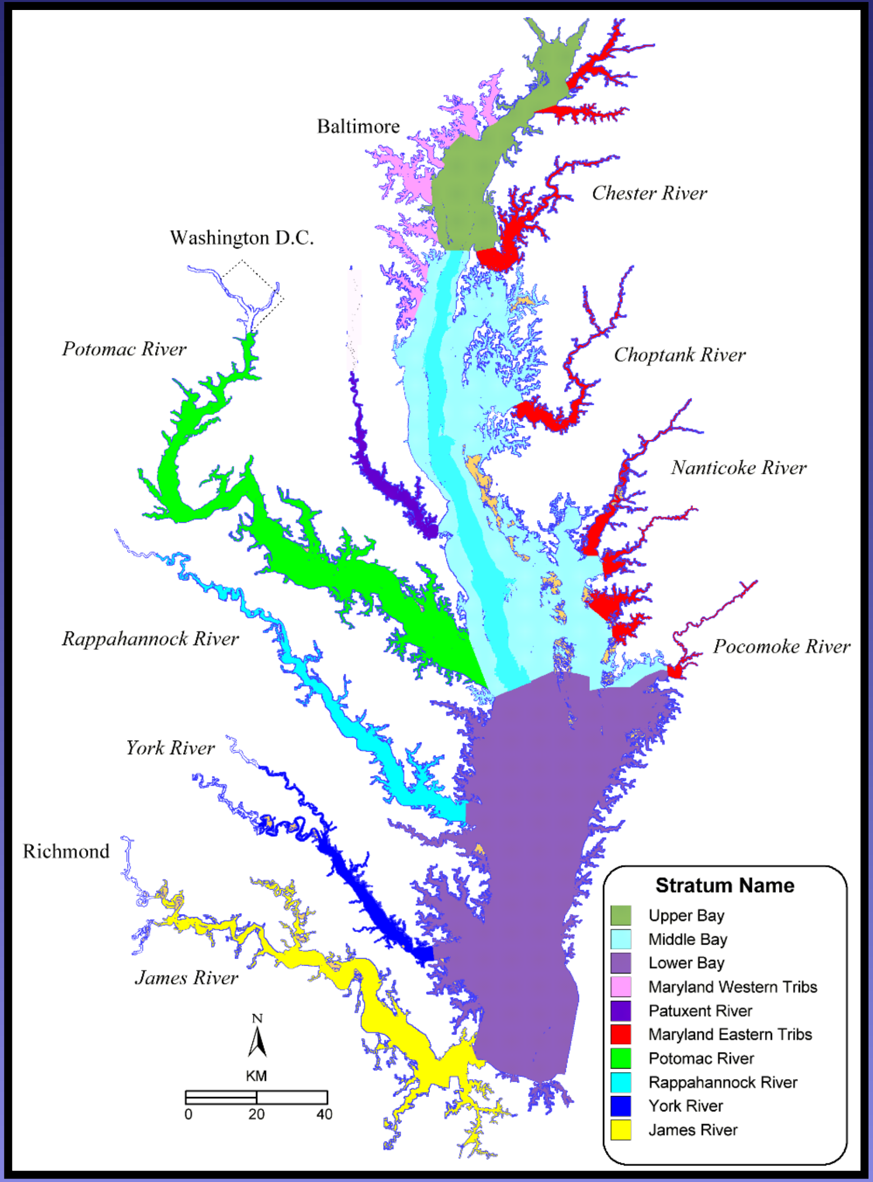
➡ Contaminant effects

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Contaminant effects

10 benthic strata
BIBI
Biomass
Benthic Productivity



Rappahannock River, PXR – Patuxent River, JAM – James River, MMS – Middle Mainstem, YRK – York River, ELR – Elizabeth River, VBY – Virginia Mainstem.

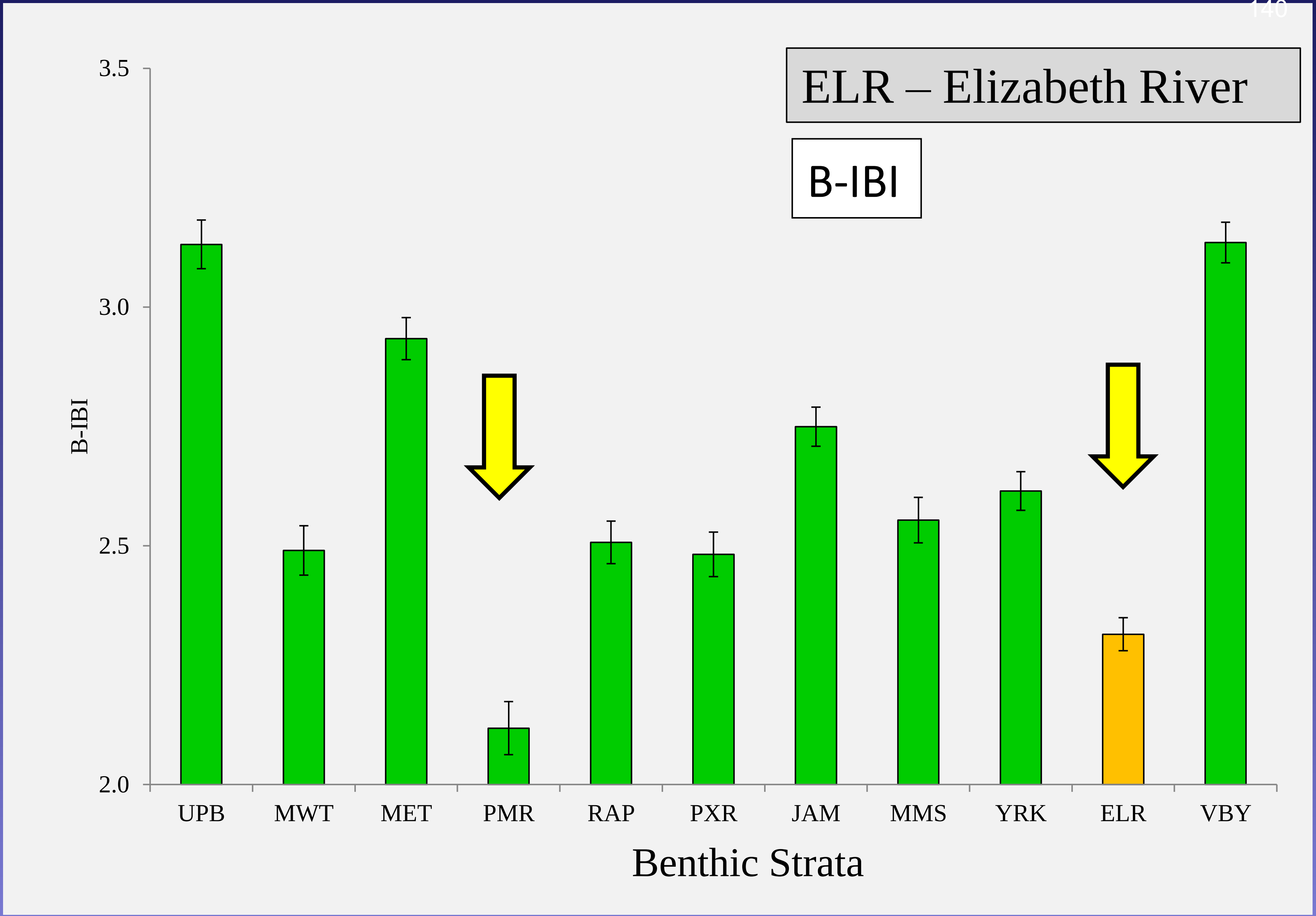


Figure 15. Mean B-IBI by the habitat types by the CBP benthic strata. Bar indicates one standard error.

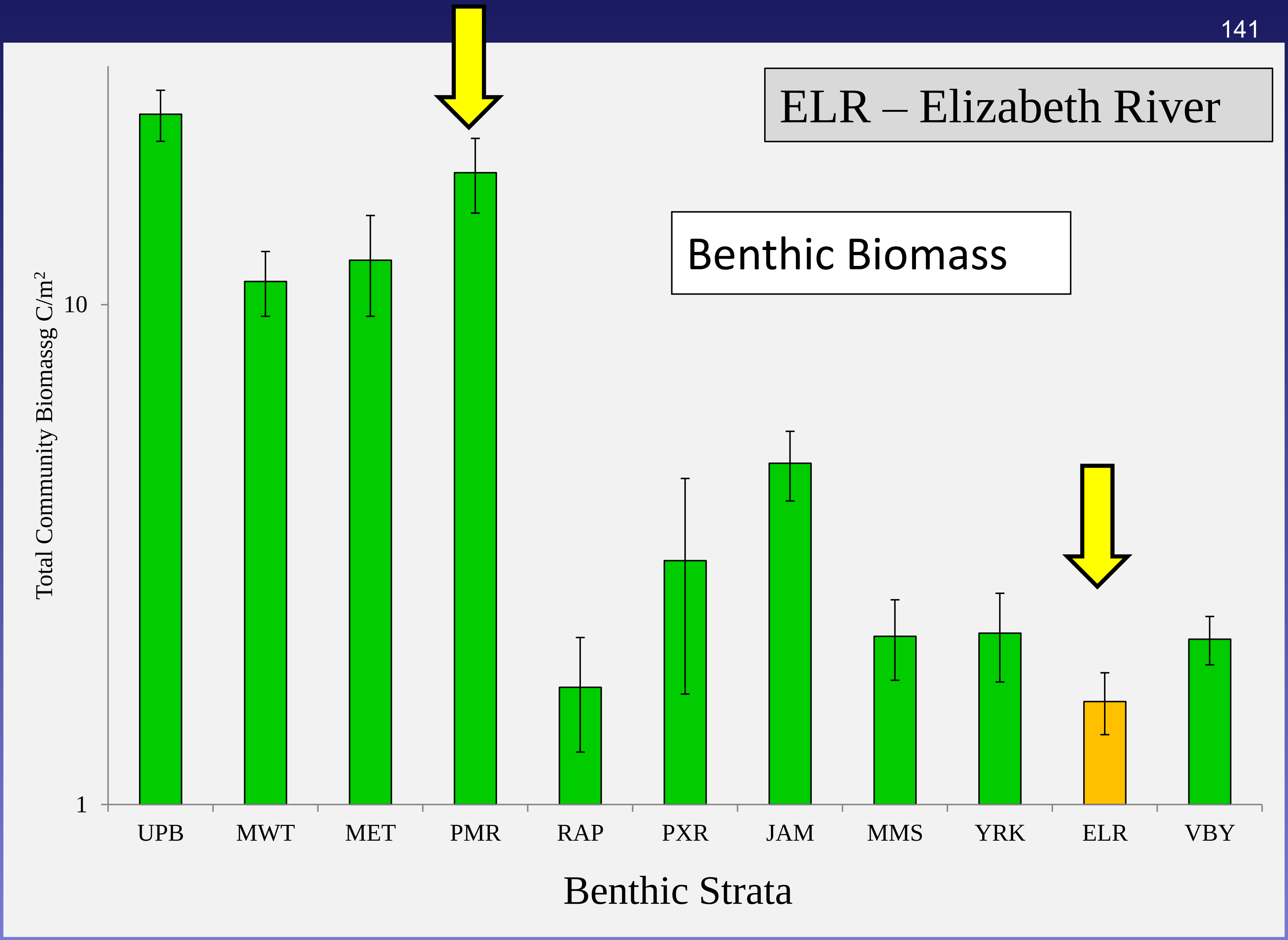


Figure 13. Mean standing stock biomass (gC/m²) by the CBP benthic strata. Bar indicates one standard error.

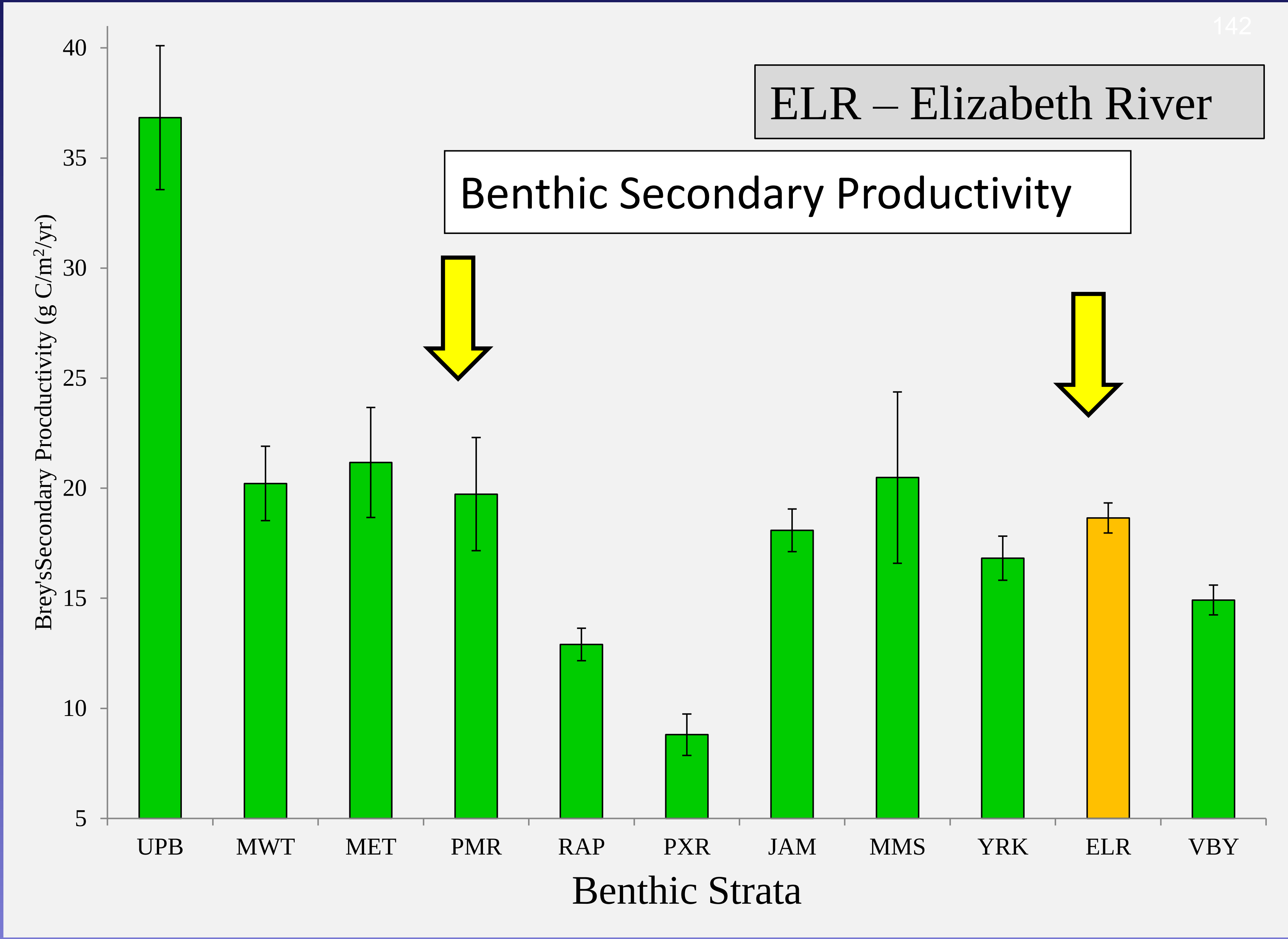
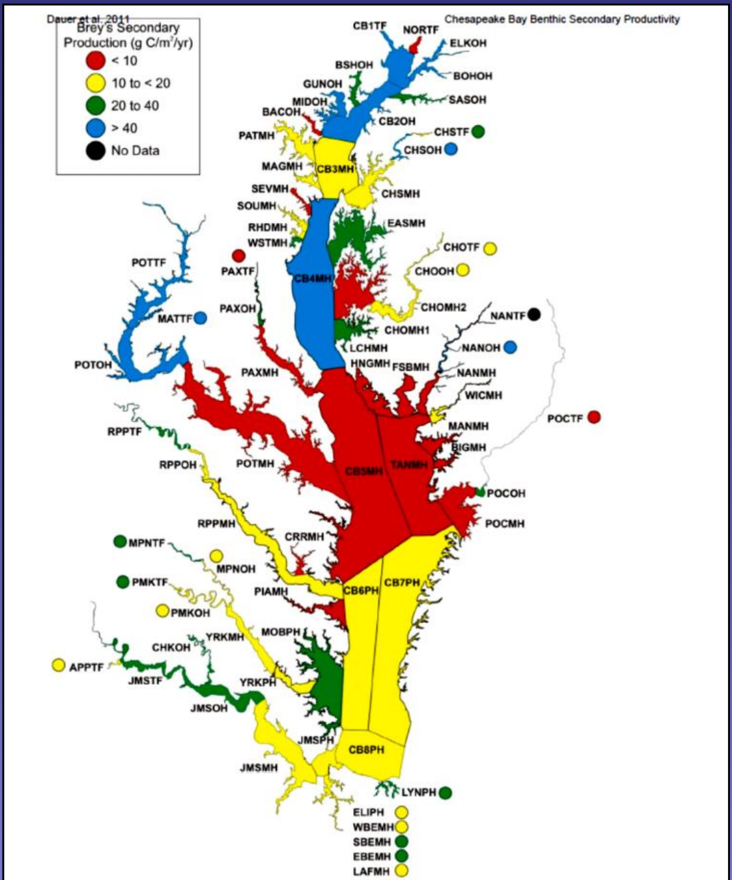


Figure 12. Mean secondary production (gC/m²/yr) by the CBP benthic strata. Bar indicates one standard error.

UPB – Upper Mainstem, MWT – Maryland Western Tributaries, MET – Maryland Eastern Tributaries, PMR – Potomac River, RAP – Rappahannock River, PXR – Patuxent River, JAM – James River, MMS – Middle Mainstem, YRK – York River, ELR – Elizabeth River, VBY – Virginia Mainstem.

(7) Functional metric/index approach - Benthic secondary productivity



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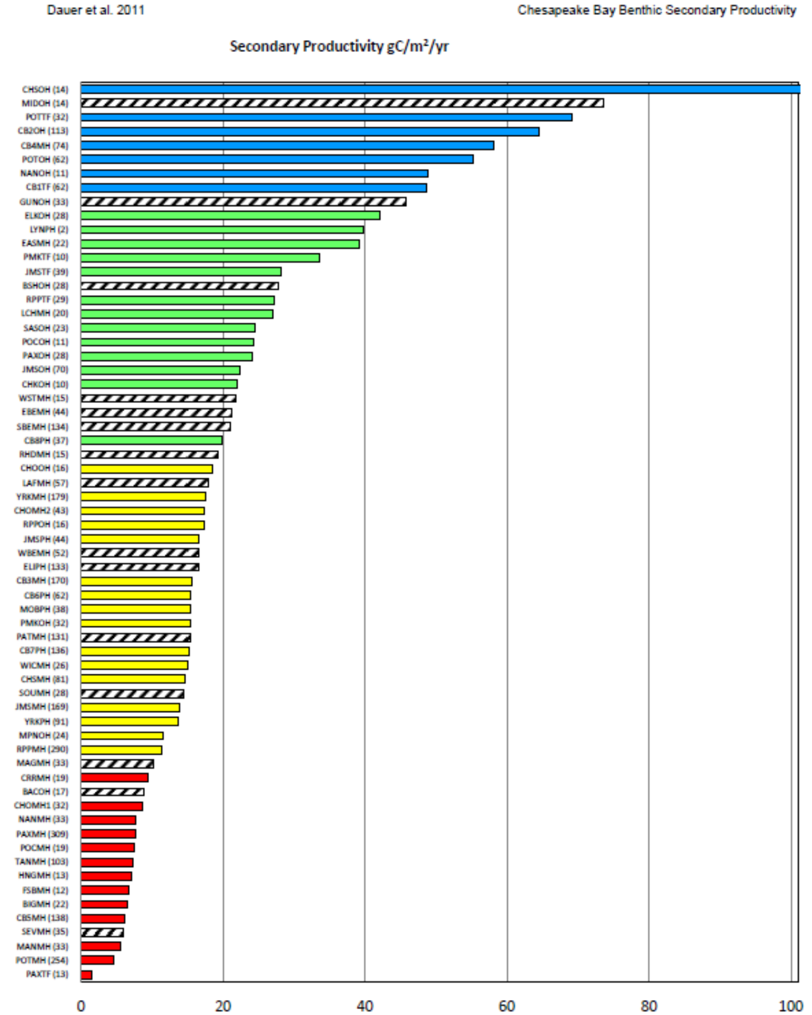


Figure 28. CBP segments and high urban land-use. Shown are secondary productivity values in gC/m²/yr. Colors correspond to the intervals of Figure 21. Segments with no color and cross hatching are located in either the Maryland Western Tributaries benthic stratum or the Elizabeth River watershed.

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Production equation matters

Estuarine pattern of benthic secondary production

Low dissolved oxygen effects

Contaminant effects

Trophic transfer challenges

- Susceptibility to predation
- Microbial sinks

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

Trophic transfer challenges

Susceptibility to predation

Microbial sinks

Develop species specific estimates of **potential availability** of the benthic production **to higher trophic levels**.

Important ecological factors are

(1) protective coverings such has molluscan shells and crustacean exoskeletons that reduce predation,

(2) depth of dwelling within the sediment that might provide a refuge from predation,

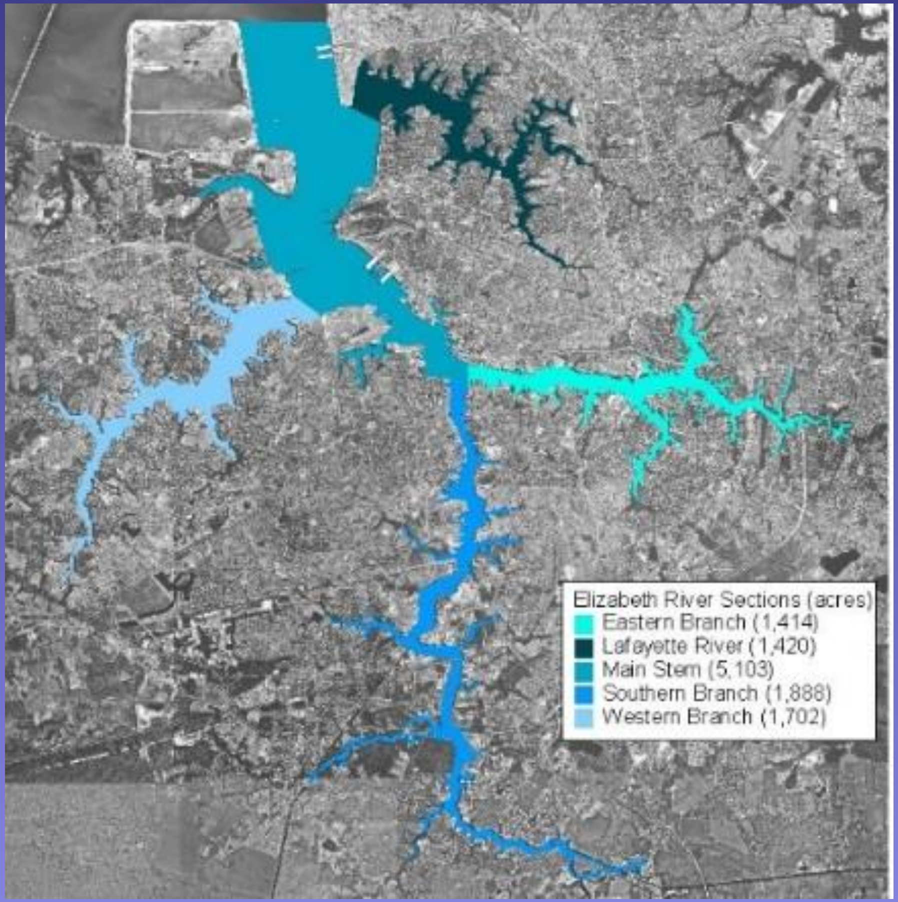
(3) body size factors that affect strength of protective coverings and/or age-related sediment depth dwelling location, and

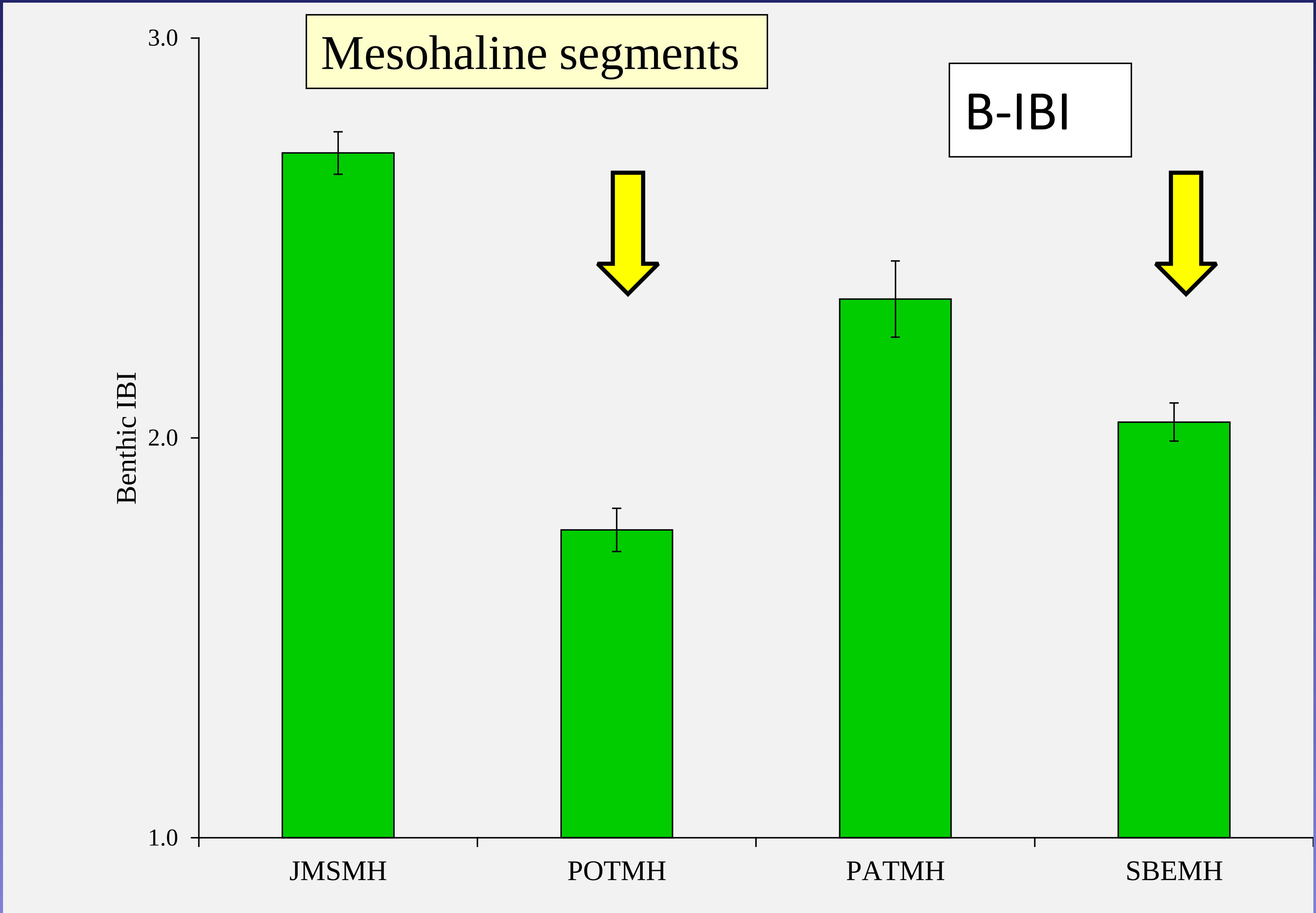
(4) general **behaviors** that can modify susceptibility to predation, e.g. rapid motility.

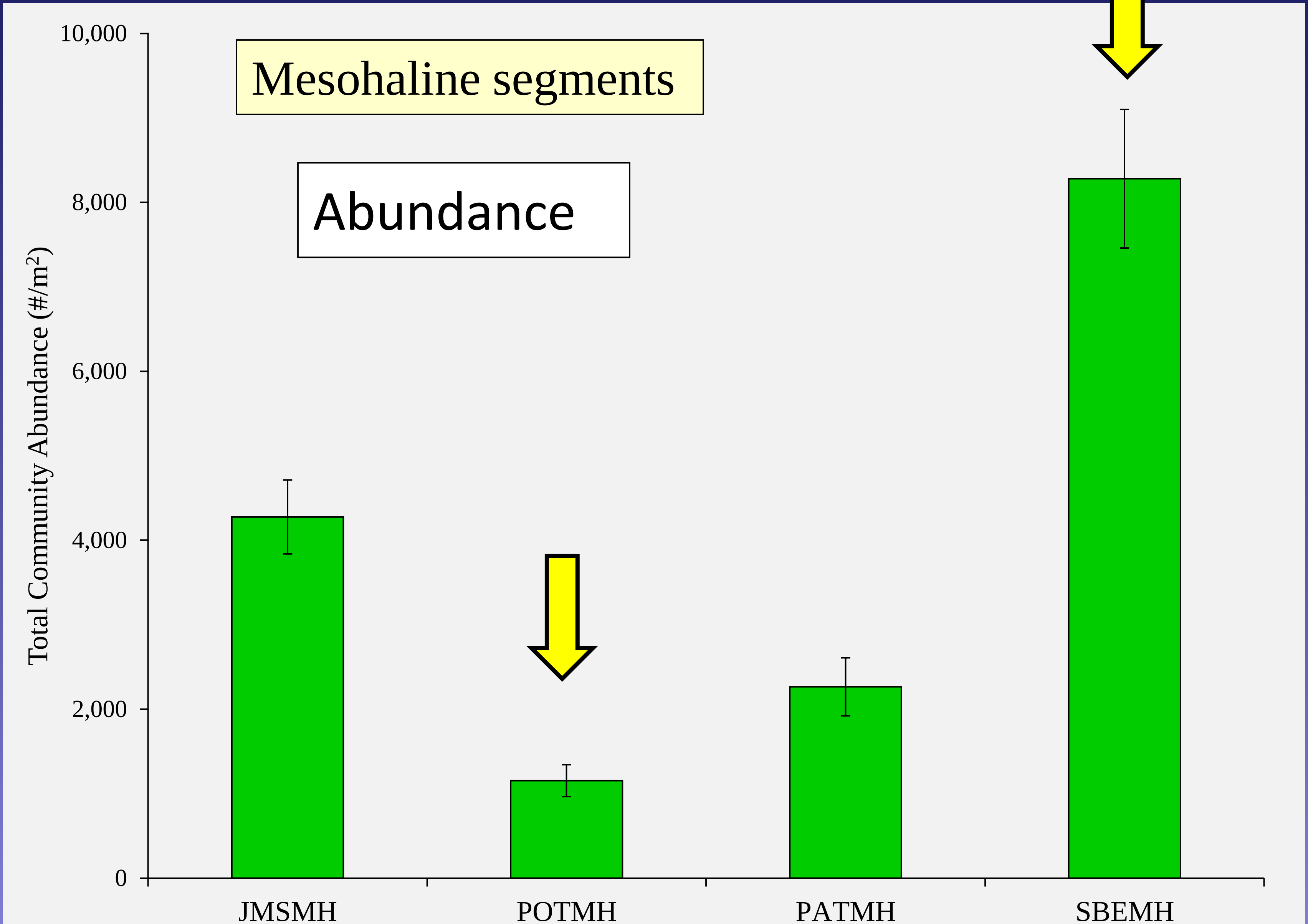
(7) Functional metric/index approach - Benthic secondary productivity

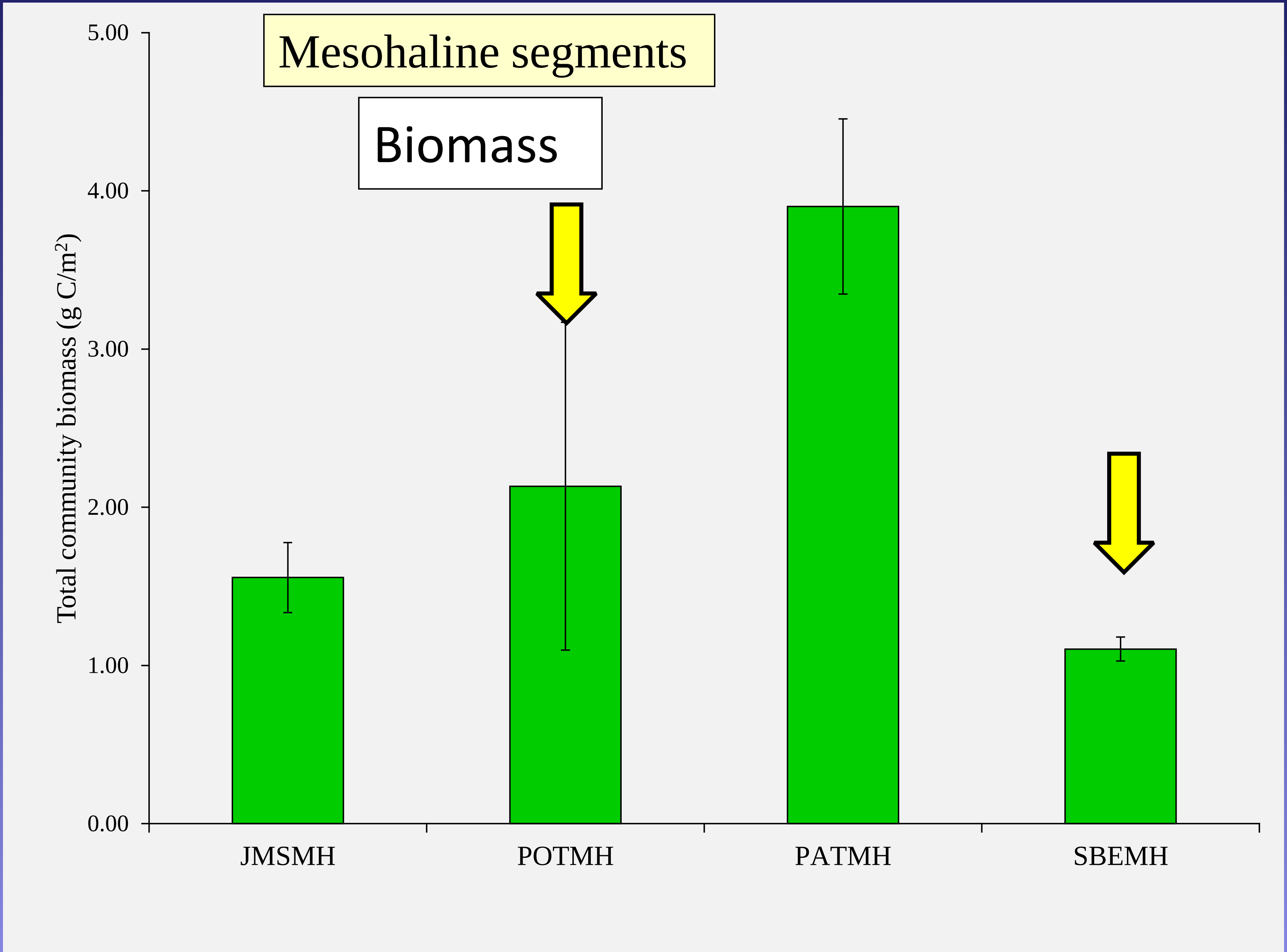
Dauer et al. 2011. VADEQ Technical Report

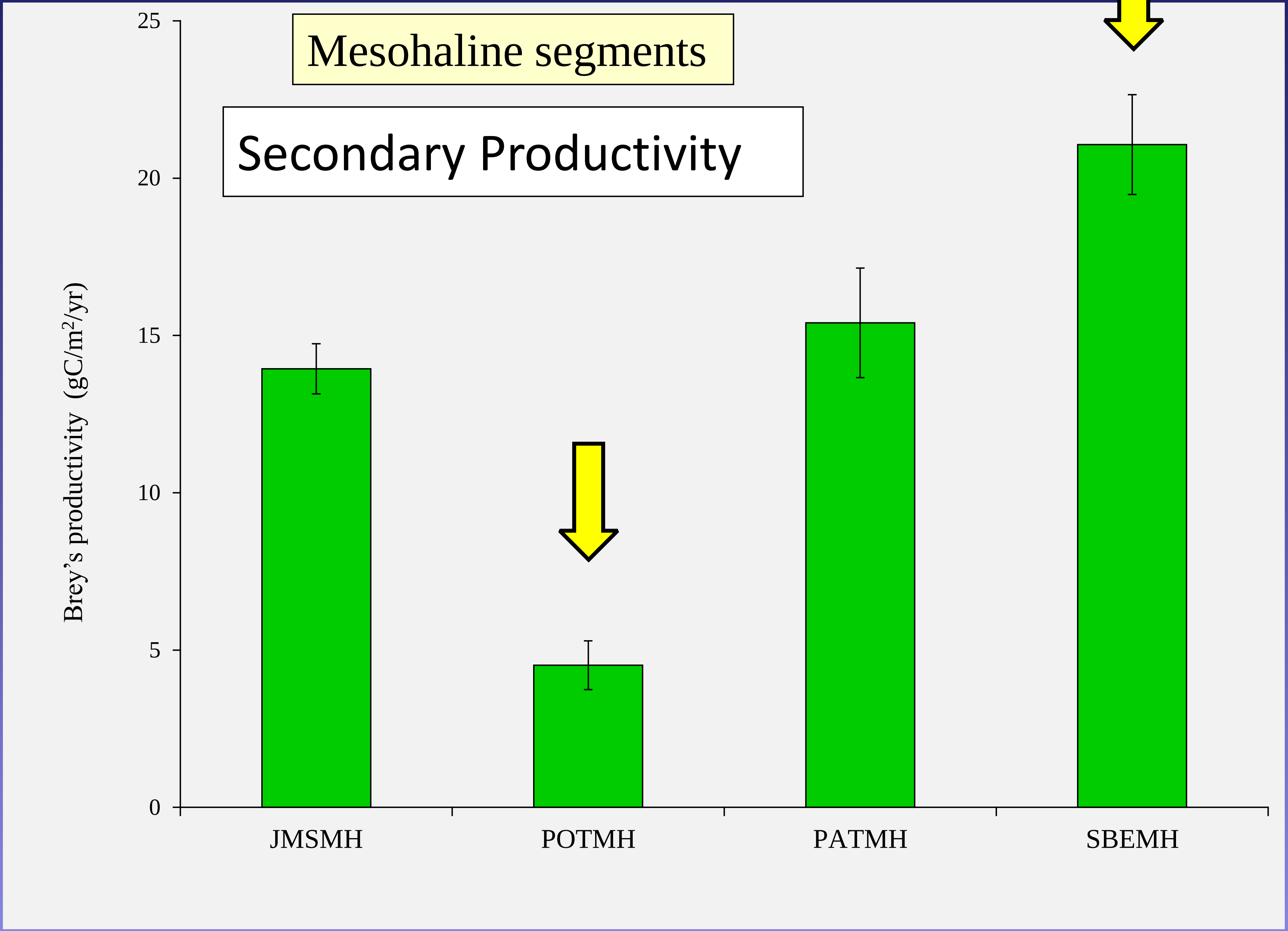
- Trophic transfer challenges
  - Susceptibility to predation
  - Microbial sinks
    - Anoxia
    - Contaminants




Mesohaline segments
B-IBI
Benthic IBI
3.0
2.0
1.0
JMSMH
POTMH
PATMH
SBEMH


Mesohaline segments
Abundance
Total Community Abundance (#/m2)
10,000
8,000
6,000
4,000
2,000
0
JMSMH
POTMH
PATMH
SBEMH


Mesohaline segments
Biomass
Total community biomass (g C/m^2)
5.00
4.00
3.00
2.00
1.00
0.00
JMSMH
POTMH
PATMH
SBEMH


Mesohaline segments
Secondary Productivity
Brey's productivity (gC/m2/yr)
25
20
15
10
5
0
JMSMH
POTMH
PATMH
SBEMH

(7) Functional metric/index approach - Benthic secondary productivity

Dauer et al. 2011. VADEQ Technical Report

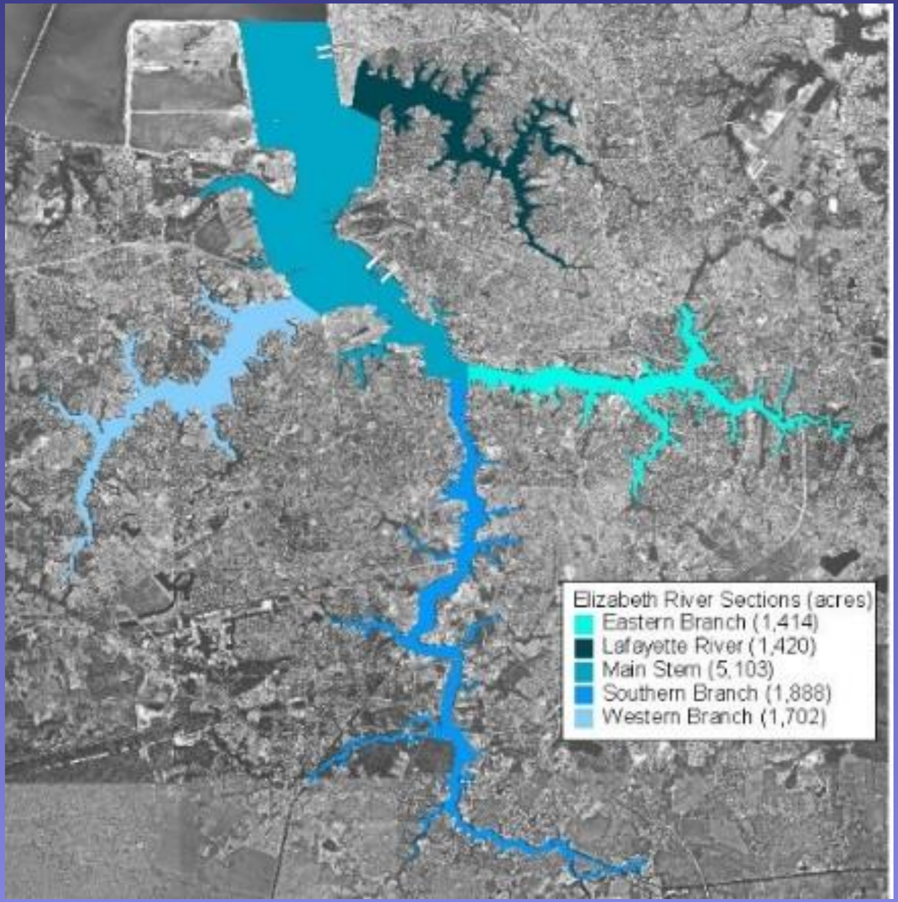
Trophic transfer challenges

Susceptibility to predation

Microbial sinks

Anoxia

Contaminants



(8) BIBI recalibration

(Llansó, et al. 2016. **VADEQ Technical Report**; de-la-Ossa et al. 2016. Ecological Indicators)

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CHESAPEAKE BAY B-IBI RECALIBRATION

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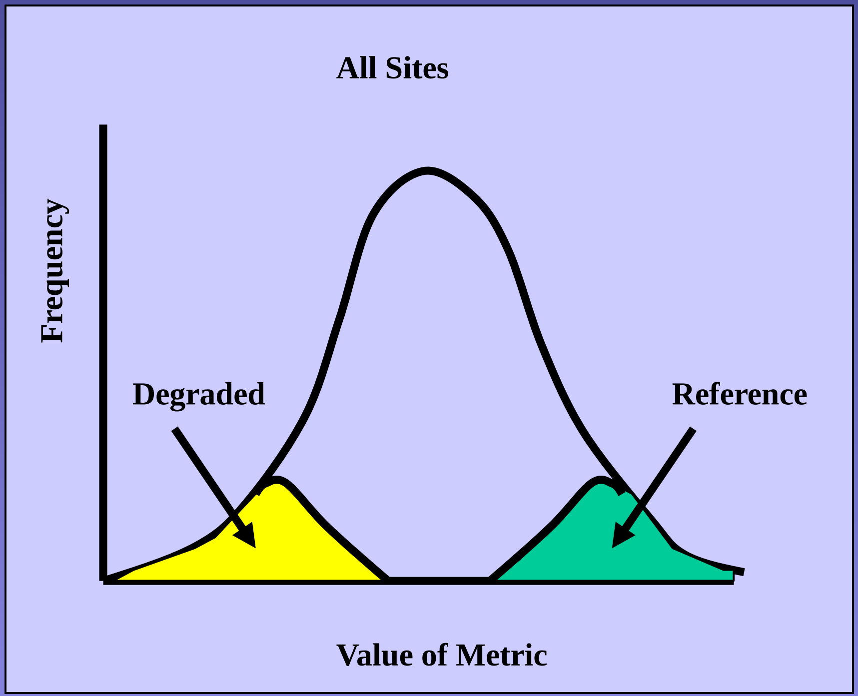
August 2016

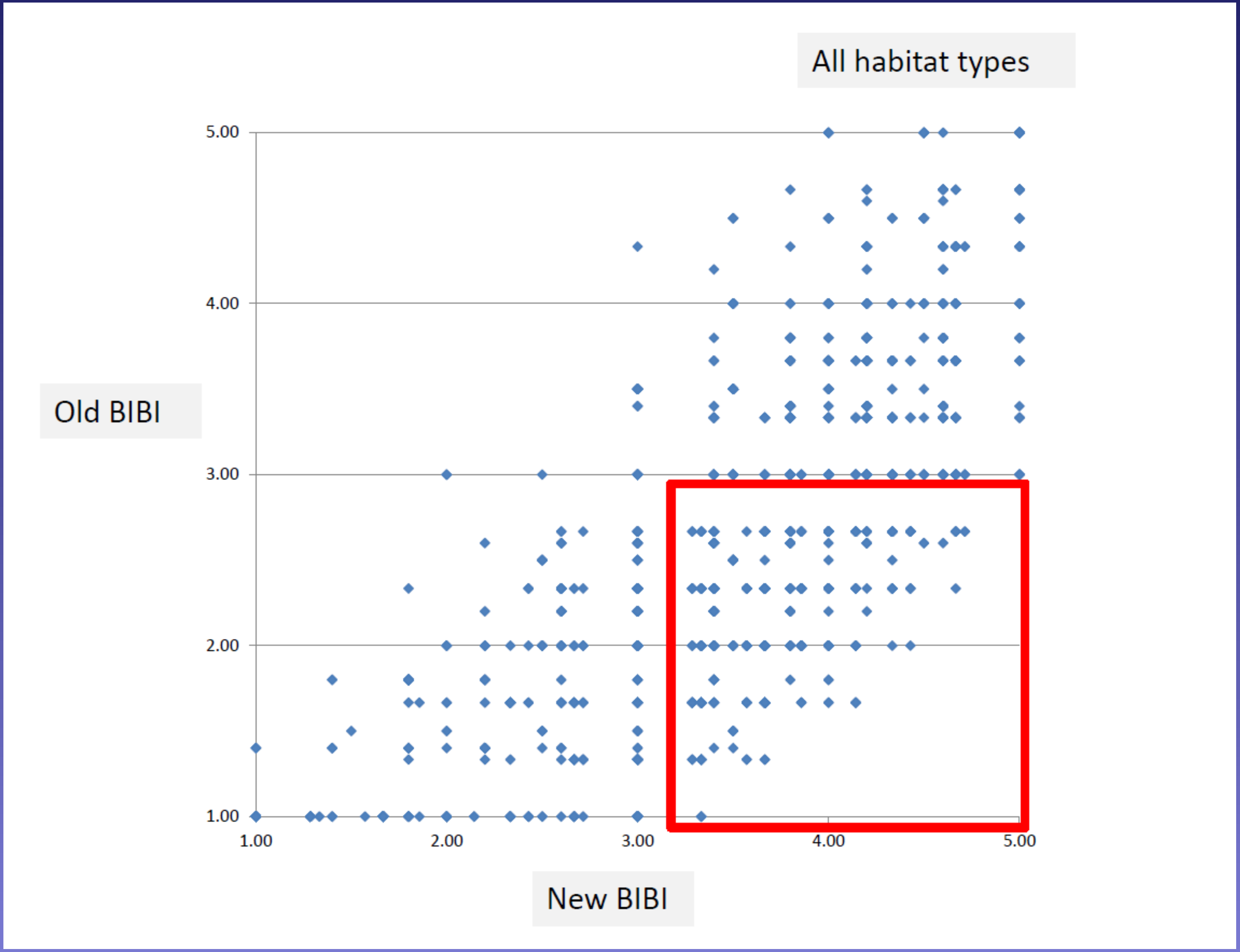


Habitat	a priori Classification	Sample #	Correctly Classified Number	Percentage
Tidal Freshwater	Reference	55	40	72.7
	Degraded	161	58	36.0
	Total	216	98	45.4
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Oligohaline	Reference	24	17	70.8
	Degraded	111	70	63.1
	Total	135	87	64.4
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Low Mesohaline	Reference	92	51	55.4
	Degraded	214	156	72.9
	Total	306	207	67.6
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
High Mesohaline Sand	Reference	189	91	48.2
	Degraded	58	32	55.2
	Total	247	123	49.8
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
High Mesohaline Mud	Reference	106	30	28.3
	Degraded	309	241	78.0
	Total	415	271	65.3
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Polyhaline Sand	Reference	240	163	67.9
	Degraded	46	23	50.0
	Total	286	186	65.0
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Polyhaline Mud	Reference	47	18	38.3
	Degraded	179	164	91.6
	Total	226	182	80.5
	Overall	1831	1154	63.0

Table 5. Classification efficiencies within habitat type and across all habitat types for both Reference and Degraded sites based on B-IBI values scored using thresholds defined in Weisberg et al. (1997) and Alden et al. (2002) and the entire calibration and validation datasets assembled for this project.

			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Tidal Freshwater	Reference	22	15	68.2
	Degraded	161	49	30.4
	Total	183	64	35.0
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Oligohaline	Reference	9	5	55.6
	Degraded	111	32	28.8
	Total	120	37	30.8
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Low Mesohaline	Reference	33	25	75.8
	Degraded	214	101	47.2
	Total	247	126	51.0
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
High Mesohaline Sand	Reference	65	53	81.5
	Degraded	58	18	31.0
	Total	123	71	57.7
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
High Mesohaline Mud	Reference	39	32	82.1
	Degraded	309	159	51.5
	Total	348	191	54.9
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Polyhaline Sand	Reference	81	77	95.1
	Degraded	46	9	19.6
	Total	127	86	67.7
			Correctly Classified	
Habitat	a priori Classification	Sample #	Number	Percentage
Polyhaline Mud	Reference	15	15	100
	Degraded	179	70	39.1
	Total	194	85	43.8
	Overall	1342	660	49.2

Table 6. Classification efficiencies within habitat type and across all habitat types for both Reference and Degraded sites based on B-IBI values scored **using new thresholds** and the validation dataset assembled for this project.



All habitat types
Old BIBI
New BIBI
5.00
4.00
3.00
2.00
1.00
1.00
2.00
3.00
4.00
5.00

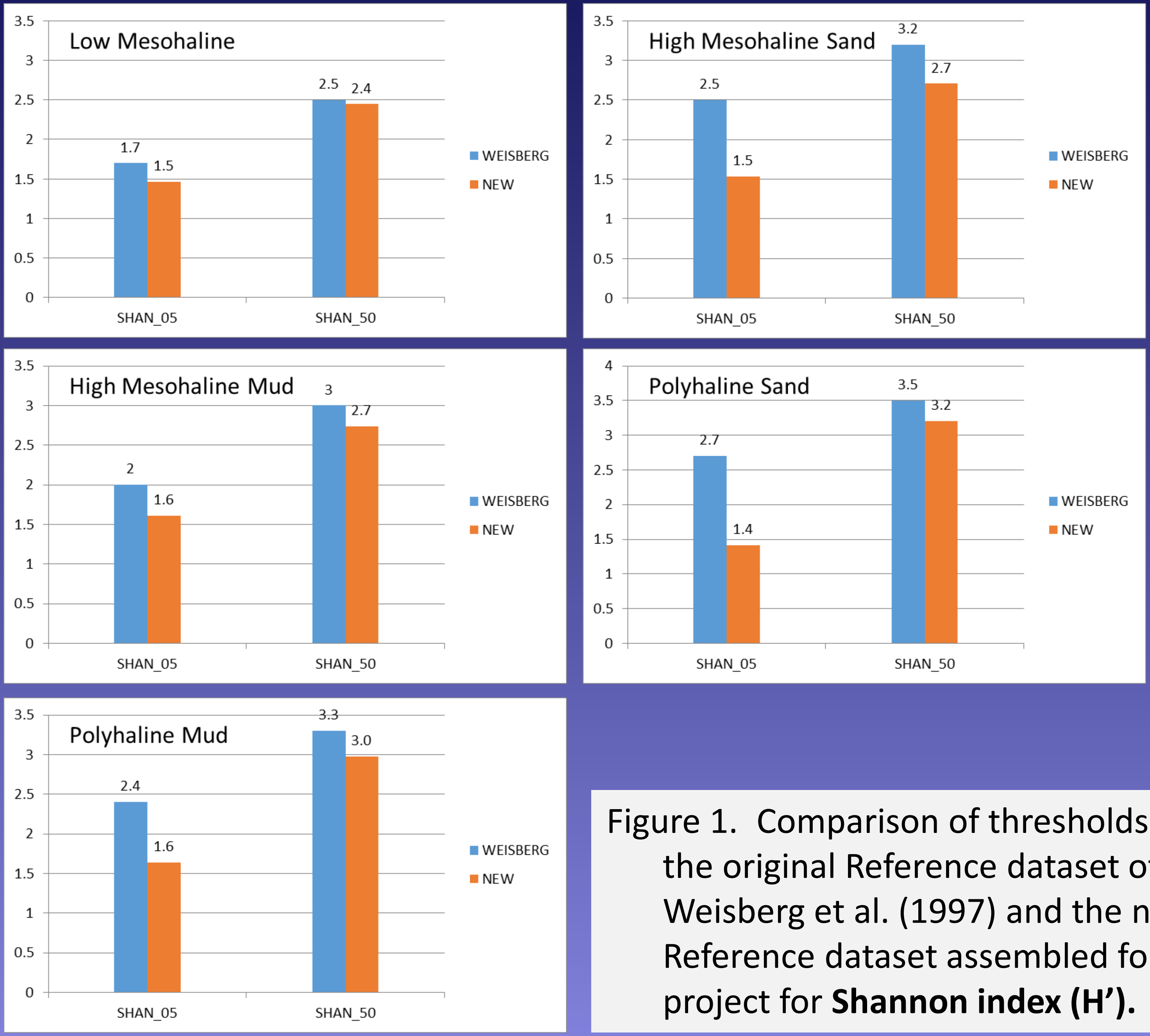
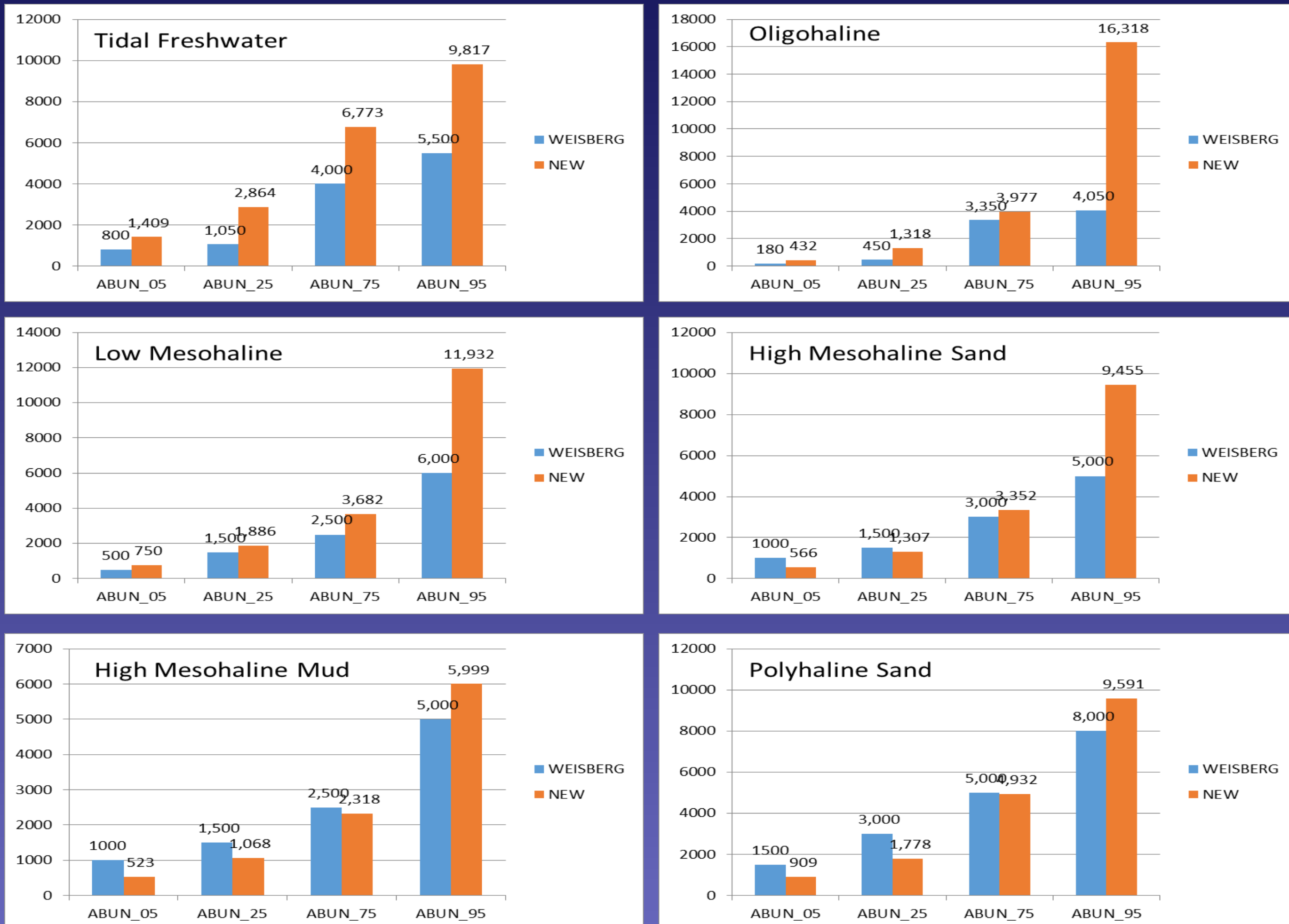


Figure 1. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for **Shannon index (H')**.



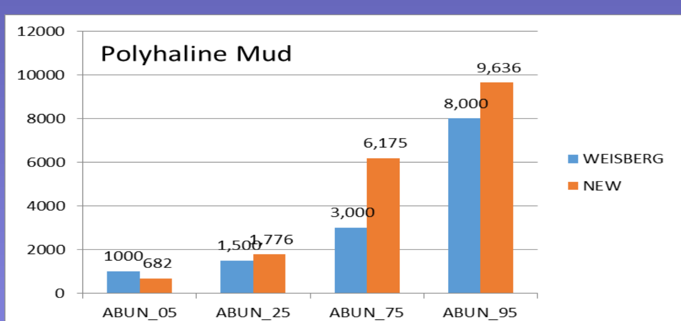
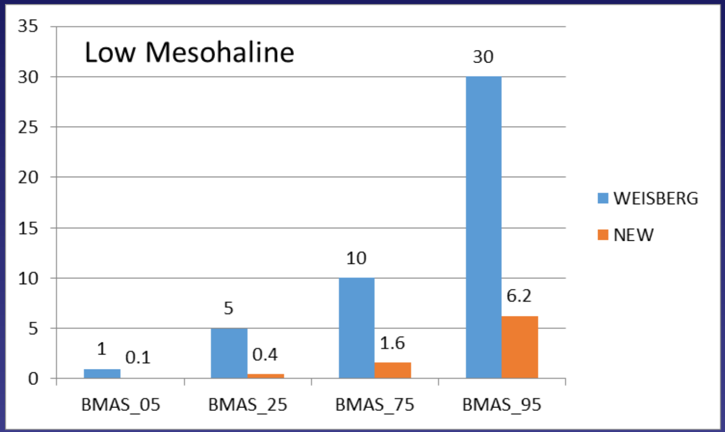
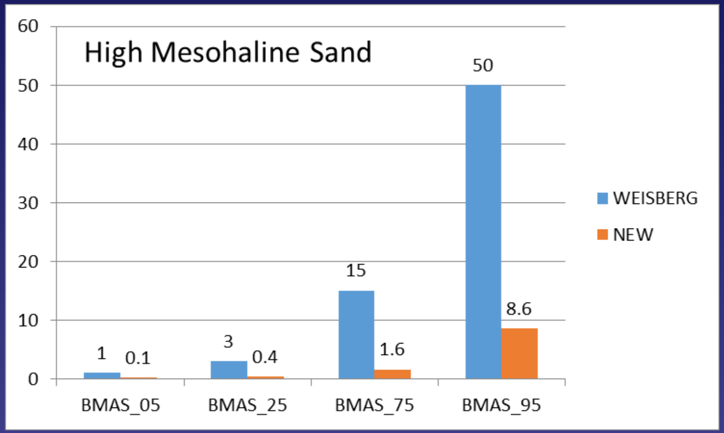
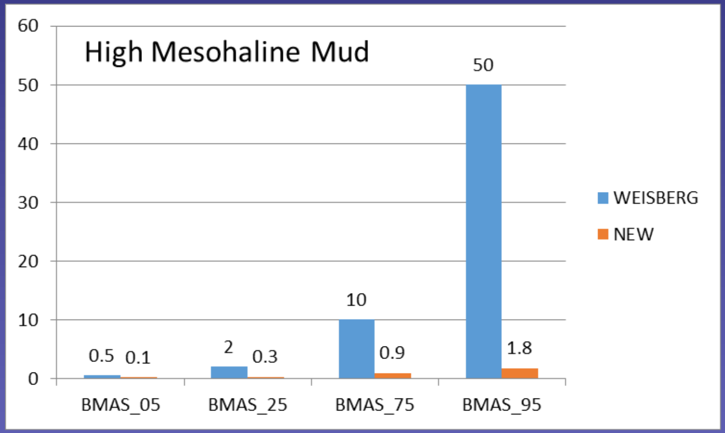
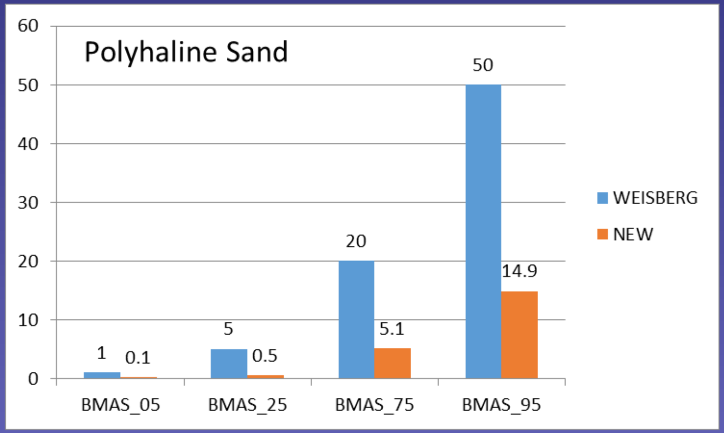


Figure 2. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for **abundance (#/m^2)**









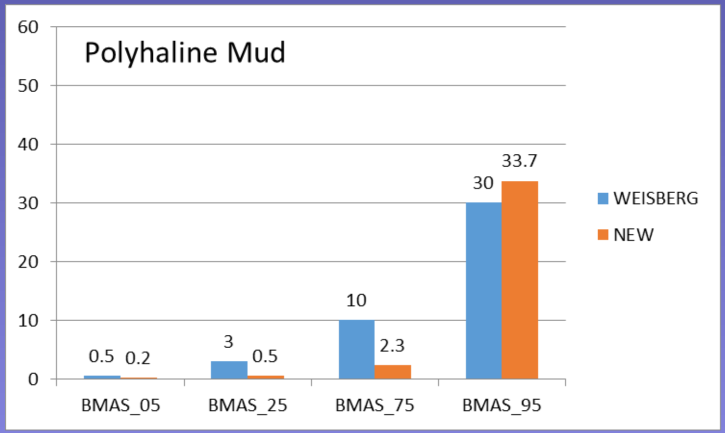
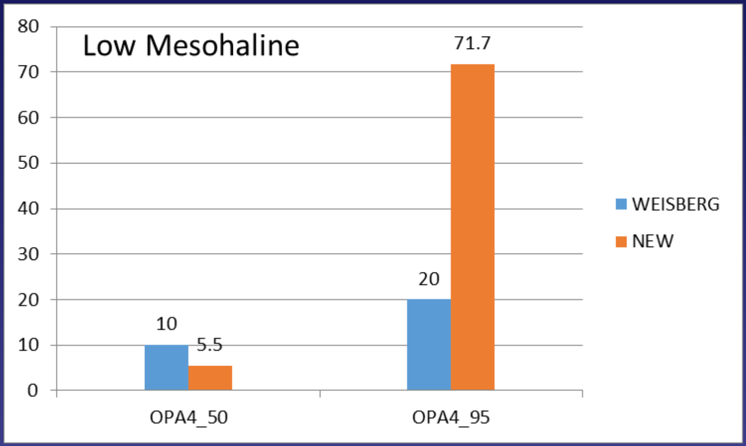
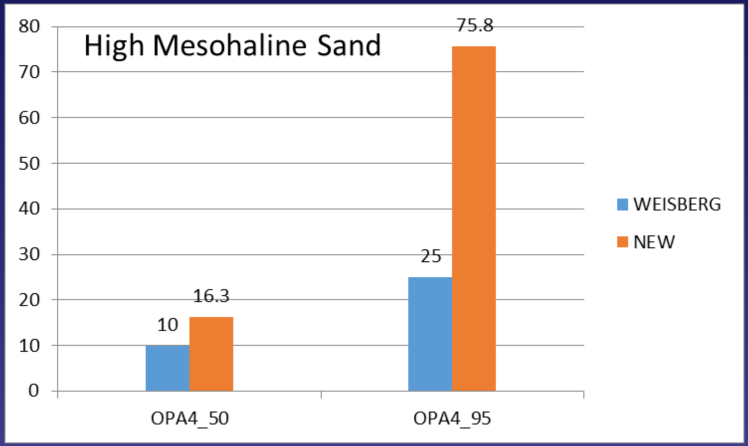
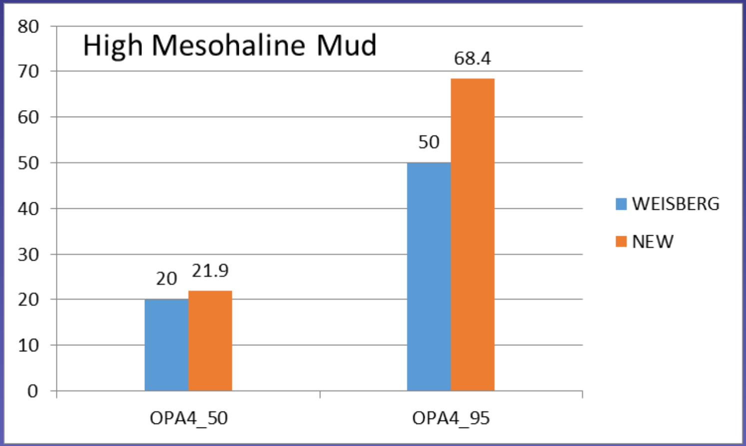
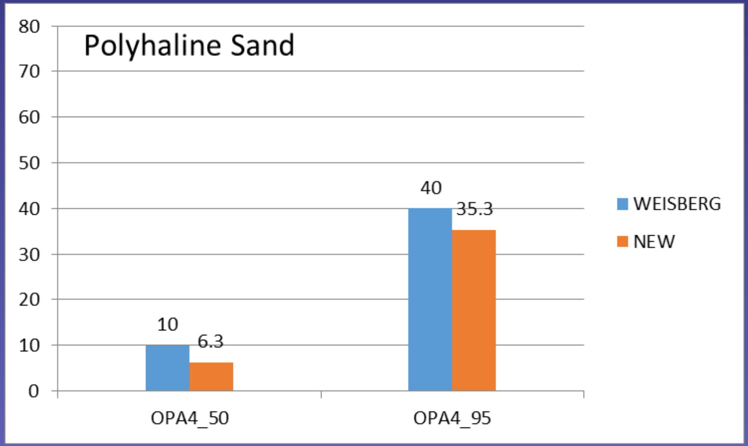


Figure 3. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for **biomass (g AFDW/m^2)**









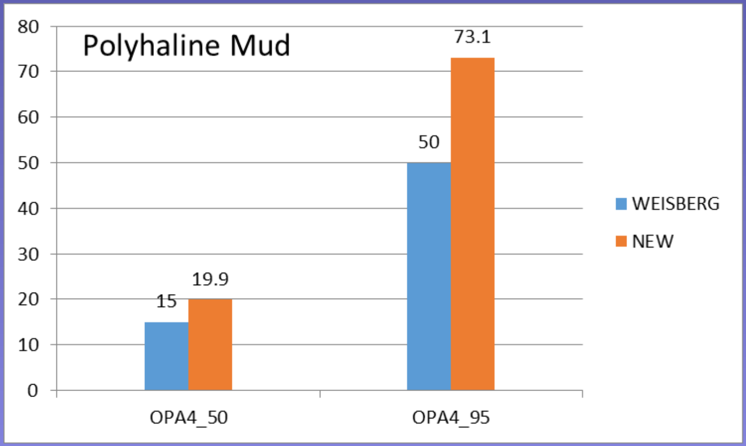


Figure 4. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for **abundance of pollution indicative taxa (%)**

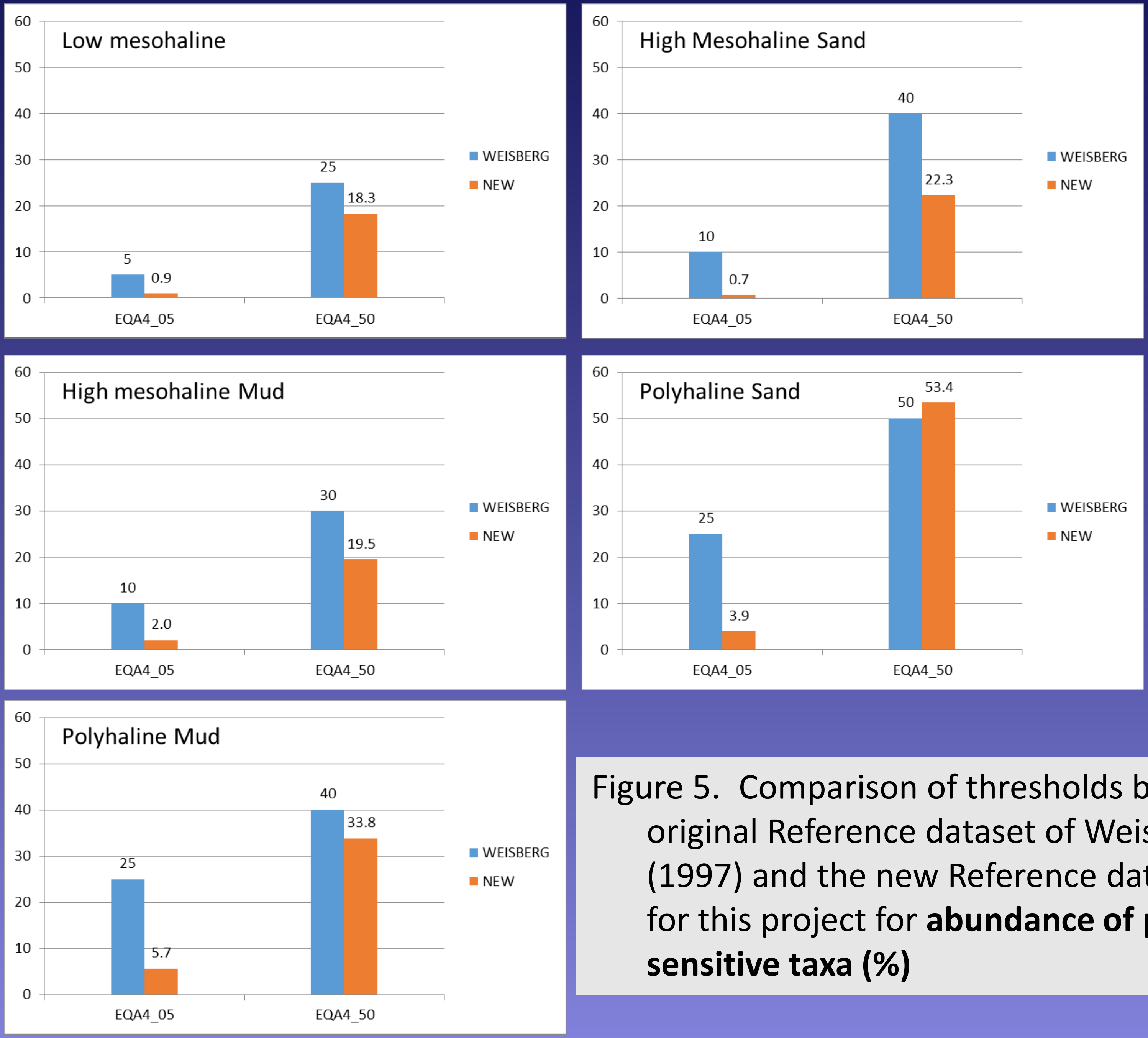
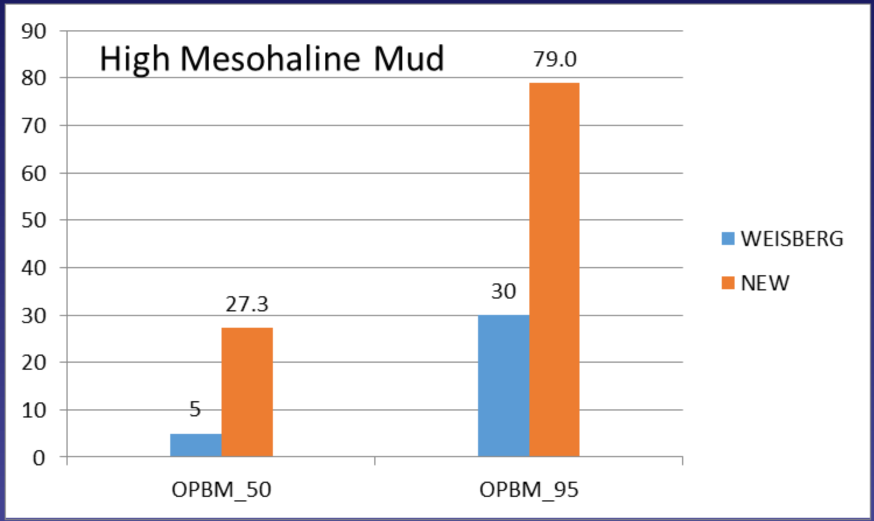
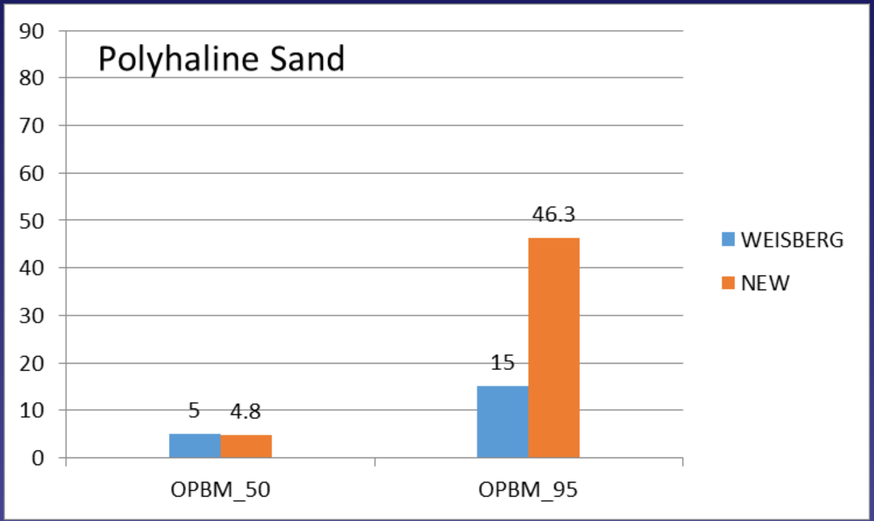


Figure 5. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for **abundance of pollution sensitive taxa (%)**





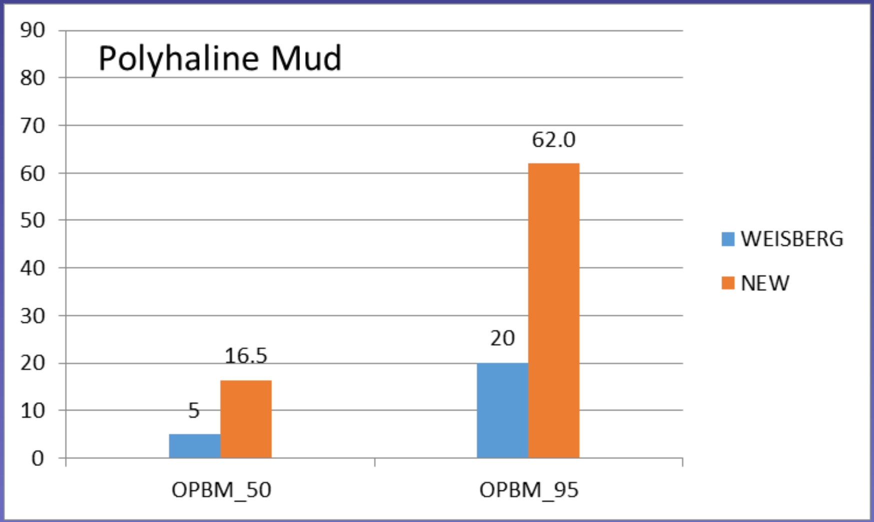


Figure 6. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for **biomass of pollution indicative taxa (%)**

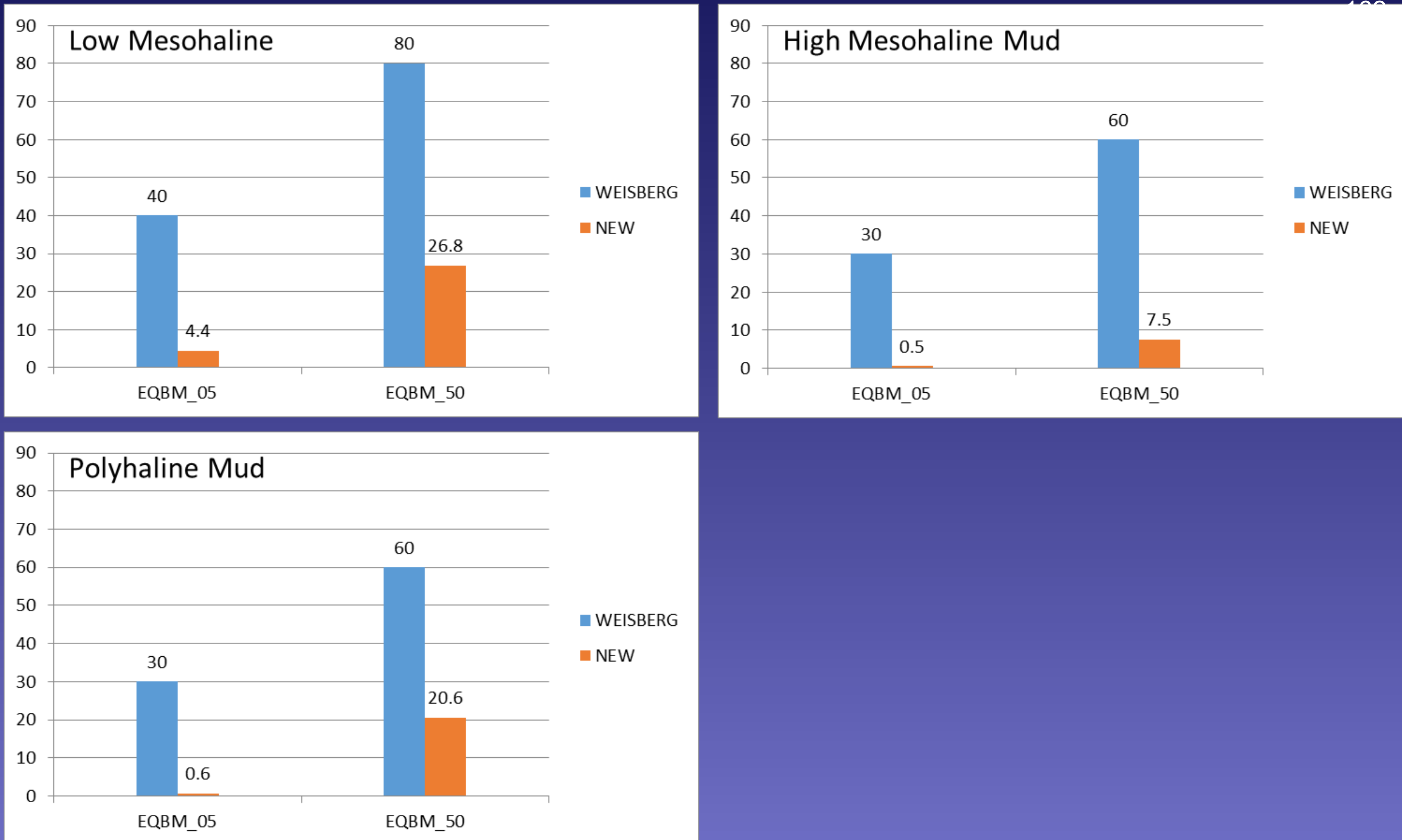


Figure 7. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for **biomass of pollution sensitive taxa (%)**

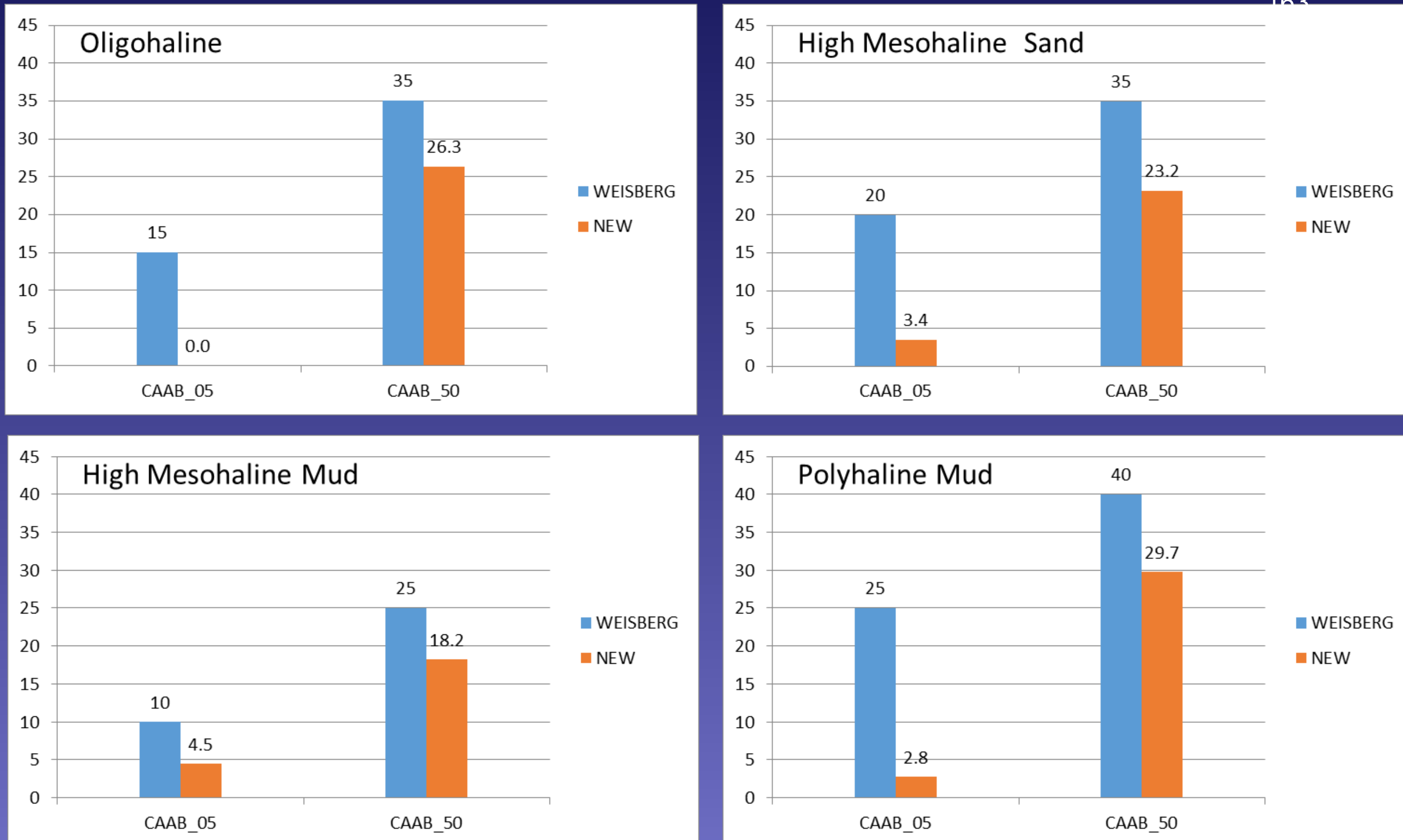
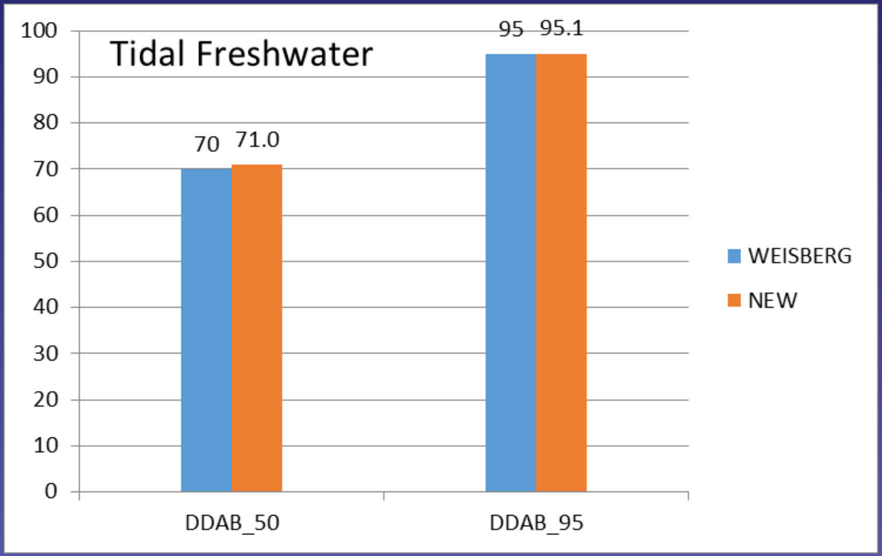


Figure 8. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for **abundance of carnivore and omnivores (%)**



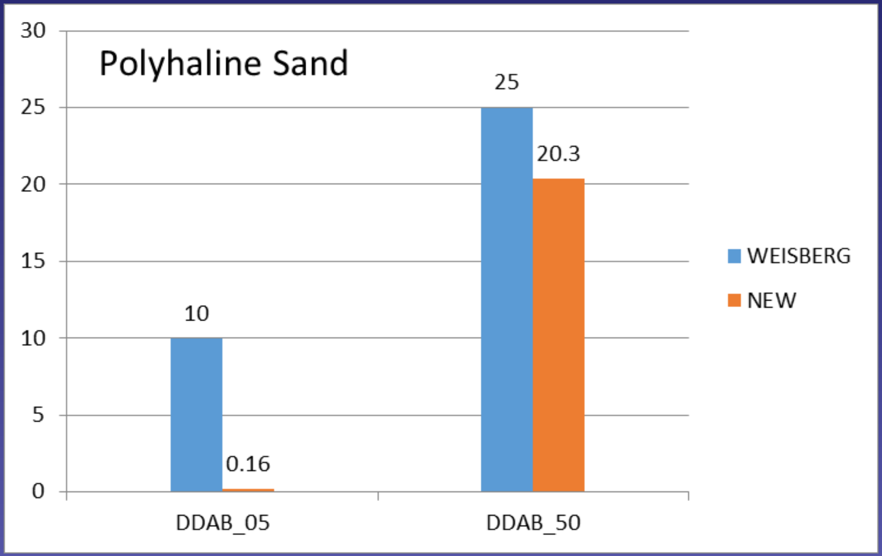


Figure 9. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for abundance of **deep-deposit feeders (%)**

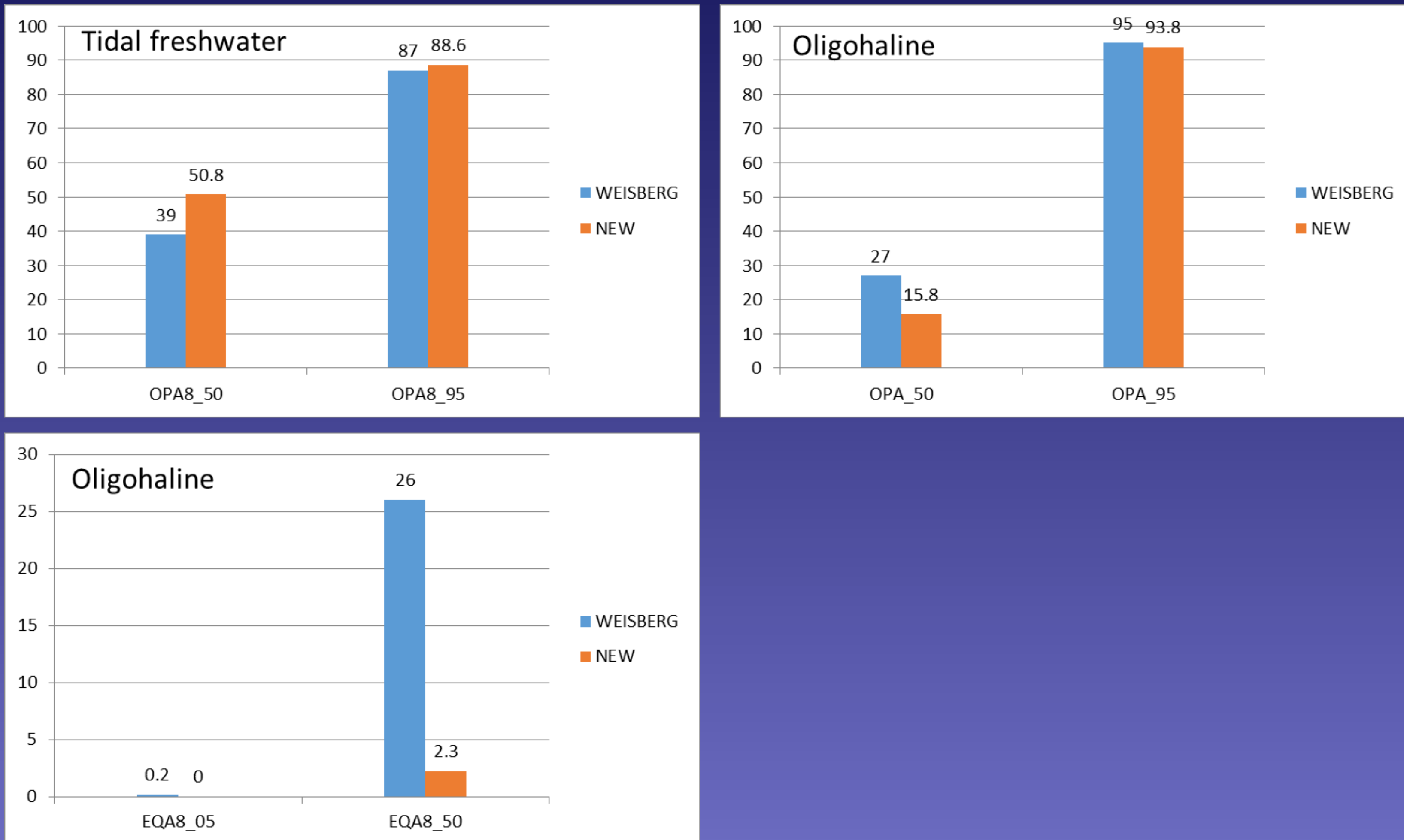


Figure 10. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for abundance of **pollution indicative freshwater and oligohaline taxa (%, upper panel),** and **abundance of pollution sensitive oligohaline taxa (%, lower panel)**

(7) Functional metric/index approach
Benthic Secondary Productivity

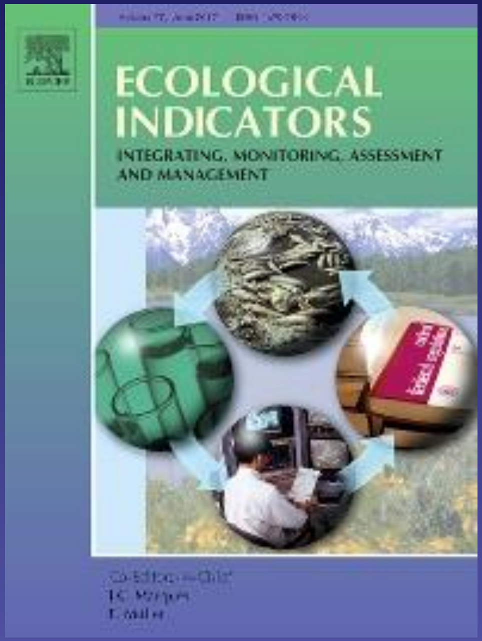
Dauer et al. 2011. VADEQ Technical Report
Sturdivant et al. 2014. Estuaries and Coasts

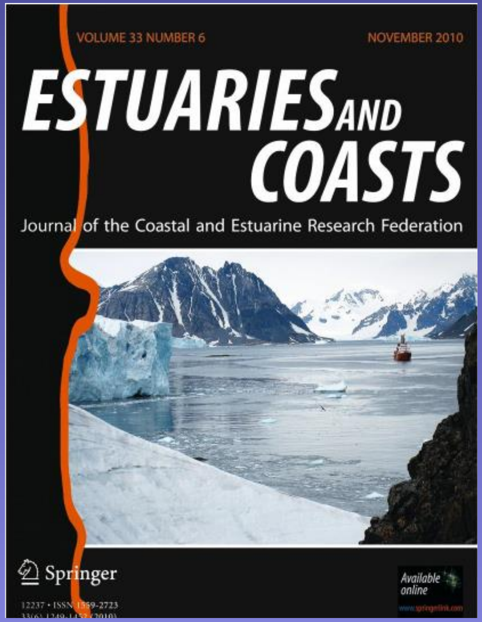
(8) BIBI recalibration

(Llansó, et al. 2016. **VADEQ Technical Report**
de-la-Ossa et al. 2016. Ecological Indicators)

(9) International collaboration

(Borja and Dauer. 2008. Ecological Indicators;
Borja et al. 2010. Estuaries and Coasts;
Borja et al. 2012. Ecological Indicators)





(9) International collaboration

(Borja and Dauer. 2008. Ecological Indicators;
Borja et al. 2010. Estuaries and Coasts;
Borja et al. 2012. Ecological Indicators)

ECOLOGICAL INDICATORS 8 (2008) 331–337

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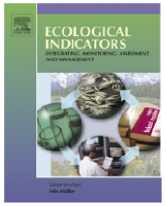

Assessing the environmental quality status in estuarine and coastal systems: Comparing methodologies and indices

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ABSTRACT

Increasingly on a worldwide scale, legislation has been adopted to determine the ecological integrity of surface waters including streams, rivers, lakes, estuaries and coastal waters. An integral part of determining ecological integrity is the measurement of biological integrity, typically emphasizing analyses of plankton, benthos, macroalgae and fish. In the development of protocols for evaluating biological integrity, benthic macroinvertebrate communities are the most consistently emphasized biotic component of aquatic ecosystems. A plethora of methodologies with hundreds of indices, metrics and evaluation tools are presently available. An ecologically parsimonious approach dictates that investigators should place greater emphasis on evaluating the suitability of indices that already exist prior to developing new ones. Hence, the authors organized within the American Society of Limnology and Oceanography 2006 Summer Meeting, 4–9 June 2006, in Victoria, BC, Canada, a special session with the objective to compare methodologies, applications and interpretations existing in various countries and attempting to contribute to an improved understanding of the suitability of such approaches when using benthic communities. From the 25 contributions presented in this session, eight manuscripts were selected to be included in

Index Characteristics

Adaptive Monitoring

Table 1 – Environmental indicators

Purpose
Summarizes and simplifies complex data
Conveys information—easily understood by the public, media, resource users, and decision-makers
Characteristics
Ecological relevance—based upon a conceptual model (theoretically, empirically or heuristically well founded)
Feasible—data to calculate index can be reliably and cost-effectively collected
Threshold or reference value—users are able to assess significance of indicator value
Representative—able to measure status and trends that are relevant to policy decisions
Sensitivity—reflects response to management actions

Note: an index that is representative and sensitive captures information relevant to anthropogenic actions—degradative and restorative.

(9) International collaboration

(Borja and Dauer. 2008. Ecological Indicators;
Borja et al. 2010. Estuaries and Coasts;
Borja et al. 2012. Ecological Indicators)

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Summarize European Water Framework Directive approaches
Ecosystem services and ecosystem function

Index development

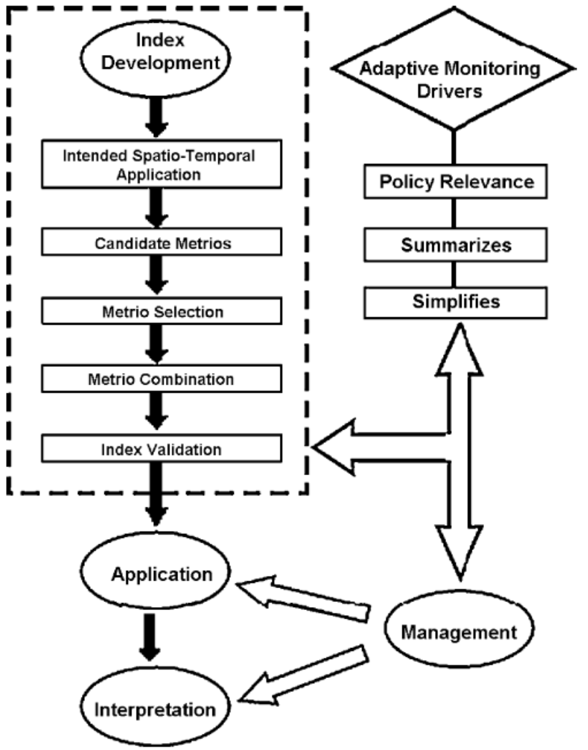


Fig. 2 – Index development, application and interpretation. Dashed rectangle encloses the primary steps in index development. Adaptive monitoring feedback loops and adaptive change decision drivers are indicted by open arrows.

332 ECOLOGICAL INDICATORS 8 (2008) 331–337

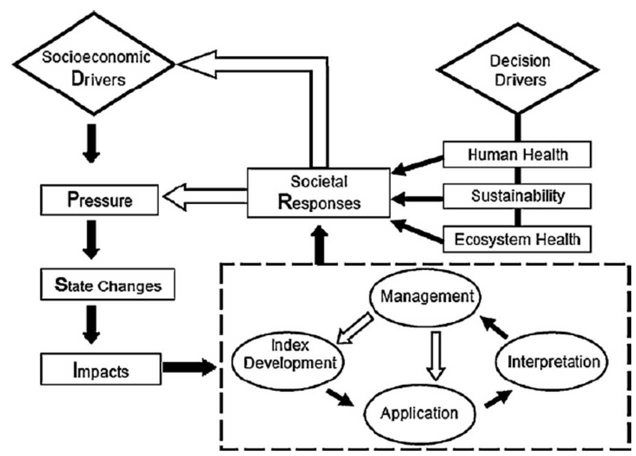
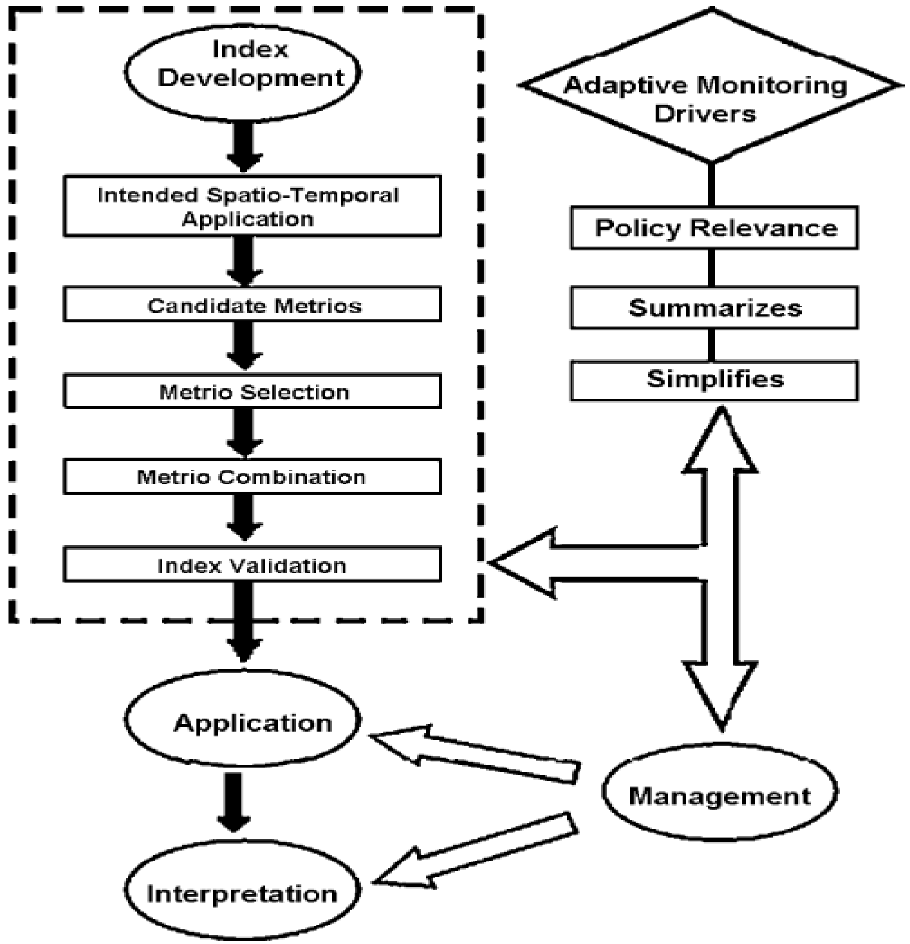


Fig. 1 – The DPSIR approach showing relationships between drivers–pressure–state–impact–responses variables. Also indicated are the primary drivers of management decisions. Societal responses meant to halt, ameliorate, mitigate or reverse unacceptable conditions are shown by open arrows. Dashed inset shows the impact assessment components with open arrows indicating adaptive monitoring feedback loops.

Summarize European Water Framework Directive approaches Ecosystem services and ecosystem function



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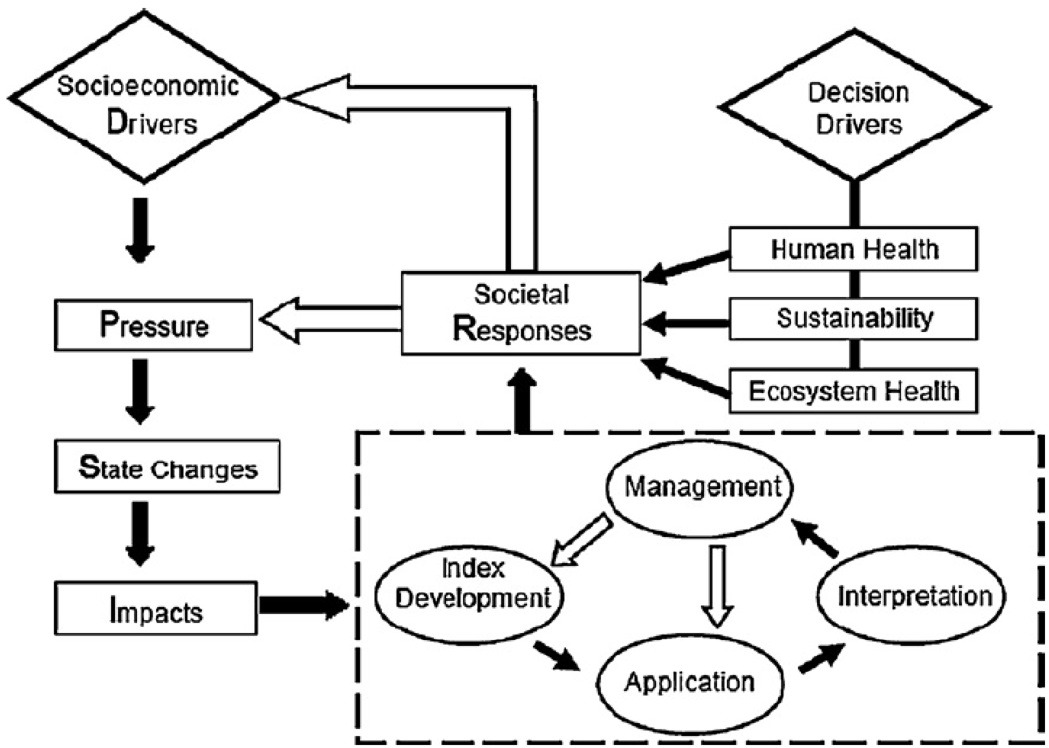
Summarize European Water Framework Directive approaches Ecosystem services and ecosystem function



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Summarize European Water Framework Directive approaches Ecosystem services and ecosystem function

Benthic recovery rates

Estuaries and Coasts (2010) 33:1249–1260
DOI 10.1007/s12237-010-9347-5

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Medium- and Long-term Recovery of Estuarine and Coastal Ecosystems: Patterns, Rates and Restoration Effectiveness

Ángel Borja · Daniel M. Dauer · Michael Elliott · Charles A. Simenstad

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Abstract Many estuarine and coastal marine ecosystems have increasingly experienced degradation caused by multiple stressors. Anthropogenic pressures alter natural ecosystems and the ecosystems are not considered to have

which includes all aspects of dredging and disposal; (2) recovery by complete removal of stressors limiting natural ecosystem processes, which includes tidal marsh and inundation restoration; (3) recovery by speed of organic

Table 1 Long-term monitoring of different anthropogenic pressures, worldwide, in different substrata and tidal levels, using different biological elements, showing the time span of recovery after restoration or removing pressure

Pressure	Location	Substrata	Intertidal/subtidal	Biological elements	Time for recovery	Authors
Sewage sludge disposal	Northumberland coast (UK)	Soft	Subtidal	Macroinvertebrates	>3 years	Birchenough and Frid 2009
Sewage sludge disposal	Garroch Head (Firth of Clyde, Scotland)	Soft	Subtidal	Macroinvertebrates	Incomplete after 14 years	Moore and Rodger 1991
Sewage sludge disposal	Liverpool Bay (UK)	Soft	Subtidal	Macroinvertebrates	Incomplete after 5 years	Whomersley et al. 2007
Wastewater discharge	California (USA)	Soft	Subtidal	Macroinvertebrates	18 years	Stein and Cadien 2009
Wastewater discharge	Boston harbour (USA)	Soft	Subtidal	Macroinvertebrates	10–15 years	Diaz et al. 2008
Wastewater discharge	Basque estuaries (Spain)	Soft	Subtidal	Macroinvertebrates	10–15 years	Borja et al. 2006, 2009b
Wastewater discharge	Marseille (France)	Soft	Subtidal	Macroinvertebrates	>7 years	Bellan et al. 1999
Wastewater discharge	Basque coast (Spain)	Soft/hard	Subtidal	Invertebrates and algae	>6 years	Borja et al. 2009b
Wastewater discharge	Abra of Bilbao (Spain)	Hard	Intertidal	Macroalgae	Incomplete after 22 years	Díez et al. 2009
Wastewater discharge	Basque estuaries (Spain)	Soft	Subtidal	Fishes	3–10 years	Uriarte and Borja 2009
Wastewater discharge	Tagus estuary (Portugal)	Soft	Intertidal/subtidal	Macroinvertebrates	Incomplete after 12 years	Chainho et al. this issue
Eutrophication	Victoria Harbour, Hong Kong	Soft	Subtidal	Macroinvertebrates	>3 years	Shin et al. 2008
Eutrophication	Orbetello lagoon (Italy)	Soft	Subtidal	Macroinvertebrates	>6 years	Lardicci et al. 2001
Eutrophication	Mondego estuary (Portugal)	Soft	Intertidal	Zostera noltii and macroinvertebrates	>4 years	Dolbeth et al. 2007; Neto et al. this issue
Eutrophication	Tampa Bay (Florida, USA)	Soft	Subtidal	Sea grasses	Incomplete after 20 years	Greening and Janicki 2006
Oxygen depletion	Gullmarsfjord (Sweden)	Soft	Subtidal	Macroinvertebrates	2 years	Rosenberg et al. 2002
Oil spill	Various	Soft/hard	Intertidal/subtidal	Various	2–10 years	Kingston 2002
Oil-refinery discharge	Barbadun estuary (Spain)	Soft	Intertidal	Macroinvertebrates	2–3 years	Borja et al. 2009b
Oil-refinery discharge	Milford Haven (UK)	Hard	Intertidal	Macroinvertebrates	2–3 years	Wake 2005
Oil-refinery discharge	Barbadun estuary (Spain)	Soft	Subtidal	Fishes	2–3 years	Uriarte and Borja 2009
Fish farm	Archipelago Sea (Finland)	Soft	Subtidal	Macroinvertebrates	Incomplete after 7 years	Kraufvelin et al. 2001
Fish farm	Hornillo Cove (Mediterranean, Spain)	Soft	Subtidal	Macroinvertebrates	2–3 years	Sanz-Lázaro and Marín 2006
Fish farm	Tasmania (Australia)	Soft	Subtidal	Macroinvertebrates	>2.5 years	Macleod et al. 2008
TBT	Crouch Estuary, Essex (UK)	Soft	Subtidal	Macroinvertebrates	3–5 years	Smith et al. 2008
Mine tailings	Rupert Inlet, British Columbia (Canada)	Soft	Subtidal	Macroinvertebrates	4–15 years	Burd 2002
Mine tailings	Affarlikassa and Quaamarujuk (Greenland)	Soft	Subtidal	Macroinvertebrates	>15 years	Josefson et al. 2008
Pulp mill	Swedish fjord	Soft	Subtidal	Macroinvertebrates	6–8 years	Rosenberg 1972, 1976
Physical disturbance	South Africa	Hard	Intertidal	Macroinvertebrates	3 years	Dye 1998
Physical disturbance	Peru Basin	Soft/hard	Deep sea	Megafauna	Incomplete after 7 years	Bluhm 2001
Land claim	Bidasoa estuary (Spain)	Soft	Intertidal	Macroinvertebrates	2 years	Marquiegui and Aguirrezabalaga 2009
Land claim	Nakdong River estuary (Korea)	Soft	Subtidal	*Zostera marina*	Incomplete after 20 years	Park et al. 2009
Marsh restoration	Delaware Bay (USA)	Soft	Subtidal	Fishes	1–2 years	Able et al. 2008
Marsh and tidal restoration	Long Island Sound (USA)	Soft	Intertidal/subtidal	Vegetation, macroinvertebrates, fishes, birds	5–20 years	Warren et al. 2002
Realignment of coastal defences	Tollesbury, Essex (UK)	Soft	Intertidal	Marshes and macroinvertebrates	>6 years	Garbutt et al. 2006
Lagoon isolation	East Harbor, Massachusetts (USA)	Soft	Subtidal	Molluscs	Incomplete after 3 years	Thelen and Thiet 2009
Lagoon isolation	Lake Veere (Netherlands)	Soft	Intertidal/subtidal	Macroinvertebrates	Incomplete after 4 years	Wijnhoven et al. this issue
Dyke and marina construction	Oria estuary (Spain)	Soft	Intertidal	Macroinvertebrates	2 years	Borja et al. 2009b
Dyke and marina construction	Oria estuary (Spain)	Soft	Subtidal	Fishes	2–3 years	Uriarte and Borja 2009
Dredging and sediment disposal	Basque coast and estuaries (Spain)	Soft	Subtidal	Macroinvertebrates	2–3 years	Borja et al. 2009b

Summarize European Water Framework Directive approaches Ecosystem services and ecosystem function

Table 2 Summary of time for recovery, for different biological elements and substrata, under different pressures

Pressure	Substrata	Intertidal/subtidal	Biological elements	Time for recovery
Sediment disposal	Soft	Intertidal	Meio and macrofauna	3–18 months
Marsh restoration	Soft	Subtidal	Fishes	1–2 years
Oxygen depletion	Soft	Subtidal	Macroinvertebrates	2 years
Land claim	Soft	Intertidal	Macroinvertebrates	2 years
Oil-refinery discharge	Soft/hard	Intertidal/subtidal	Macroinvertebrates, fishes	2–3 years
Dyke and marina construction	Soft	Intertidal/subtidal	Macroinvertebrates, fishes	2–3 years
Lagoon isolation	Soft	Subtidal	Molluscs	>3 years
Aggregate dredging	Soft	Subtidal	Macroinvertebrates, epifauna	2–4 years
TBT	Soft	Subtidal	Macroinvertebrates	3–5 years
Dredging	Soft	Intertidal/subtidal	Sea grasses, macroinvertebrates, fishes	2–>5 years
Sediment disposal	Soft	Subtidal	Sea grass, macroinvertebrates, fishes	>5 years
Eutrophication	Soft	Subtidal	Macroinvertebrates	>3–>6 years
Realignment of coastal defences	Soft	Intertidal	Marshes and macroinvertebrates	>6 years
Fish farm	Soft	Subtidal	Macroinvertebrates	2–>7 years
Physical disturbance	Soft/hard	Intertidal/deep sea	Macroinvertebrates, megafauna	3–>7 years
Pulp mill	Soft	Subtidal	Macroinvertebrates	6–8 years
Oil spill	Soft/hard	Intertidal/subtidal	Various	2–10 years
Fish trawling	Sand–gravel	Subtidal	Macroinvertebrates, fishes	2.5–10 years
Wastewater discharge	Soft	Subtidal	Fishes	3–10 years
Sewage sludge disposal	Soft	Subtidal	Macroinvertebrates	3–>14 years
Mine tailings	Soft	Subtidal	Macroinvertebrates	4–>15 years
Marsh and tidal restoration	Soft	Intertidal/subtidal	Vegetation, fishes, birds	5–20 years
Wastewater discharge	Soft	Subtidal	Macroinvertebrates, sea grasses	7–20 years
Land claim	Soft	Subtidal	*Zostera marina*	>20 years
Wastewater discharge	Hard	Intertidal	Macroalgae	>6–>22 years

Summarize European Water Framework Directive approaches
Ecosystem services and ecosystem function

Benthic recovery rates

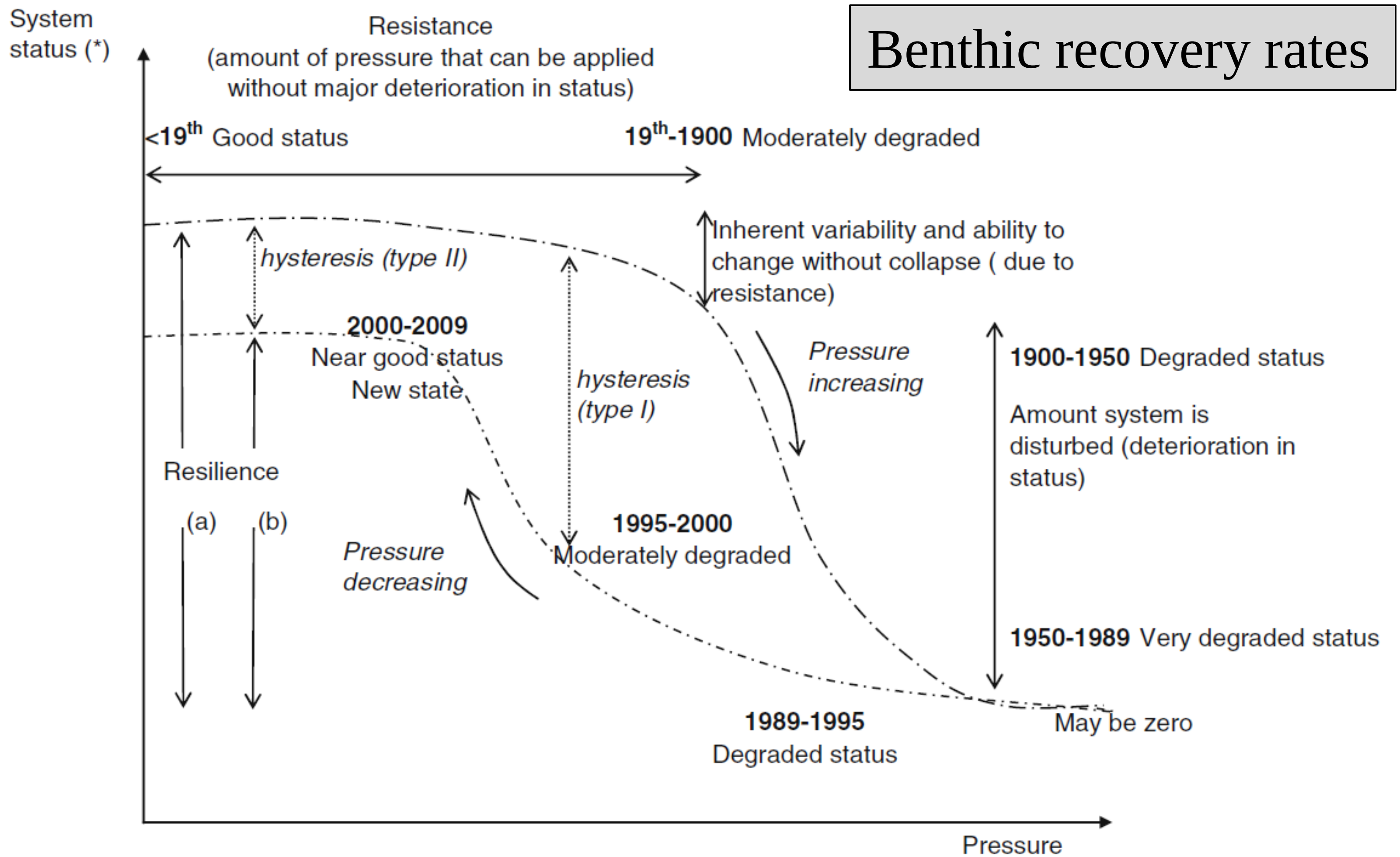

Fig. 2 A conceptual model of changes to the state of Nervión estuary (Basque Country, northern Spain) with increasing (increasing wastewater discharge volume) and decreasing (wastewater treatment improvement) pressure (adapted from Elliott et al. (2007)). (*a*) Complete resilience; (*b*) incomplete resilience

Summarize European Water Framework Directive approaches
Ecosystem services and ecosystem function

Reference Conditions

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The importance of setting targets and reference conditions in assessing marine ecosystem quality

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ABSTRACT

Assessing benthic quality status of marine and transitional water habitats requires to set up both: (i) tools (i.e. indices) to assess the relative quality of the considered habitat, and (ii) reference conditions for which such indices can be computed and used to infer the absolute ecological status (ES) of the considered habitat. The development of indices, their comparison and the assessment of the causes of their discrepancies have been largely discussed but less attention has been paid to the methods used for the setting of adequate reference conditions, although this step is clearly crucial for the sound assessment of ES. This contribution reviews the approaches available in setting both reference conditions (pristine areas, hindcasting, modelling and best professional judgment) and targets (baseline set in the past, current baseline and directional/trends). We scored the use of pristine or minimally impacted conditions as the best single method; however, the other methods were judged as adequate then combined with best professional judgment. The case of multivariate AMBI (AZTI's Marine Biotic Index) is used to highlight the importance of setting correct reference conditions. Hence, data from 29 references, including 14 countries from Europe and North America, and both coastal (15 cases) and transitional (17 cases) waters, have been used to study the response of multivariate AMBI to human pressures. Results show that the inability of this index to detect human pressure is in most cases linked with the use of inappropriate methods for setting reference conditions.

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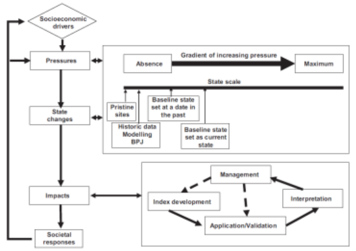
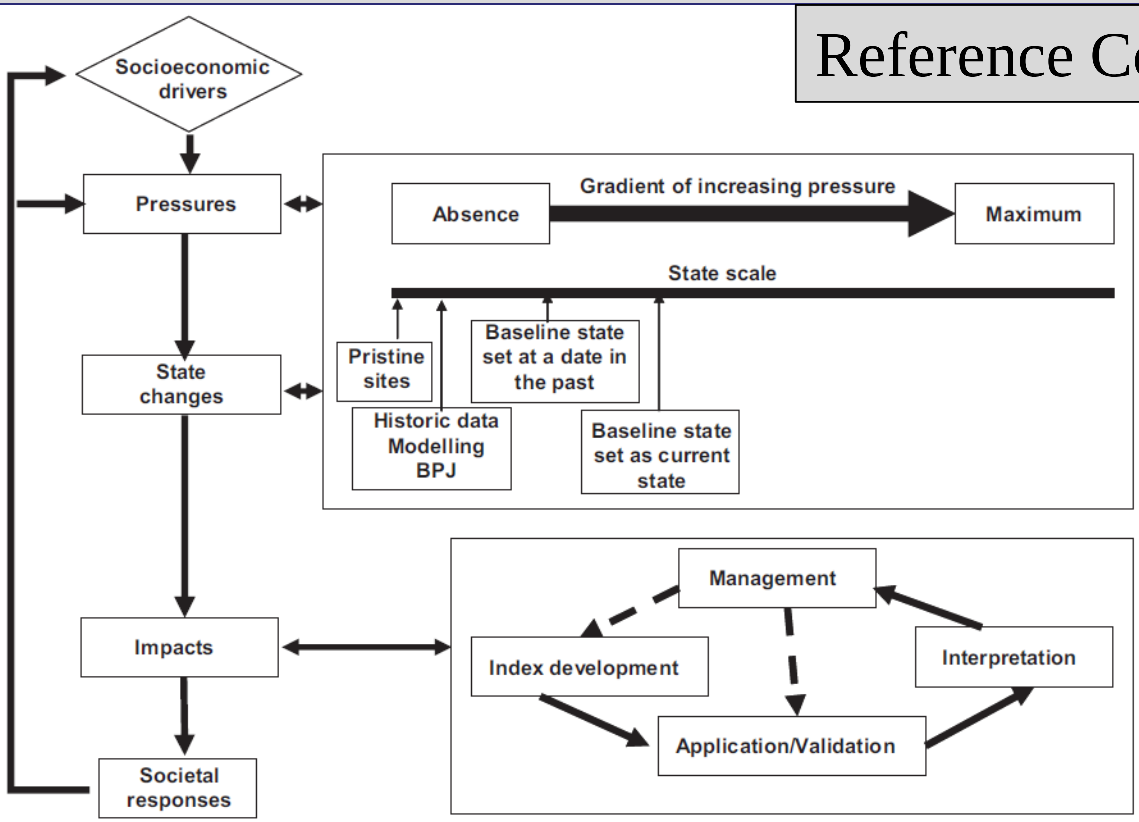


Fig. 1. The DPSIR approach showing relationships between Drivers-Pressure-State of change-Impact-Responses variables, in assessing environmental quality status in marine waters. Environmental status can be considered as a gradation from pristine conditions (high status in absence of human pressures) to an irrecoverable status (bad status, in a maximum human pressure). Assessment systems need to set reference conditions or baseline targets along the pressure (and subsequent state) gradient to assist in status assessment and for monitoring progress against time and actions. In this step the development and validation of impact assessment methods is needed.
Adapted from Borja and Dauer (2008) and Cochrane et al. (2010). BPJ—best professional judgment.

Summarize European Water Framework Directive approaches
Ecosystem services and ecosystem function

Reference Conditions



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Adapted from Borja and Dauer (2008) and Cochrane et al. (2010). BPJ—best professional judgment.

Summarize European Water Framework Directive approaches Ecosystem services and ecosystem function

The development of indices, their comparison and the assessment of the causes of their discrepancies have been largely discussed but less attention has been paid to the methods used for the setting of adequate reference conditions, although this step is clearly crucial for the sound assessment of ES.

This contribution reviews the approaches available in setting both reference conditions:

Pristine areas
Hindcasting
Modelling and
Best Professional Judgment

and targets:

Baseline set in the past
Current baseline and
Directional/trends

We scored the use of pristine or minimally impacted conditions as the best single method.

Benthic Indicators, Monitoring Design and Interpretation Issues

Overview

Chesapeake Bay accomplishments

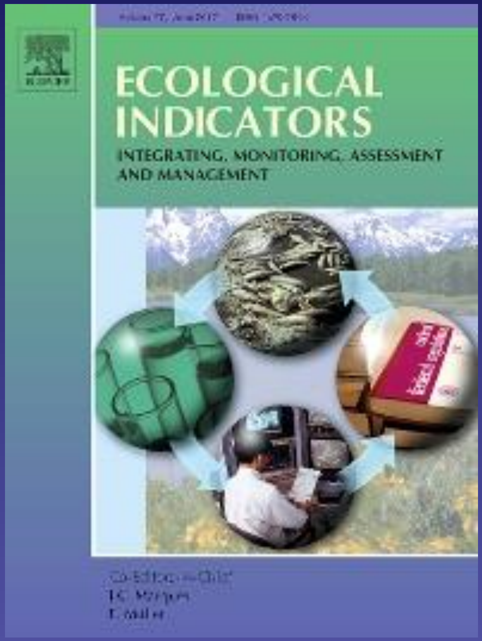
1. Index development
2. Index relationship to watershed stressors
3. Sample allocation
4. Index relationship to habitat quality
5. Causes of degradation (diagnostics)
6. Impaired waters designations – 303(d)
7. Functional metric/index (Secondary productivity)
8. BIBI recalibration
9. International collaboration

(9) International collaboration

(Borja and Dauer. 2008. Ecological Indicators;
Borja et al. 2010. Estuaries and Coasts;
Borja et al. 2012. Ecological Indicators)

(10) Index comparisons - Chesapeake Bay

(Ranasinghe et al. 2002. Environmetrics;
Llanso et al. 2009. Environmental Monitoring and Assessment;
Borja et al. 2008. Ecological Indicators)



(10) Index comparisons - Chesapeake Bay

(Ranasinghe et al. 2002. Environmetrics)

ENVIRONMETRICS
Environmetrics 2002; **13**: 499–511 (DOI: 10.1002/env.529)

Application of two indices of benthic community condition in Chesapeake Bay

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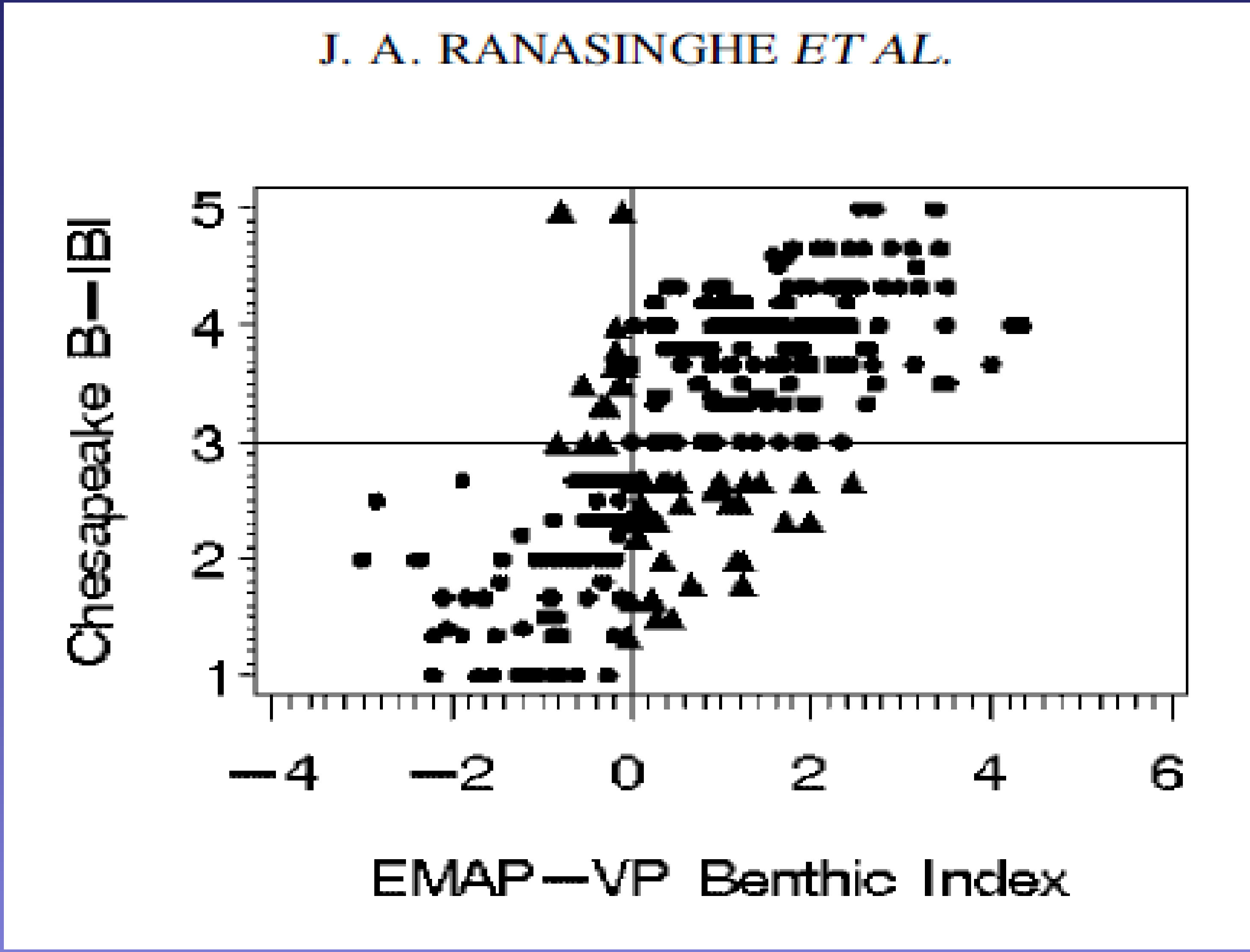
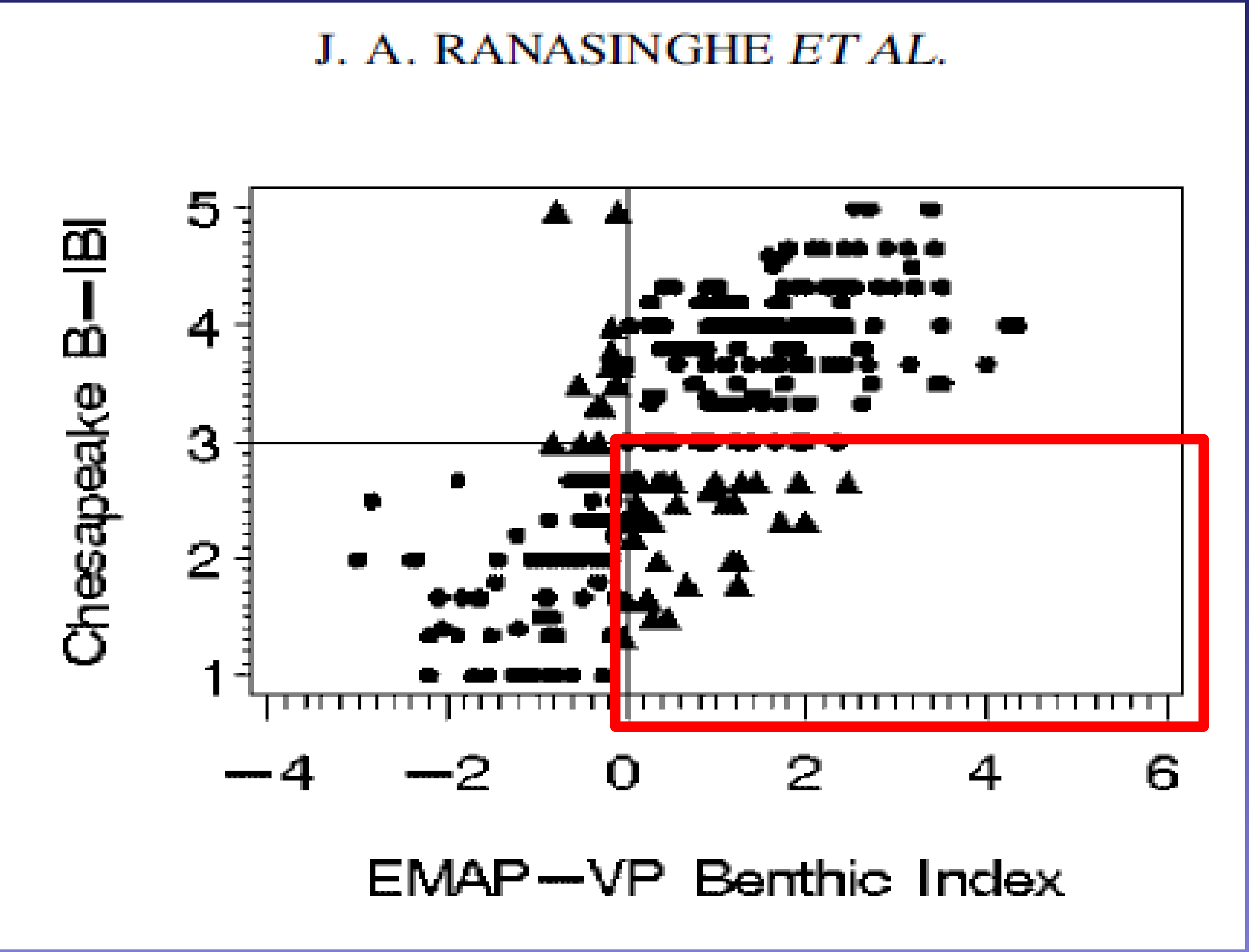
(10) Index comparisons - Chesapeake Bay

(Ranasinghe et al. 2002. Environmetrics)



(10) Index comparisons - Chesapeake Bay

(Ranasinghe et al. 2002. Environmetrics)



(10) Index comparisons - Chesapeake Bay

(Ranasinghe et al. 2002. Environmetrics)

1. **B-IBI** includes several community measures and weights them equally using a simple scoring system that compares them against values expected for undegraded sites. It includes measures of species diversity, productivity, indicator species and trophic composition.

2. **The EMAP-VP** BI uses discriminant function coefficients to weight contributions of species diversity and the abundances of two indicator families.

3. **The two indices agreed** on degraded or undegraded classifications for benthos **at 81.3%** of the sites.

4. The **B-IBI** was **more conservative** than the EMAP-VP BI, **classifying 72.7% of the disagreements as degraded.** Many of the classification disagreements were at sites with index values close to, but on opposite sides of, the degraded–undegraded thresholds

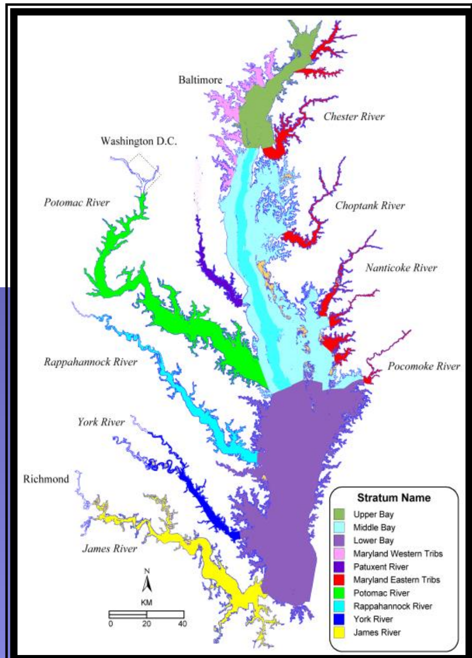
(10) Index comparisons - Chesapeake Bay

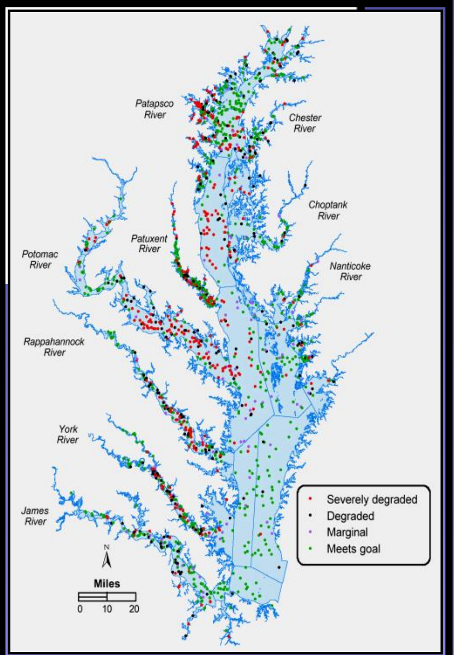
(Llanso et al. 2009. Environmental Monitoring and Assessment)

Environ Monit Assess (2009) 150:119–127
DOI 10.1007/s10661-008-0678-7

Assessing benthic community condition in Chesapeake Bay: does the use of different benthic indices matter?

Roberto J. Llansó · Jon H. Vølstad · Daniel M. Dauer · Jodi R. Dew





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Assessing benthic community condition in Chesapeake Bay: does the use of different benthic indices matter?

Roberto J. Llansó · Jon H. Vølstad · Daniel M. Dauer · Jodi R. Dew

Compared (1) BIBI, (2) MAIA, and (3) EMAP_VP

1. Higher level of degradation with BIBI
2. Other indices classified degraded samples as good at higher rate
3. There were sample design interactions with level of degradation.

(10) Index comparisons - Chesapeake Bay

(Llanso et al. 2009. Environmental Monitoring and Assessment)

Environ Monit Assess (2009) 150:119–127 123

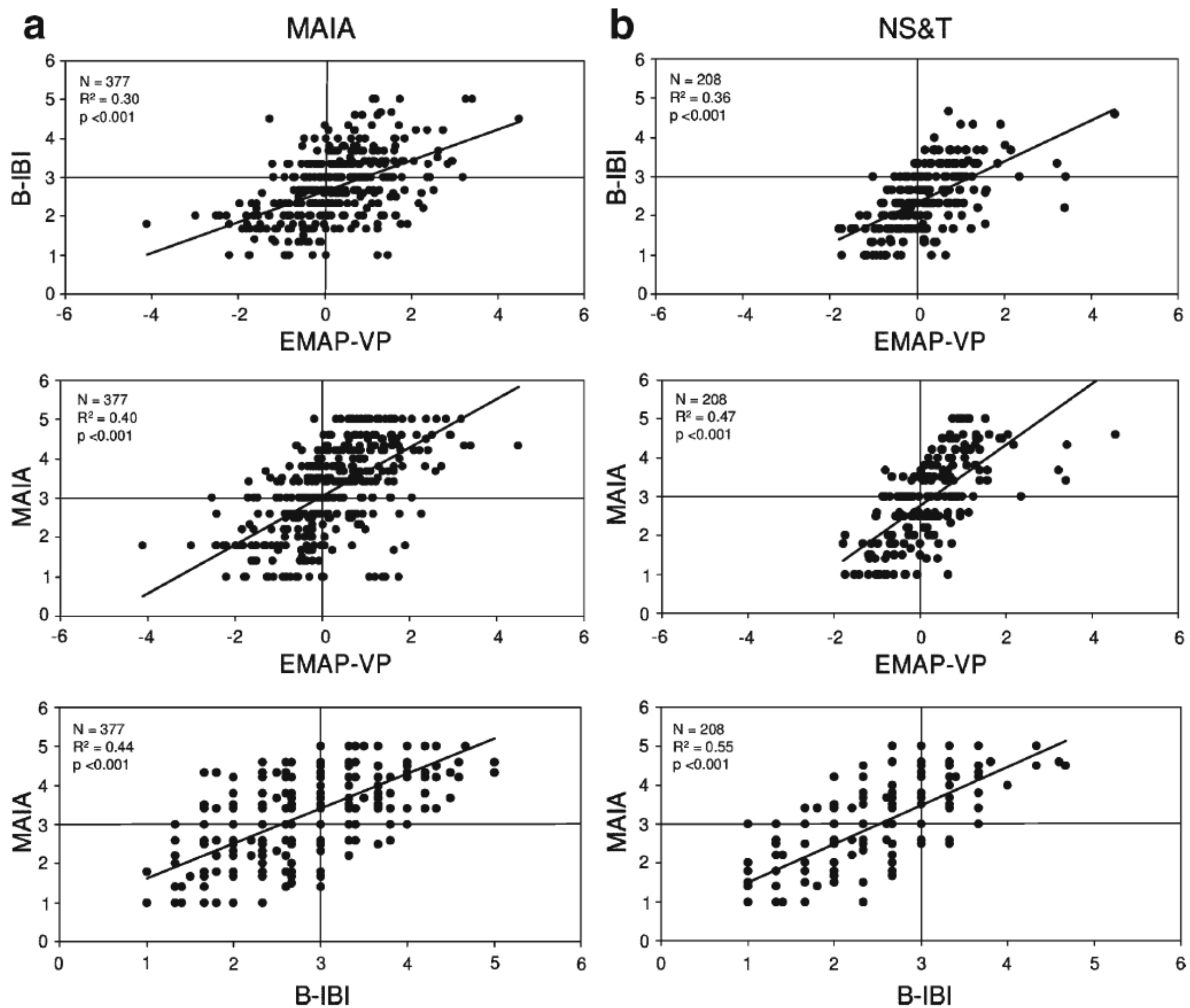


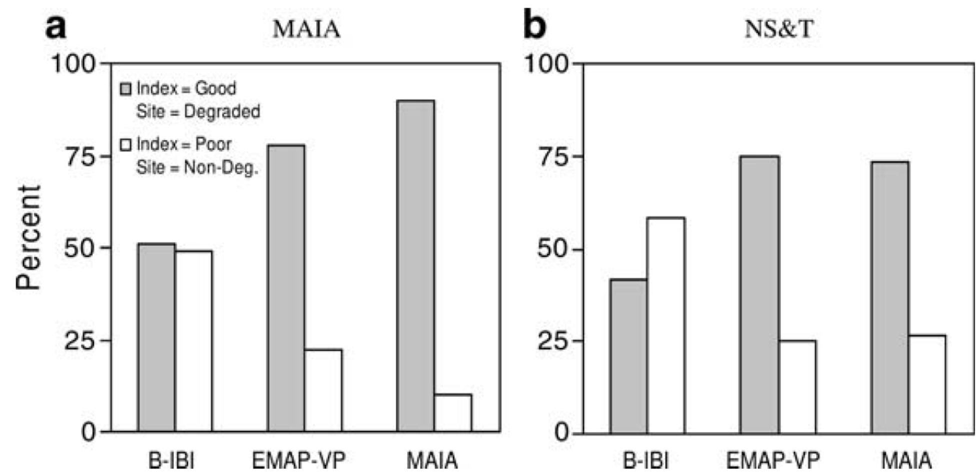
Fig. 1 Linear regressions between the values of three indices calculated on the Chesapeake Bay Mid-Atlantic Integrated Assessment (MAIA) (**a**) and National Status & Trends (NS&T) (**b**) survey datasets. Reference lines indicate degraded/nondegraded thresholds

(10) Index comparisons - Chesapeake Bay

(Llanso et al. 2009. Environmental Monitoring and Assessment)

Environ Monit Assess (2009) 150:119–127

Fig. 5 Percent of Type I and Type II errors (sites misclassified) by three indices, for Mid-Atlantic Integrated Assessment (MAIA) (**a**) and National Status & Trends (NS&T) (**b**) survey datasets



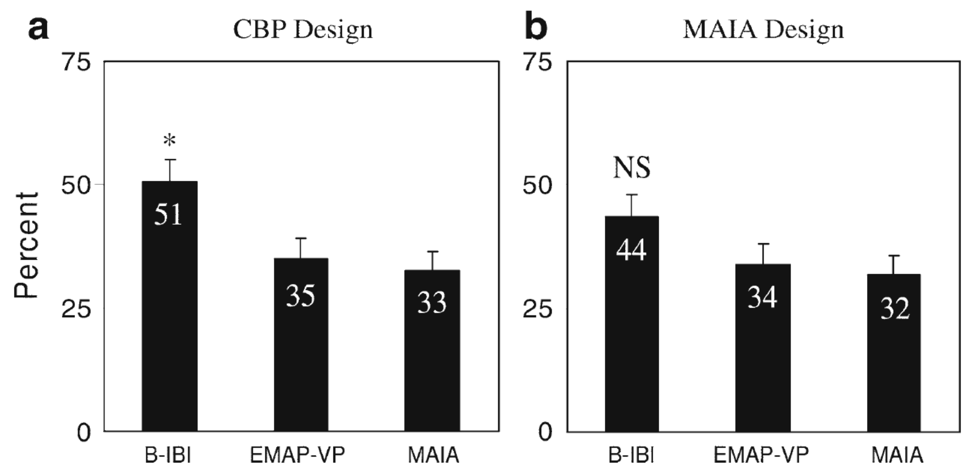


Fig. 6 Percent of Chesapeake Bay (+SE) with degraded benthic condition as measured by three indices, for Chesapeake Bay Program (CBP) (**a**) and Mid-Atlantic Integrated Assessment (MAIA) (**b**) survey designs. *N* = 250 and 244, respectively. * Significant difference by confidence interval overlap test, *NS* not significant

(10) Index comparisons - Chesapeake Bay

(Borja et al. 2008. Ecological Indicators)

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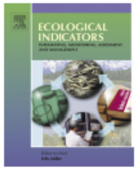

Assessing estuarine benthic quality conditions in Chesapeake Bay: A comparison of three indices

A. Borja [a,*], D.M. Dauer [b], R. Díaz [c], R.J. Llansó [d], I. Muxika [a], J.G. Rodríguez [a], L. Schaffner [c]

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ABSTRACT

Legislation in US and Europe has been adopted to determine the ecological integrity of estuarine and coastal waters, including, as one of the most relevant elements, the benthic macroinvertebrate communities. It has been recommended that greater emphasis should be placed on evaluating the suitability of existing indices prior to developing new ones. This study compares two widely used measures of ecological integrity, the Benthic Index of Biotic Integrity (B-IBI) developed in USA and the European AZTI's Marine Biotic Index (AMBI) and its multivariate extension, the M-AMBI. Specific objectives were to identify the frequency, magnitude, and nature of differences in assessment of Chesapeake Bay sites as 'degraded' or

Table 5 – Correlation coefficients between indices, environmental and structural parameters, by salinity zone

	Polyhaline (30)	High mesohaline (99)	Low mesohaline (102)	Oligohaline (26)	Tidal freshwater (18)
AMBI–M-AMBI	−**0.887**	−**0.897**	−**0.884**	−0.513	−0.472
AMBI–B-IBI	−**0.615**	−**0.617**	−**0.591**	−0.413	−0.500
M-AMBI–B-IBI	**0.743**	**0.744**	**0.651**	0.255	0.441
AMBI–Depth	0.562	0.517	0.233	−0.522	−0.469
AMBI–Salinity	−0.217	−0.058	0.130	−0.060	−0.541
AMBI–Oxygen	−**0.591**	−**0.462**	−**0.404**	0.047	−0.345
AMBI–TOC	−0.108	**0.482**	**0.388**	0.113	−0.300
AMBI–Silt/Clay	−0.016	0.281	**0.369**	−0.025	−0.132
AMBI–Richness	−**0.634**	−**0.714**	−**0.655**	−0.084	−0.021
AMBI–Diversity	−**0.615**	−**0.753**	−**0.759**	−0.154	−0.151
M-AMBI–Depth	−0.316	−**0.570**	−**0.449**	0.294	−0.188
M-AMBI–Salinity	0.265	0.110	−0.244	0.232	0.161
M-AMBI–Oxygen	0.388	**0.547**	**0.524**	−0.142	0.611
M-AMBI–TOC	0.037	−**0.594**	−**0.499**	−0.353	−0.301
M-AMBI–Silt/Clay	−0.024	−**0.445**	−**0.483**	−0.337	−0.292
M-AMBI–Richness	**0.836**	**0.922**	**0.881**	**0.837**	**0.850**
M-AMBI–Diversity	**0.831**	**0.931**	**0.918**	**0.863**	**0.884**
B-IBI–Depth	−0.116	−**0.557**	−**0.370**	0.260	0.226
B-IBI–Salinity	**0.571**	−0.105	−0.290	−0.347	0.165
B-IBI–Oxygen	0.328	**0.624**	**0.359**	0.217	0.064
B-IBI–TOC	−0.218	−**0.381**	−0.219	−0.442	0.012
B-IBI–Silt/Clay	−0.242	−0.239	−0.240	−0.204	0.116
B-IBI–Richness	**0.754**	**0.661**	**0.517**	−0.084	0.240
B-IBI–Diversity	**0.533**	**0.773**	**0.657**	0.278	0.304

Bold and underlined numbers are significant at $p < 0.001$; underlined numbers are significant at $p < 0.01$. Number of sites in parentheses.

Table 3 – Number of sites classified as meets goal, marginal, degraded, and very degraded by the B-IBI and the M-AMBI

	M-AMBI				Total
	Meets goal	Marginal	Degraded	Severely degraded	
B-IBI					
Meets Goal	63 (44)	14 (11)	17 (11)	4 (1)	98 (67)
Marginal	5 (5)	8 (8)	4 (3)	2 (1)	19 (17)
Degraded	31 (26)	17 (16)	18 (16)	10 (9)	76 (67)
Very degraded	7 (7)	10 (10)	27 (24)	38 (38)	82 (79)
Total	106 (82)	49 (45)	66 (54)	54 (49)	275 (230)

Numbers in parentheses exclude tidal freshwater and oligohaline sites.

(10) Index comparisons - Chesapeake Bay

(Borja et al. 2008. Ecological Indicators)

ECOLOGICAL INDICATORS 8 (2008) 395–403

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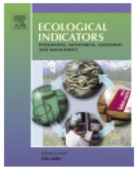

Assessing estuarine benthic quality conditions in Chesapeake Bay: A comparison of three indices

A. Borja [a,*], D.M. Dauer [b], R. Díaz [c], R.J. Llansó [d], I. Muxika [a], J.G. Rodríguez [a], L. Schaffner [c]

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ABSTRA

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Table 5 – Correlation coefficients between indices, environmental and structural parameters, by salinity zone

	Polyhaline (30)	High mesohaline (99)	Low mesohaline (102)	Oligohaline (26)	Tidal freshwater (18)
AMBI–M-AMBI	**−0.887**	**−0.897**	**−0.884**	−0.513	−0.472
AMBI–B-IBI	**−0.615**	**−0.617**	**−0.591**	−0.413	−0.500
M-AMBI–B-IBI	**0.743**	**0.744**	**0.651**	0.255	0.441
AMBI–Depth	0.562	0.517	0.233	−0.522	−0.469
AMBI–Salinity	−0.217	−0.058	0.130	−0.060	−0.541
AMBI–Oxygen	**−0.591**	**−0.462**	**−0.404**	0.047	−0.345
AMBI–TOC	−0.108	**0.482**	**0.388**	0.113	−0.300
AMBI–Silt/Clay	−0.016	0.281	**0.369**	−0.025	−0.132
AMBI–Richness	**−0.634**	**−0.714**	**−0.655**	−0.084	−0.021
AMBI–Diversity	**−0.615**	**−0.753**	**−0.759**	−0.154	−0.151
M-AMBI–Depth	−0.316	**−0.570**	**−0.449**	0.294	−0.188
M-AMBI–Salinity	0.265	0.110	−0.244	0.232	0.161
M-AMBI–Oxygen	0.388	**0.547**	**0.524**	−0.142	0.611
M-AMBI–TOC	0.037	**−0.594**	**−0.499**	−0.353	−0.301
M-AMBI–Silt/Clay	−0.024	**−0.445**	**−0.483**	−0.337	−0.292
M-AMBI–Richness	**0.836**	**0.922**	**0.881**	**0.837**	**0.850**
M-AMBI–Diversity	**0.831**	**0.931**	**0.918**	**0.863**	**0.884**
B-IBI–Depth	−0.116	**−0.557**	**−0.370**	0.260	0.226
B-IBI–Salinity	**0.571**	−0.105	−0.290	−0.347	0.165
B-IBI–Oxygen	0.328	**0.624**	**0.359**	0.217	0.064
B-IBI–TOC	−0.218	**−0.381**	−0.219	−0.442	0.012
B-IBI–Silt/Clay	−0.242	−0.239	−0.240	−0.204	0.116
B-IBI–Richness	**0.754**	**0.661**	**0.517**	−0.084	0.240
B-IBI–Diversity	**0.533**	**0.773**	**0.657**	0.278	0.304

Bold and underlined numbers are significant at $p < 0.001$; underlined numbers are significant at $p < 0.01$. Number of sites in parentheses.