A Benthic Index for the Nearshore Gulf of Maine: Evaluating Ecological Indicators with Signal Detection Theory

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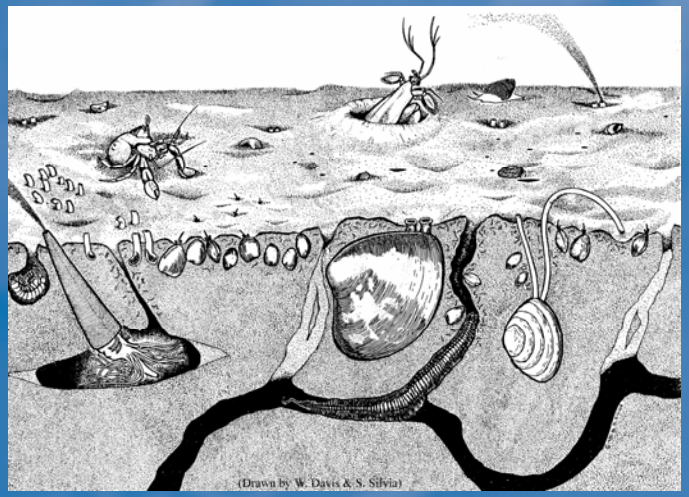
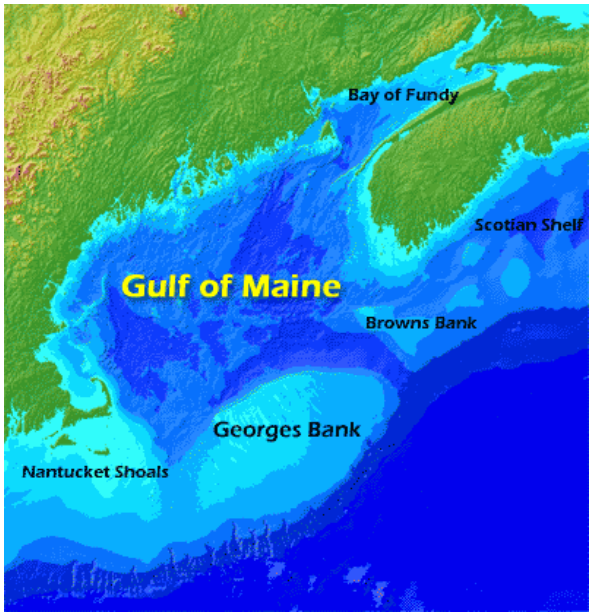
RARGOM Workshop – Nov 15, 2006



Drawn by W. Davis & S. Silvia

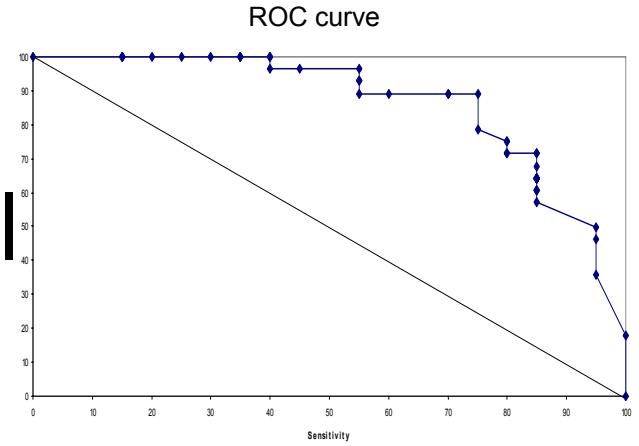
This presentation focuses on:

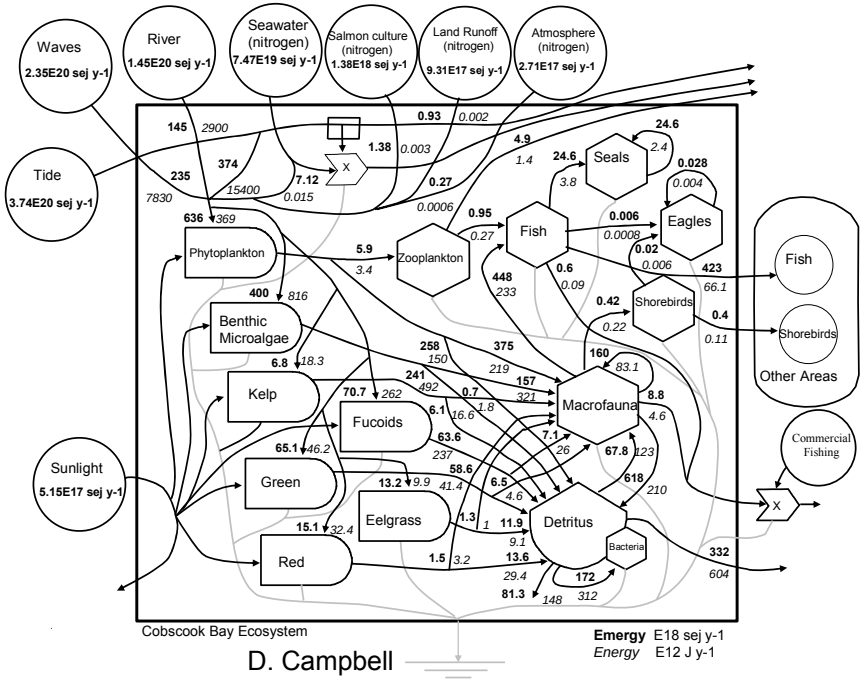
1. Development of a benthic index for the near-shore Gulf of Maine



Credit: GOMMI

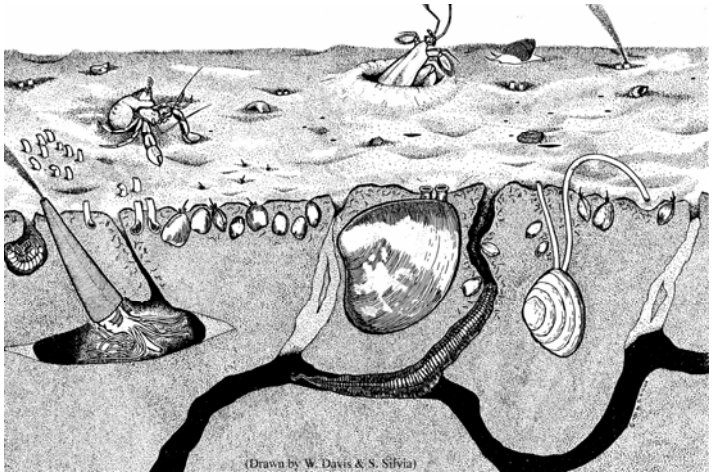
2. Use of signal detection theory, a rigorous standard for evaluating ecological indicators





D. Campbell

Station 3
BI = 2.16



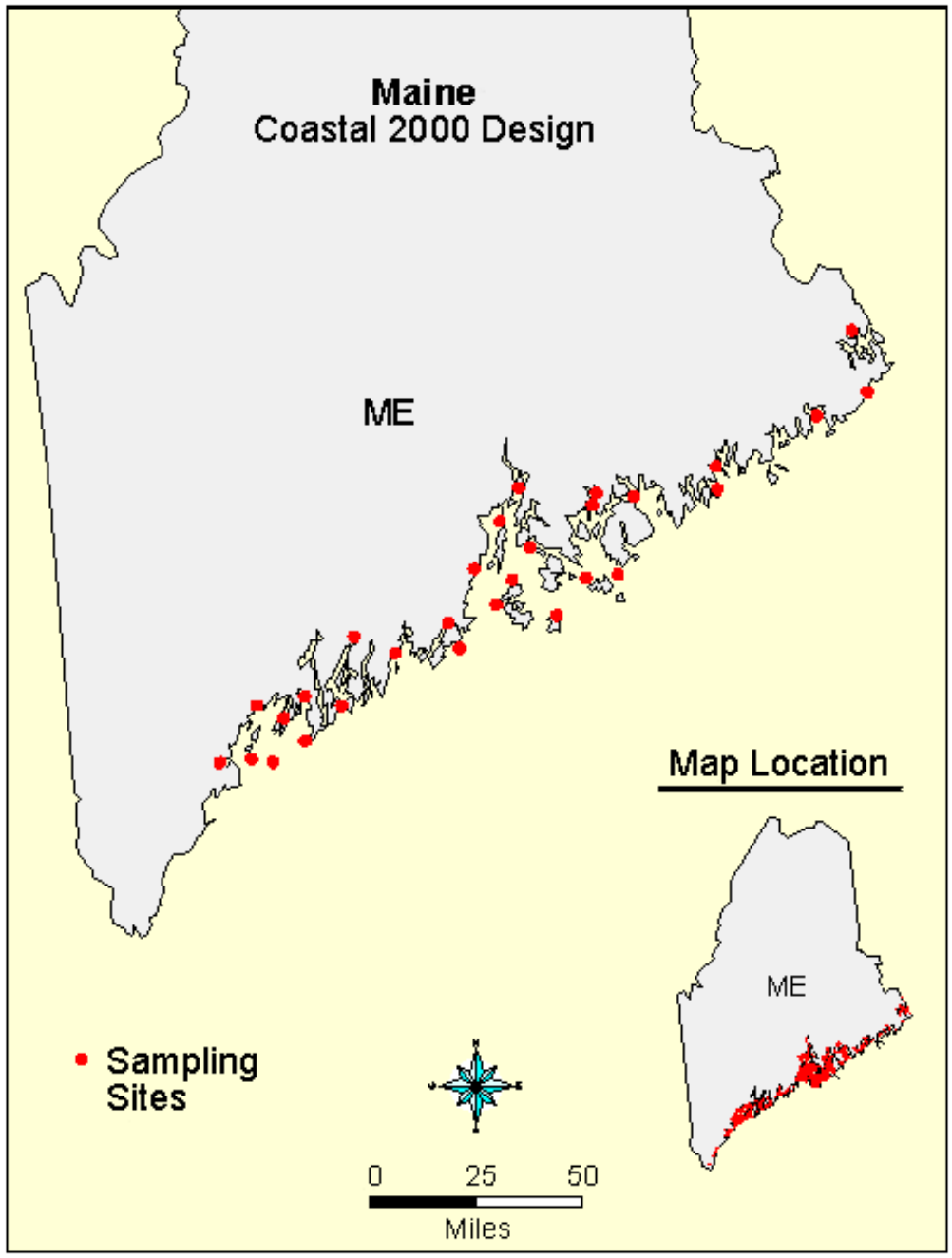
Drawn by W. Davis & S. Silvia

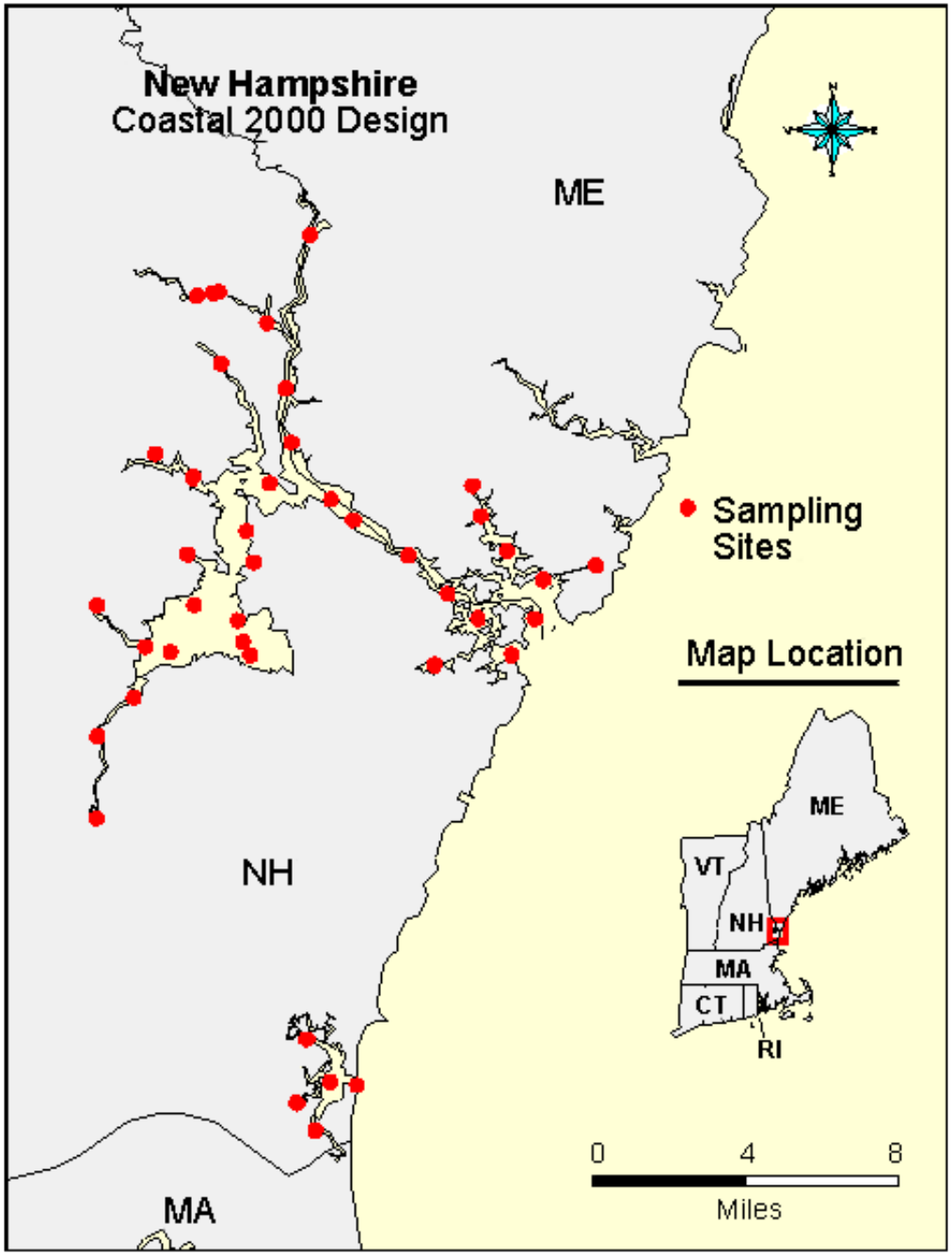
During 2000-2001, states (Maine, New Hampshire, Massachusetts) sampled 182 stations as part of the USEPA's National Coastal Assessment

Nearly 600 benthic invertebrate species

Physical-chemical data in bottom layer of water column

Sediment grain size, TOC, contaminants and sediment toxicity


Maine
Coastal 2000 Design
ME
Map Location
ME
Sampling Sites
0
25
50
Miles


New Hampshire
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NH
MA
Sampling Sites
Map Location
ME
VT
NH
MA
CT
RI
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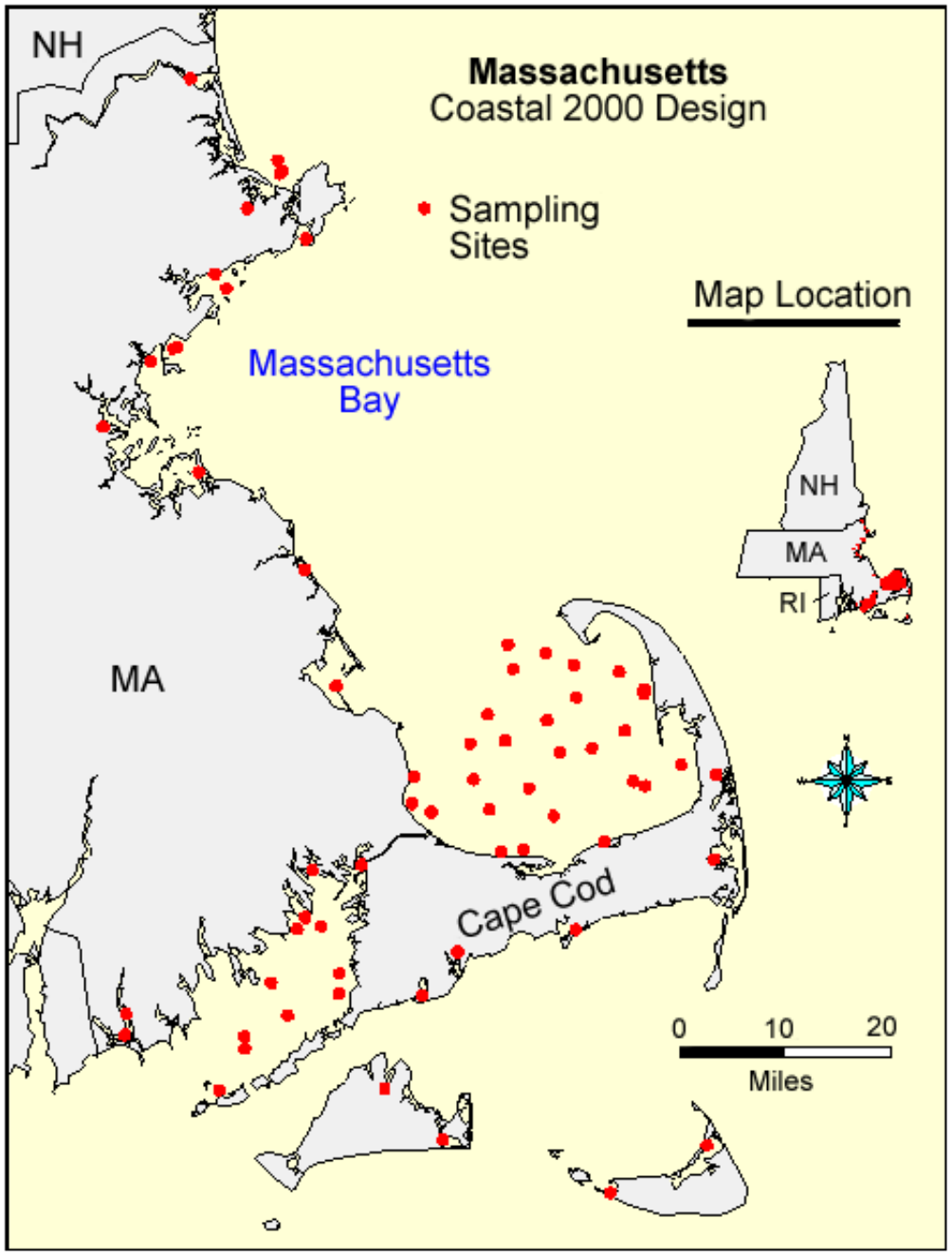
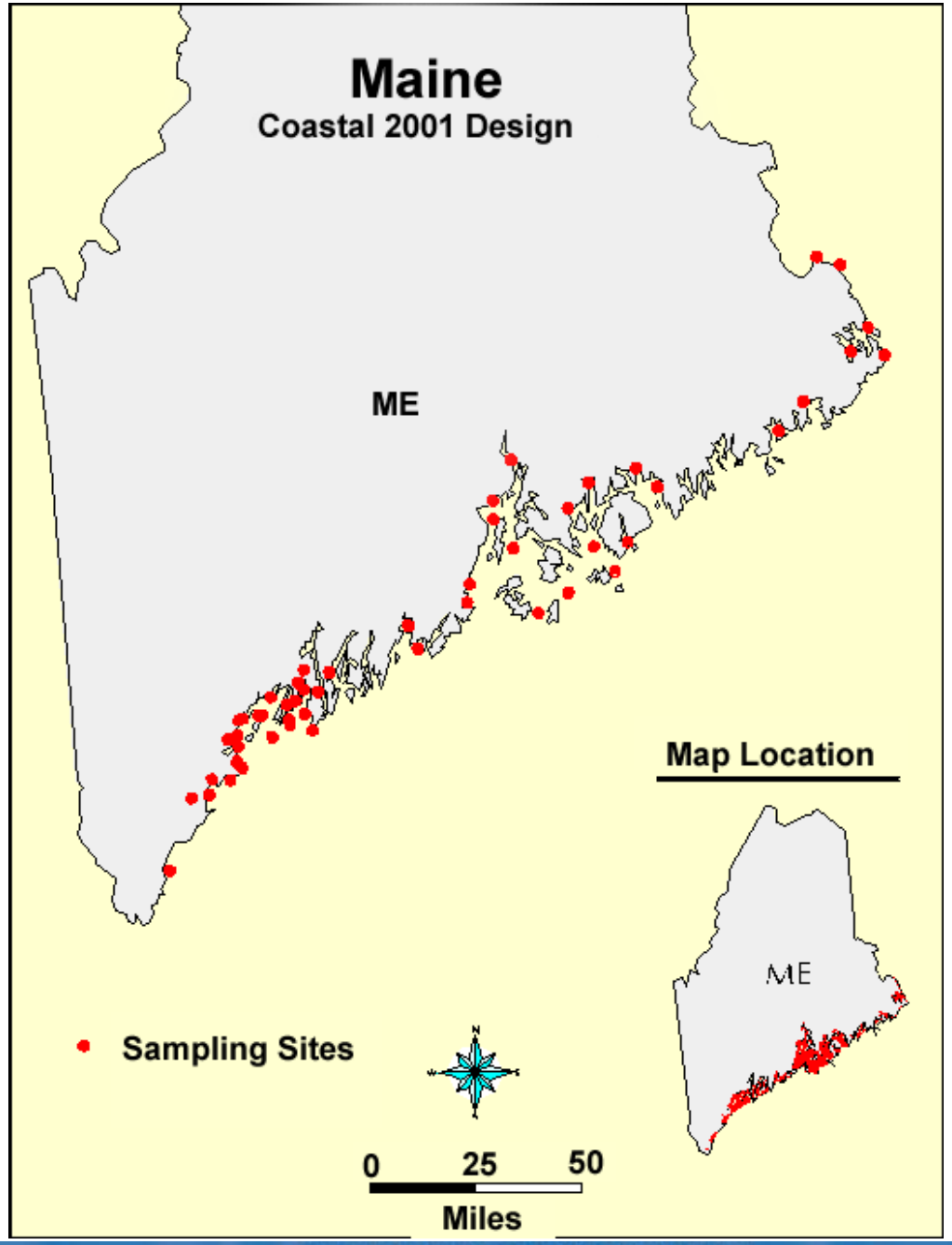
4
8
Miles


NH
Massachusetts
Coastal 2000 Design
Sampling Sites
Map Location
Massachusetts Bay
NH
MA
RI
MA
Cape Cod
0
10
20
Miles


Maine
Coastal 2001 Design
ME
Map Location
ME
Sampling Sites
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25
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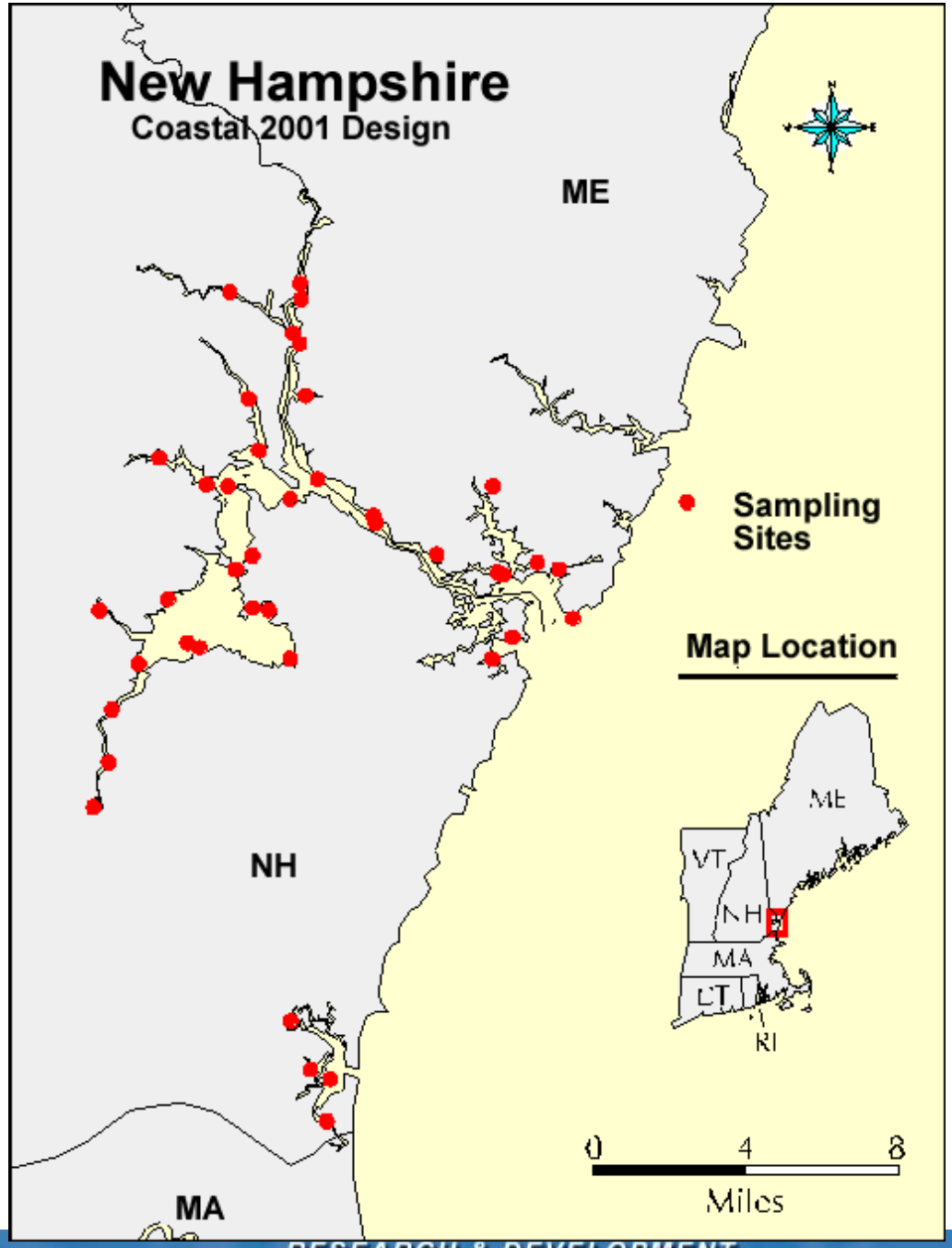
New Hampshire
Coastal 2001 Design
ME
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Sampling Sites
Map Location
ME
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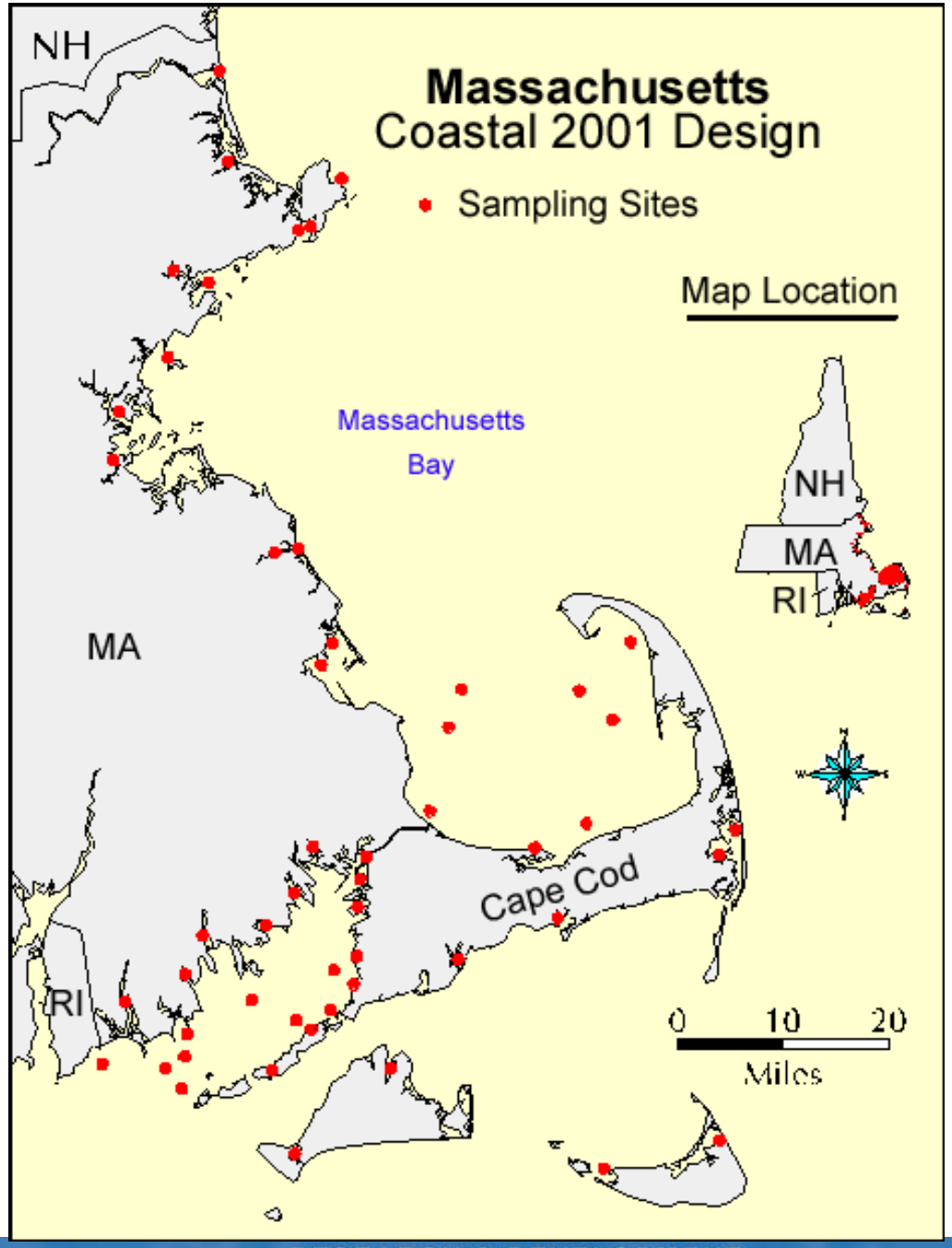
NH
Massachusetts
Coastal 2001 Design
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Massachusetts
Bay
NH
MA
RI
MA
Cape Cod
RI
0
10
20
Miles

Data

Calibration data set:

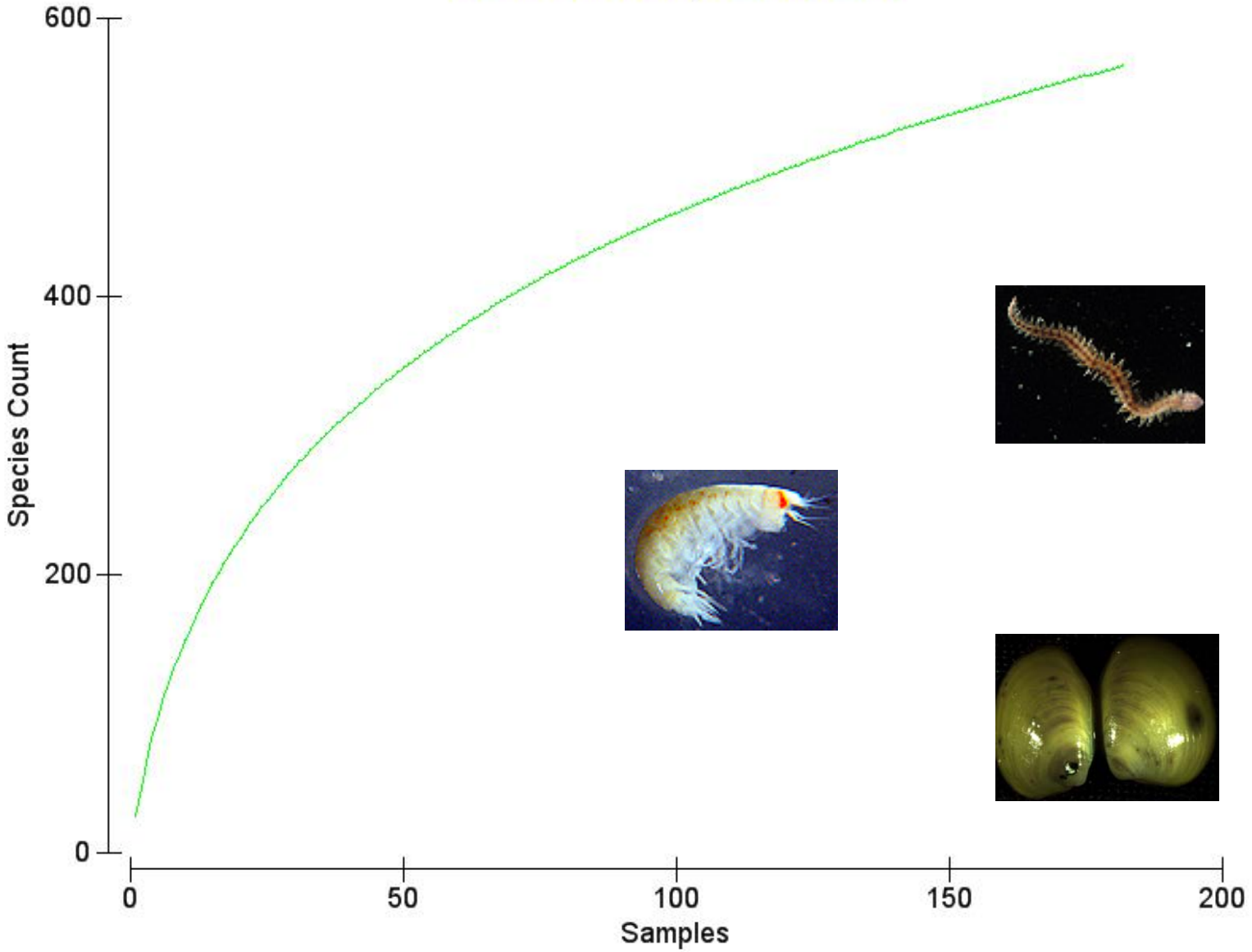
National Coastal Assessment, 2000-2001 (n = 182)

Validation data sets:

1. Massachusetts Water Resources Authority, Mass. Bay, 1991-1994 (n = 49)
2. National Coastal Assessment data, 2002-2003 (n = 67)
3. Larsen et al. (1983) Casco Bay, 1980 (n = 56)

Bottom water. 182 stations.

Gulf of Maine, 2000-2001



Can we use metrics derived from benthic community data to create a multivariate function that accurately predicts a degraded benthic environment?

Benthic Environmental Quality (BEQ)

Candidate benthic metrics (adjusted for habitat effects, such as salinity)

Stepwise logistic regression

Photo: G. Cicchetti

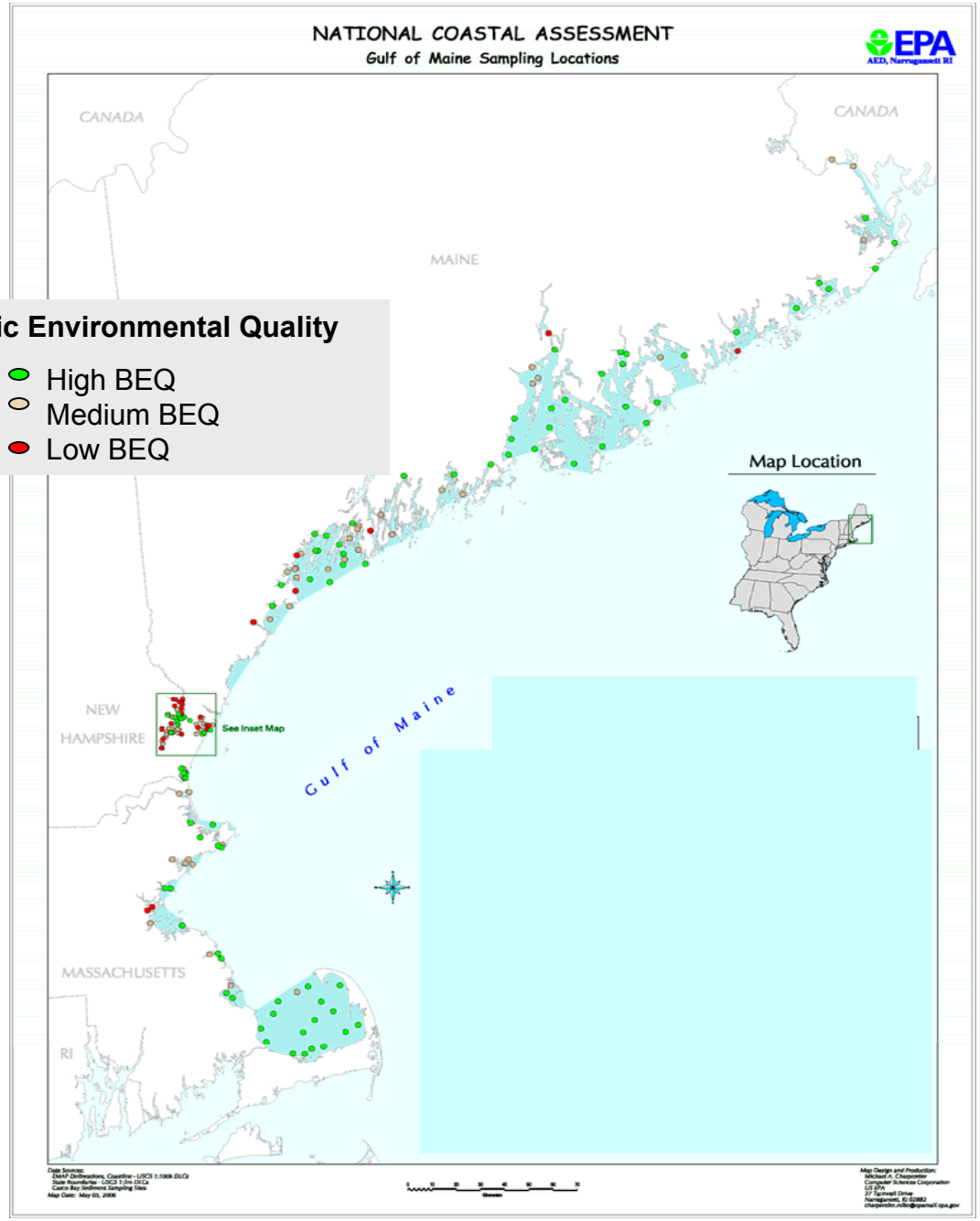
Criteria for Benthic Environmental Quality were chosen to provide a "gold standard" of benthic condition

Stations classified as low BEQ had to meet at least one of these criteria:

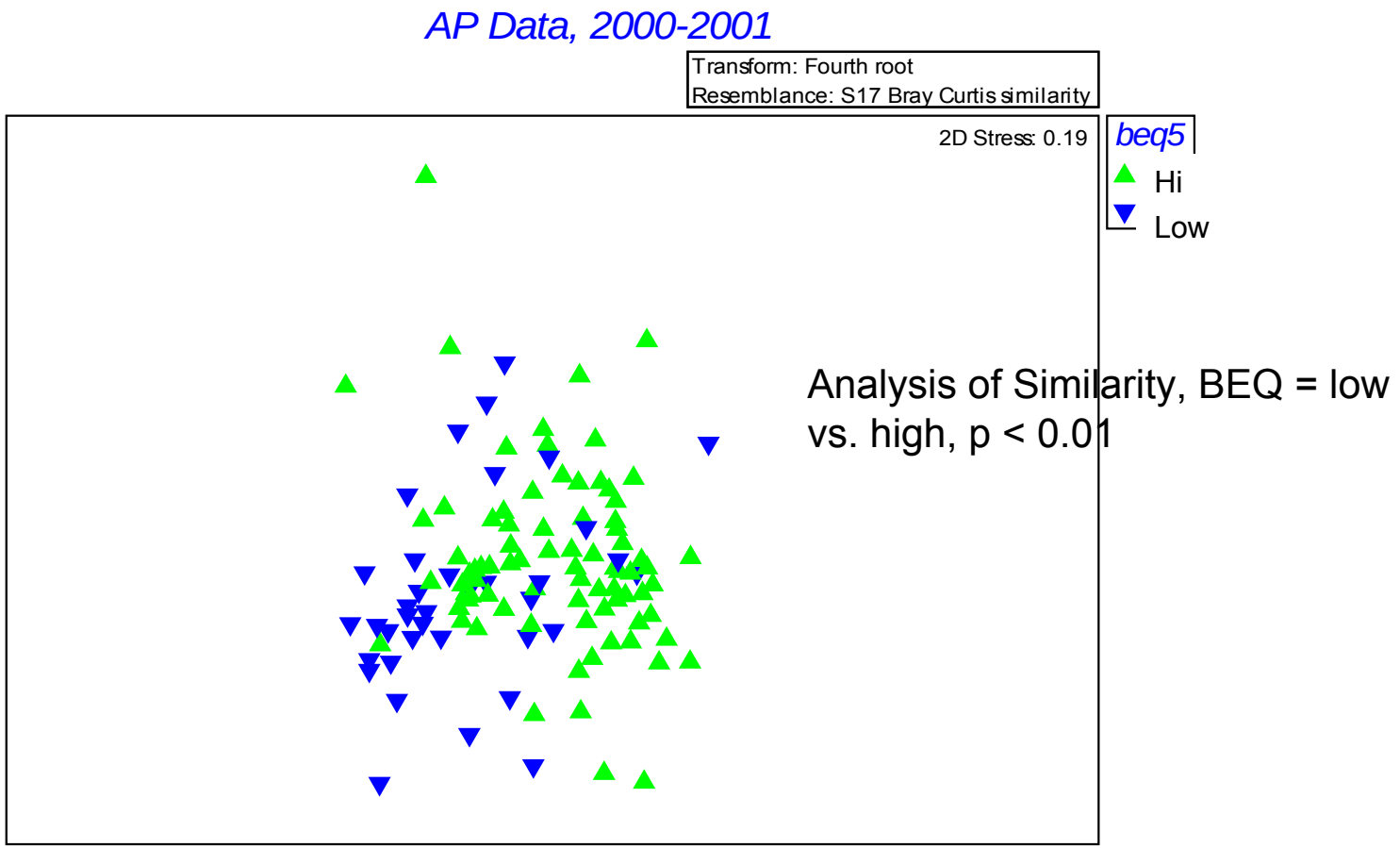
1. Metal and organic contaminants: At least one exceedance of Long et al. (1995) effects range-median (ER-M) values or ≥ 10 exceedances of effects range-low (ER-L) values
2. Sediment toxicity test: Ampelisca survival < 80% of controls
3. Total organic carbon: ≥ 5 % dry wt.
4. Concentration of dissolved oxygen in bottom water: < 4.8 mg/l.

Stations classified as high BEQ had to meet all of these criteria:

1. Metal and organic contaminants: No exceedances of ER-M values and ≤ 3 exceedances of ER-L values
2. Sediment toxicity test: Ampelisca survival ≥ 80% of controls
3. Total organic carbon: < 4 % dry wt.
4. Concentration of dissolved oxygen in bottom water: ≥ 4.8 mg/l.


NATIONAL COASTAL ASSESSMENT
Gulf of Maine Sampling Locations
EPA
AED, Narragansett RI
CANADA
CANADA
MAINE
Benthic Environmental Quality
High BEQ
Medium BEQ
Low BEQ
Map Location
NEW
HAMPSHIRE
See Inset Map
Gulf of Maine
MASSACHUSETTS
RI

A non-metric multidimensional scaling of the benthic species abundance data shows that the composition of benthic assemblages at the low BEQ stations is different from that at the high BEQ stations.



Dominant benthic species at high (n = 81) Benthic Environmental Quality (BEQ) stations.

Scientific name	Abundance
Ampharete arctica	3863
Tubificidae	2672
Prionospio steenstrupi	2659
Nucula proxima	2648
Polygordius spp.	2390
Streblospio benedicti	2211
Ampelisca	1489
Aricidea catherinae	1438
Pygospio elegans	1382
Tharyx acutus	1307
Gemma gemma	1044
Exogone hebes	1027
Prionospio spp.	960
Mediomastus californiensis	956
Polydora cornuta	893
Nephtys incisa	840
Ninoe nigripes	777
Cirratulidae	692
Nucula tenuis	660
Exogone verugera	639

Dominant species at low (n = 37) Benthic Environmental Quality (BEQ) stations

Scientific name	Abundance
Tubificidae	4903
Polygordius spp.	2568
Mytilus edulis	2353
Streblospio benedicti	1518
Exogone hebes	1112
Monocorophium tuberculatum	1057
Parapionosyllis longicirrata	792
Mya arenaria	605
Heteromastus filiformis	567
Polydora cornuta	554
Tharyx acutus	506
Nucula proxima	482
Marenzellaria viridis	450
Prionospio steenstrupi	438
Spionidae	381
Cyathura polita	378
Nereis diversicolor	373
Nephtys incisa	339
Prionospio spp.	330
Capitella capitata	265

Multivariate logistic regression is conducive to evaluation by signal detection theory.

- Probability of the dependent variable (a low BEQ), given the independent variables (the benthic metrics)
- Chose a cutpoint to develop an indicator of benthic condition
  if $p_i \geq k$, then Y = 1
  if $p_i < k$, then Y = 0
- Developed several logistic regression models. Criteria: 80% accuracy
- Evaluated indicators with signal detection theory

A partial list of potential benthic metrics:

Richness, diversity, and evenness measures:
Number of species S
Shannon-Wiener H′
Gleason's D
ES(50) Expected number of species in a random sample of 50 individuals
Average taxonomic diversity (Clarke and Warwick 2001) Δ
Average taxonomic distinctness (Clarke and Warwick 2001) Δ*
Pielou's evenness J'
% abundance three most dominant species

Pollution tolerance-sensitivity:
mn_es(50).05 - Station mean of Rosenberg et al.'s (2004) species tolerance value
First term of Rosenberg et al.'s (2004) Benthic Quality Index
% abundance pollution-indicative species (from literature)
% abundance pollution-sensitive species (from literature)

Productivity:
Total number of individuals

Species composition (percent of total abundance)**:**

Means of benthic metrics used in logistic regressions at high and low BEQ (n=118) were compared by t-tests.

Benthic metric	Mean Low BEQ	Mean High BEQ	p
Shannon-Wiener H′	0.71	0.94	0.0001
Gleason's D	2.91	5.05	0.0001
PctDom3	80.0	64.4	0.0001
ES(50)	8.12	12.78	0.0001
$mn\_es(50)_{.05}$	6.28	7.58	0.0001
First term of BQI	5.11	6.32	0.002
Δ Taxon. diversity	50.86	55.50	0.09
Pct Capitellidae	11.2	4.2	0.03
Pct Capitella	3.29	0.53	0.0001
Pct Tellinidae	0.4	1.2	0.08

Results of Pearson correlation of final list of benthic metrics with six habitat variables. Significance at $p < 0.10$.

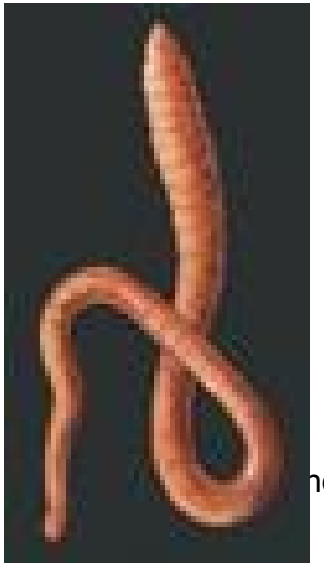
Habitat variables	# Signif. Corr.	# $R^2 \geq 0.25$
Latitude	2	0
Longitude	4	0
Depth, m	7	2
Bottom Temperature, °C	8	2
Bottom Salinity, PSU	8	1
Percent silt-clay	2	0

A candidate benthic index:

logit(p) = 6.13 + 0.05 pctCap – 0.76 H′ – 0.84 mn_es(50).05
p = e(logit(p)) / 1 + e(logit(p))
BI = 10(1 – p)

where:
H′ = Shannon-Wiener H′ diversity index
mn_es(50).05 = Station mean of species tolerance value of Rosenberg et al. (2004)
PctCap = percent abundance of capitellid polychaetes

n = 118
c = 0.82
accuracy on calibration dataset = 80%



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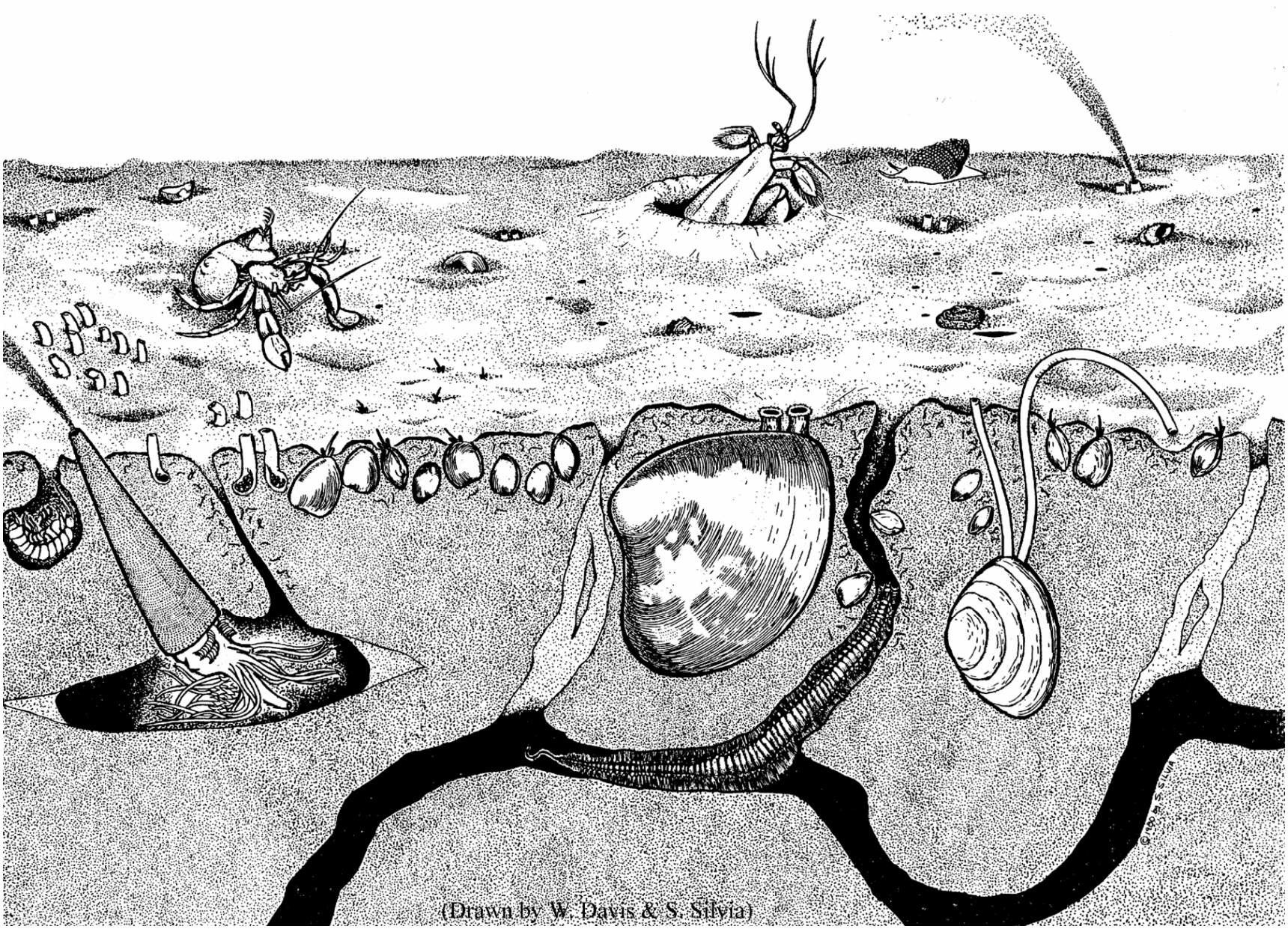
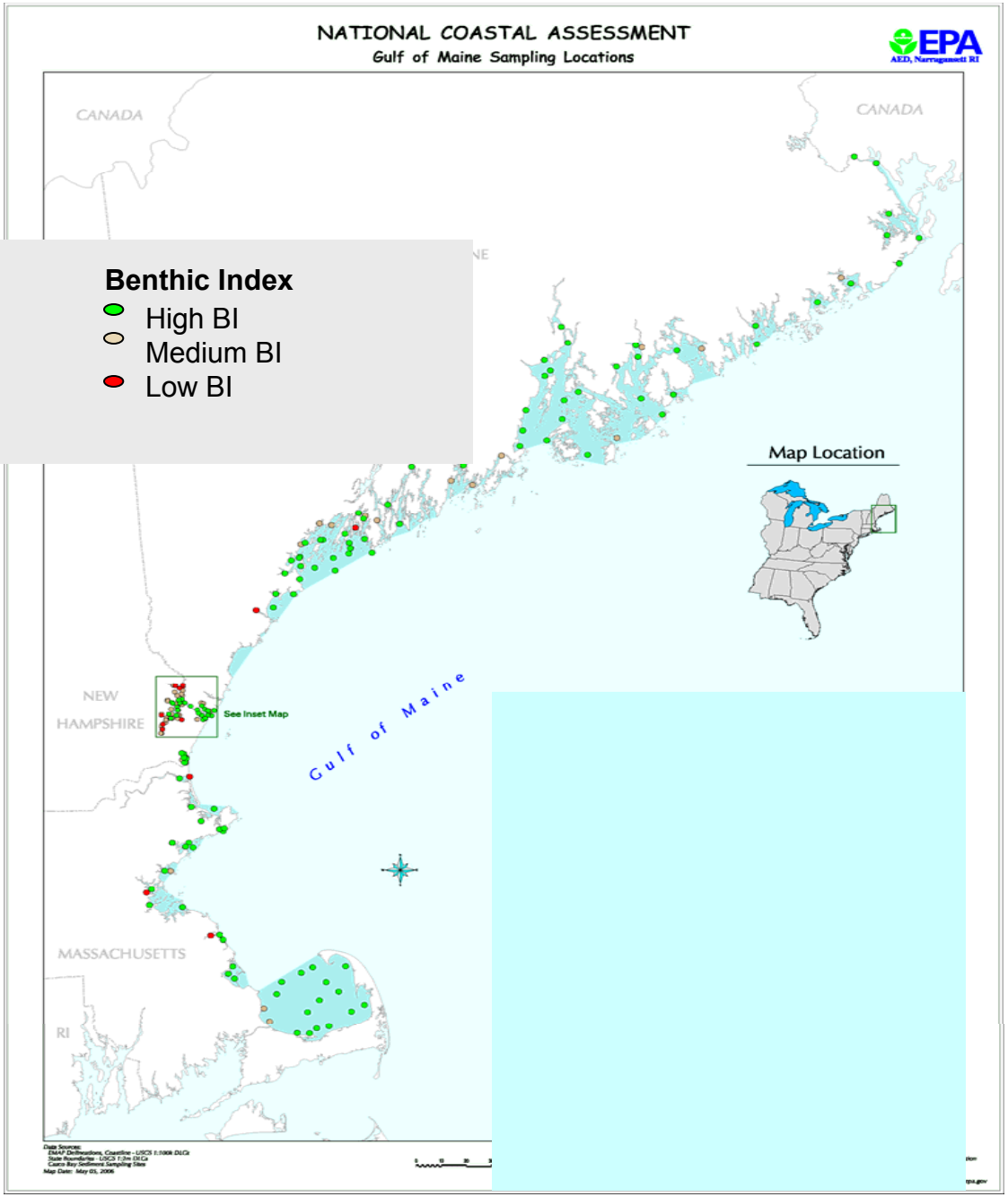


(Drawn by W. Davis & S. Silvia)


NATIONAL COASTAL ASSESSMENT
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CANADA
CANADA
Benthic Index
High BI
Medium BI
Low BI
Map Location
NEW
HAMPSHIRE
See Inset Map
Gulf of Maine
MASSACHUSETTS
RI

Validation from Massachusetts Water Resources Authority data set (n = 49 stations)

		Benthic Index		
		Low	High	
BEQ	Low	22	6	28
	High	4	17	21
	Total	26	23	49

Accuracy = (22 + 17) / 49 = 80%

Casco Bay: overall accuracy = 74% but too few low BEQ stations to validate positive responses.

Validation from National Coastal Assessment 2002-2003 data set. (n = 67 stations).

		Benthic Index		
		Low	High	
BEQ	Low	17	4	21
	High	12	34	46
	Total	29	38	67

Accuracy = (17 + 34) / 67 = 76%

How do environmental managers use a benthic index or ecological indicator?

Signal Detection Theory provides a rigorous standard for evaluating ecological indicators and can guide environmental mgmt decisions.

Sensitivity of an indicator is the probability of a positive indicator, given that the true response is positive.

Specificity is the probability of a negative indicator, given that the true response is negative.

Receiver Operating Characteristic (ROC) curve is a plot of sensitivity versus specificity.

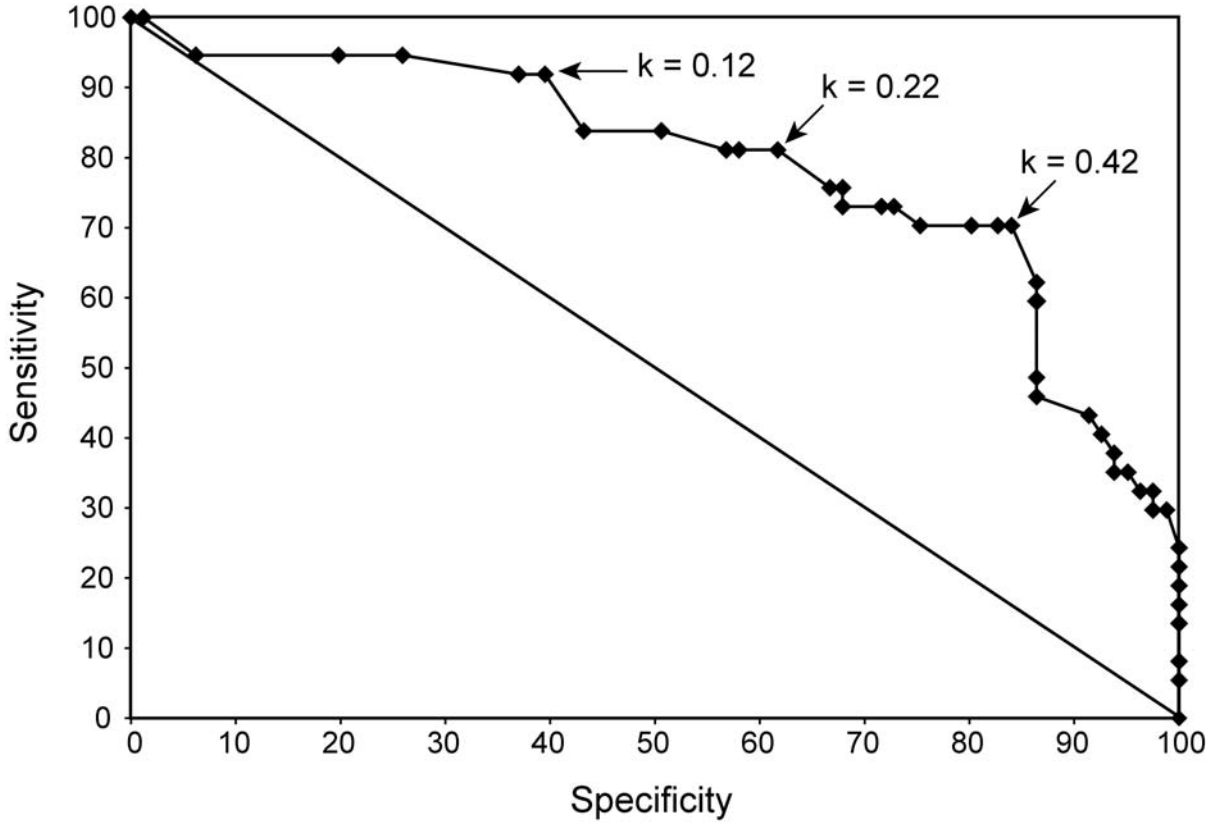
Positive predictive value (PPV) is the probability of a positive response, given that the indicator is positive.

Negative predictive value (NPV) is the probability of a negative response, given that the indicator is negative.

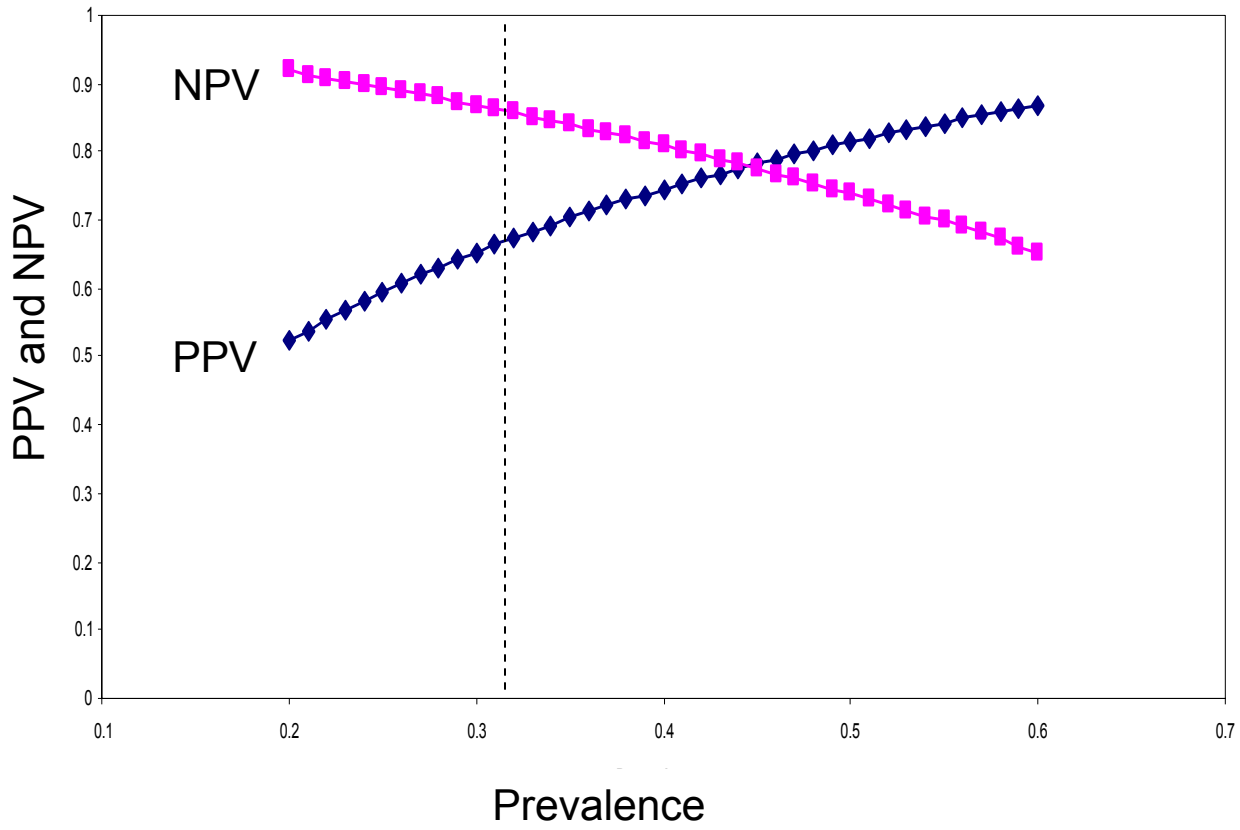
Receiver Operating Characteristic (ROC)

Gulf of Maine: All Stations

Fig. 4



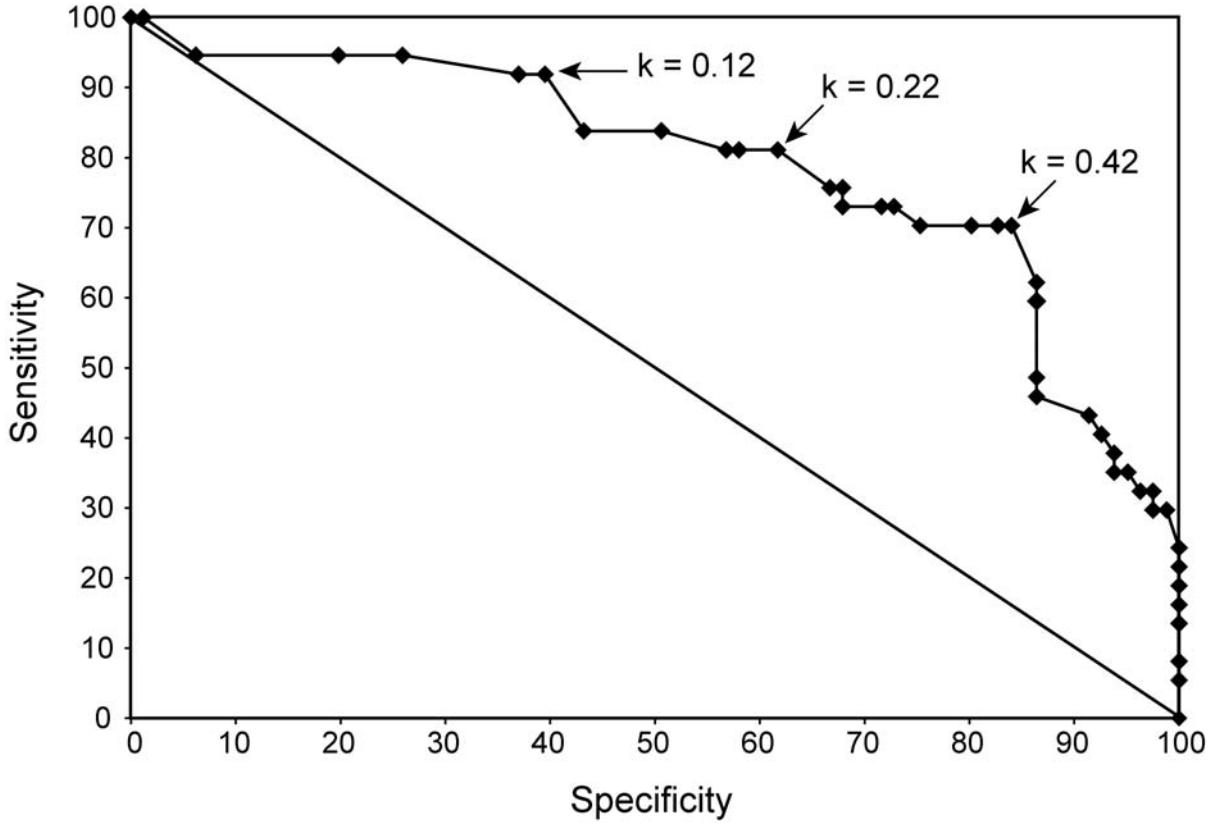
Positive and Negative Predictive Values
Gulf of Maine: All Stations
Rule: Y > 0.42



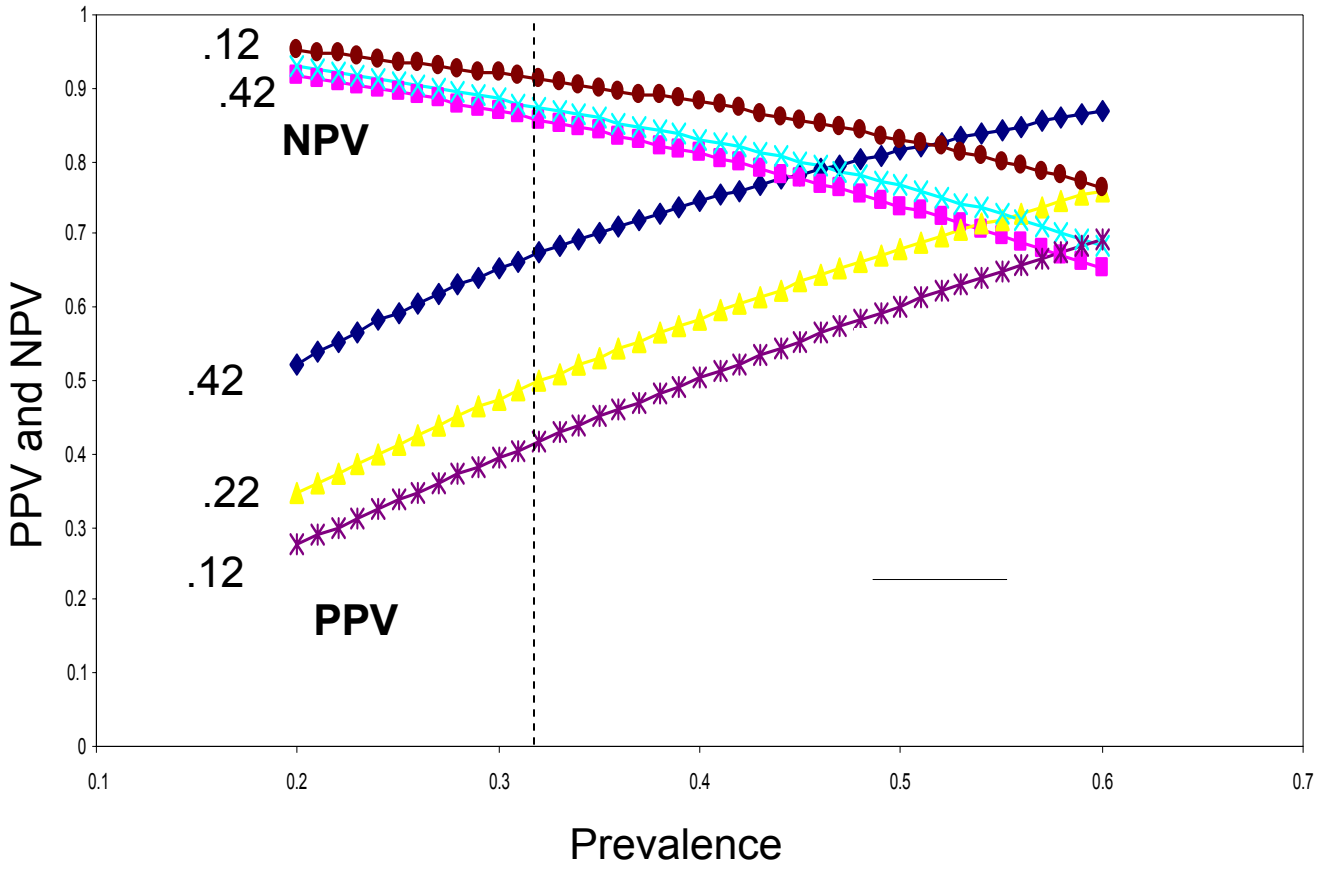
Receiver Operating Characteristic (ROC)

Gulf of Maine: All Stations

Fig. 4



Positive and Negative Predictive Values
Gulf of Maine: All Stations
Rules: Y > 0.42; Y > 0.22, Y > 0.12



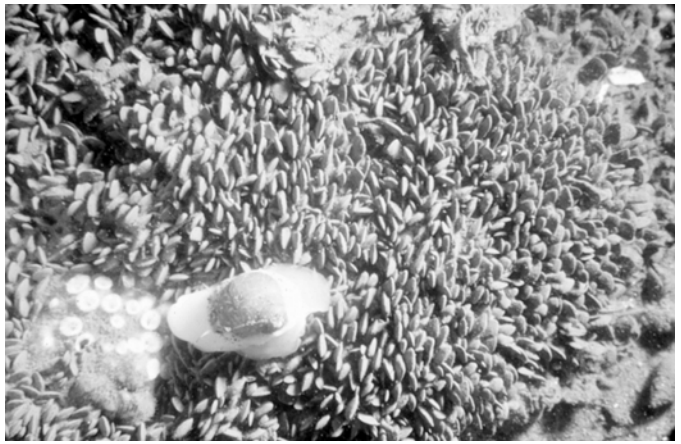
In summary, this benthic index will be useful for marine monitoring by showing spatial and temporal changes in benthic condition

> 80% correct classification with ecologically meaningful metrics

Stations with higher H′ and $mn\_es(50)_{.05}$ and lower pctCap had higher benthic index values

Validated by 75-80% correct classification of independent datasets

Indicator evaluated with signal detection theory



H. W. Pratt

Next steps

- Further refine and validate candidate indices (2004-2006 data)
- Better account for habitat differences
- Testing by other people, other datasets
- Inter-calibration exercise with Virginian Province benthic index
- Expand to Canadian portion of the Gulf of Maine?

Acknowledgments

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  - Lee Doggett — Maine DEP
  - Stephen Hale — USEPA
  - Brian Howes — UMass-Dartmouth
  - Ken Keay — MWRA
  - Peter Larsen — Bigelow Lab
  - Jerry Pesch — USEPA
  - Gerhardt Pohl — Can. DFO
  - Sheldon Pratt — Univ. of RI
  - Phil Trowbridge — NH DES
  - Tom Trott — Suffolk Univ.
- Wells, ME workshop participants, Nov 2006