# *Use of Stressor - Response Indicators in Managing Estuarine Water Quality*

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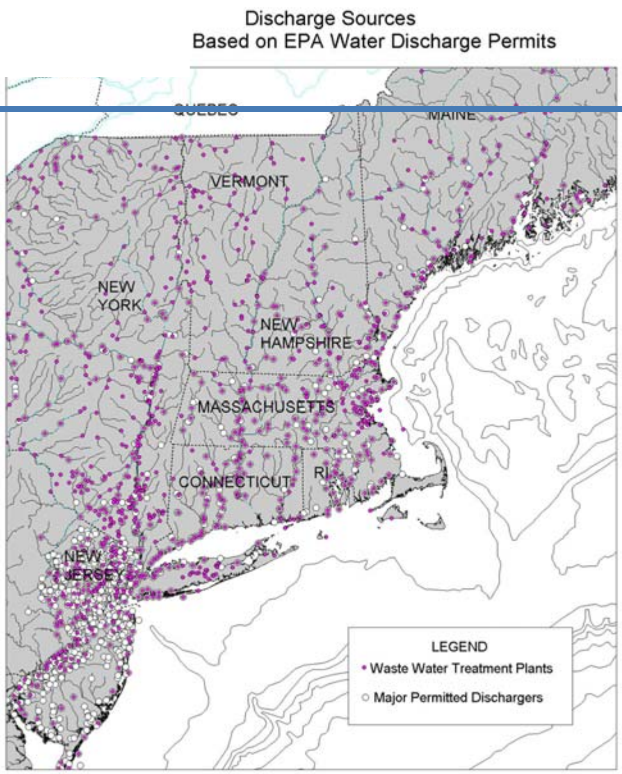
**Photo by Cicchetti**

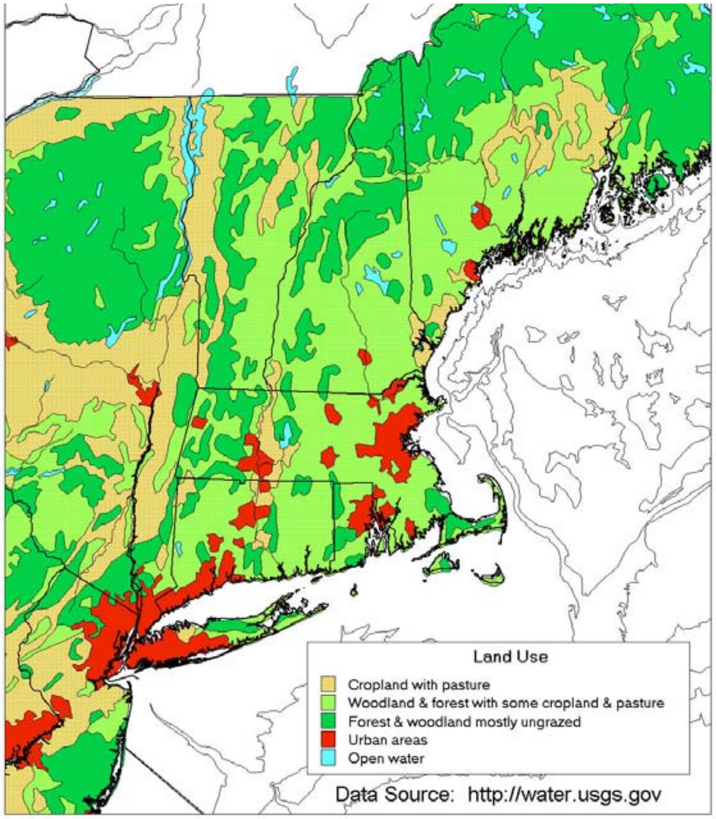
# *Credits to projects & colleagues*

Jim Latimer, Giancarlo Cicchetti, Ed Dettmann, Steve Rego, Carol Pesch, Barb Bergen, Skip Nelson, Laura Coiro, Warren Boothman, Geln Thursby, Darryl Keith, Mohammed Abdelhrmann, Naomi Detenbeck, Peg Pelletier, Dan Campbell, Kay Ho, Rob Burgess, Jim Coles, Cornel Rosiu

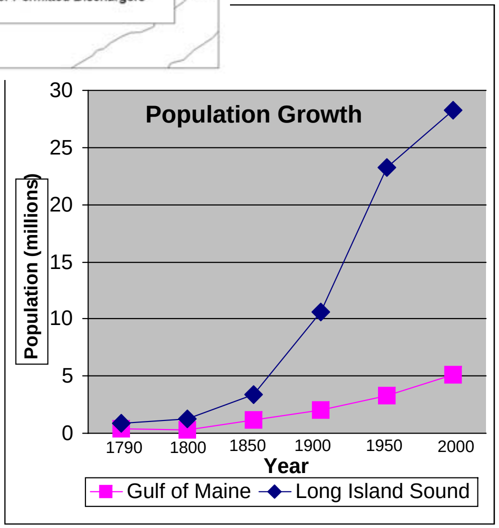
# *People on the landscape*

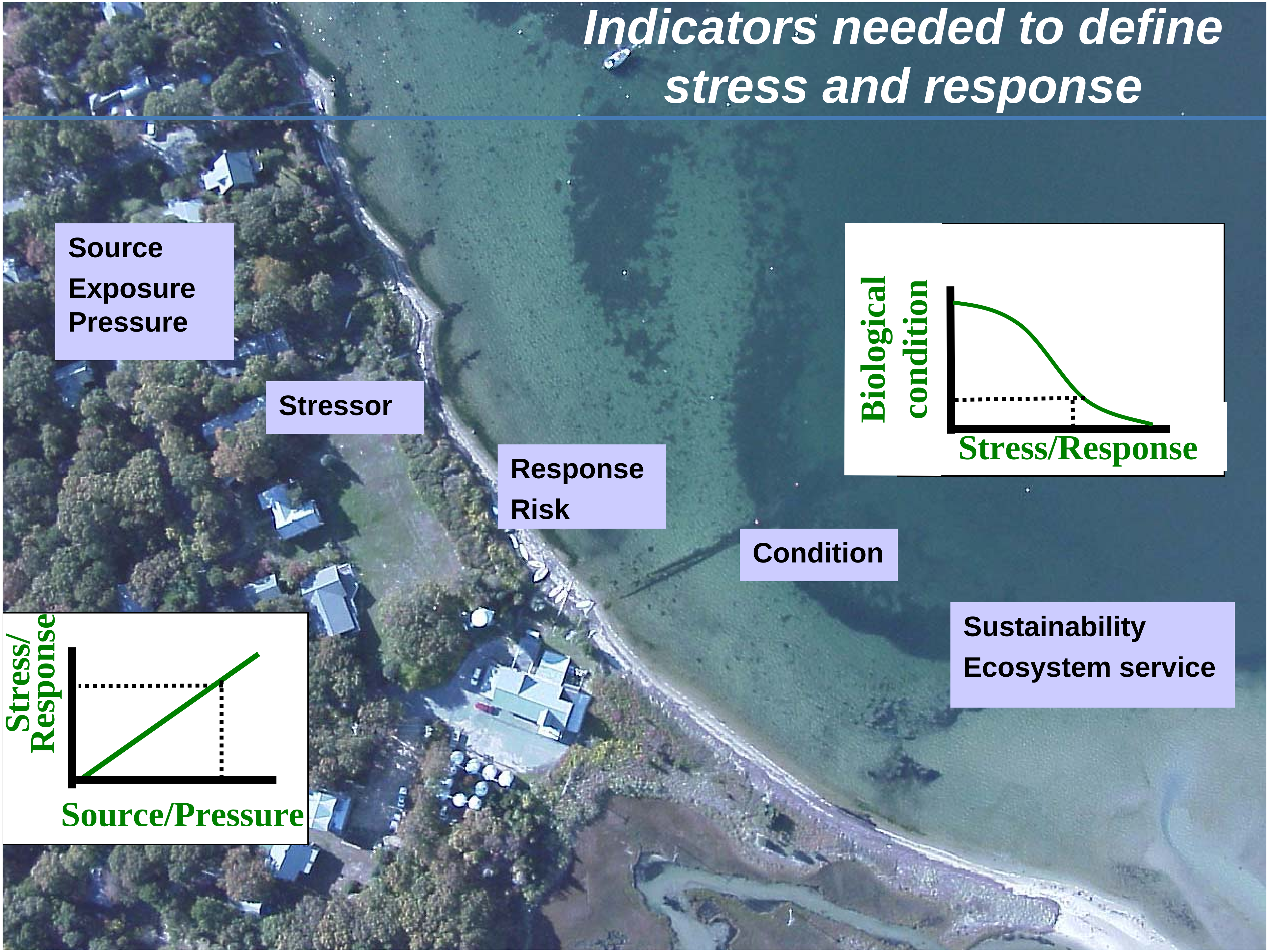
Both location and magnitude of many stressors are correlated with population distribution and land use




Population pressure is expected to increase in coastal regions




Indicators needed to define stress and response
Source
Exposure
Pressure
Stressor
Response
Risk
Condition
Sustainability
Ecosystem service
Biological condition
Stress/Response
Stress/ Response
Source/Pressure

# *Key pressures and stressors*

## Practice

- Population
- Land use
- Industry
- Agriculture
- Climate change

- Land-based
- Marine-based
- Local or remote
- Dispersed or point
- Constant or episodic

## Stressor

- Excess nutrients
- Excess sediments
- Toxic chemcials
- Habitat loss or change
- EDCs and emerging componds
- Invasive species
- Temperature shifts
- Salinity shifts

- & interaction and integration of multiple stressors

## *Indicators to fit the data available and the model desired*

**Stressor gradients occur in both time and space**

*Coastal receiving waters*

*Past….Time ….present*

*Sedimentary or historical record*

**Stressor-response models**

- Controlled experiments
- Gradients in the environment
- Single locations over time

**Indicator types**

- Integrative
- Representative
- Proxy
- Sentinel

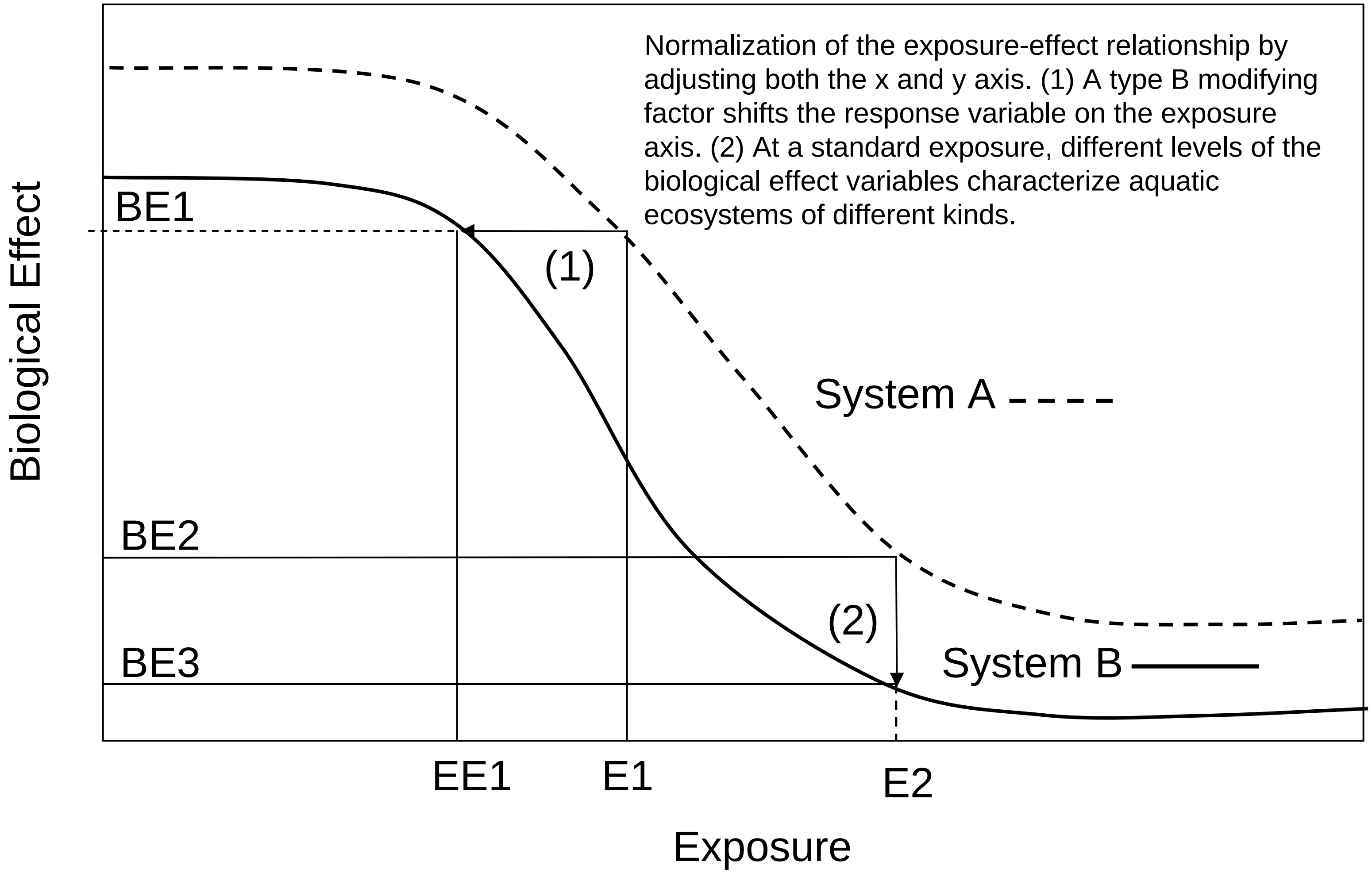
-Threshold

-Discrete or function

-Population/individual

***Must fit the space, time, magnitude, and mechanisms***

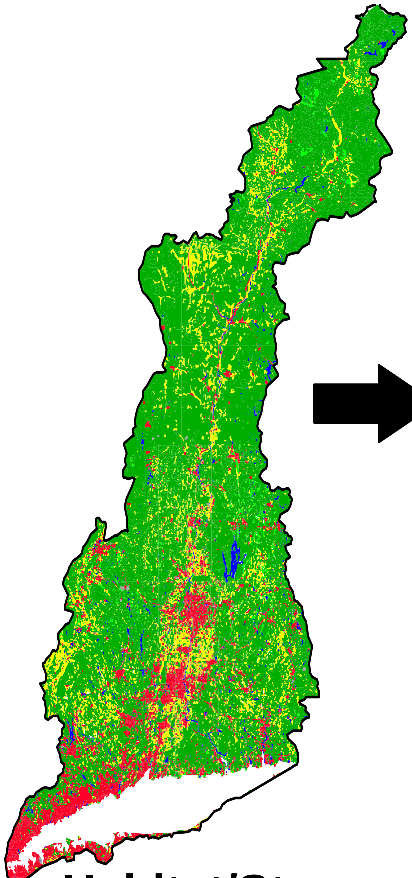
## *Normalization can accommodate differences in sensitivity for individual, community, habitat, class, or population response*



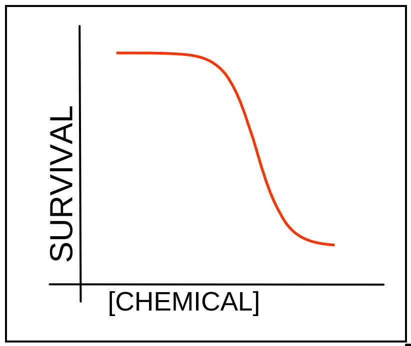


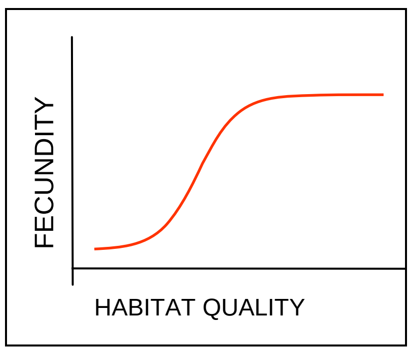

From Campbell et al. , 2006

***Integration of multiple stressor-responses through population dynamics models allows projections of population-level effects and ecological risk-assessment.***



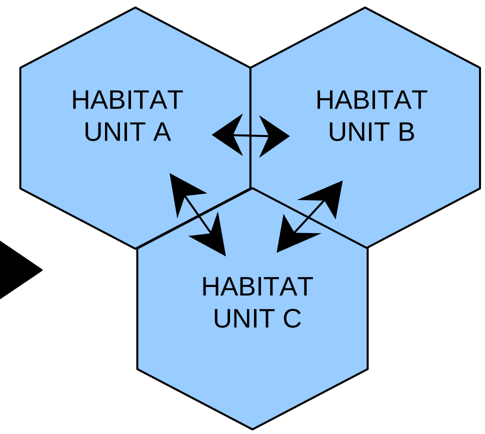
**Habitat/Stressor Distributions**




**Multi-Stressor Relationships**

$$n_t = Mn_{t-1}$$




**Non-spatial and Spatially-Explicit Population Models**

***How can we best estimate the relative and cumulative risks from chemical, biological, and physical stressors to populations of aquatic and aquatic-dependent wildlife?***

From NHEERL Wildlife Research Strategy, 2005

# *Examples of regulatory tools*

Identify condition, sensitivity, and risk……in dynamic ecosystems

**Determine designated use and choose protection, restoration, or alternate**.

- Set criteria for acceptable value of pollutant or biological condition
- TMDL (Total maximum daily load) for watershed management
- TALU (Tiered aquatic life use) for biocriteria
- Endangered or regulated species laws

- Identify potential controls on source of stressor
- Set restoration targets
- Set monitoring points or parameters
- Project scenarios for valuation (cost/benefit and accountability)

- Multi-scaled management– federal, state, area, municipality

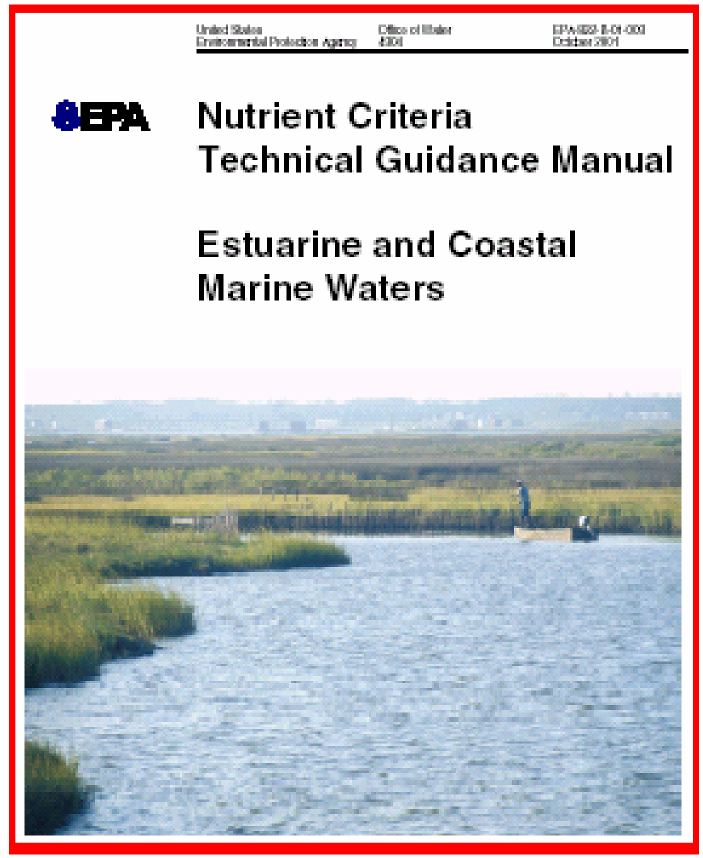
## ***Agency Problem***

Nutrient over-enrichment is one of the most often cited causes of impairment (CWA 305b reports) in coastal waters

Section 304(a) of CWA requires EPA to develop water quality criteria (nutrient criteria is a subset)

To identify <u>nutrient levels</u> and <u>biological effects</u> below which nuisance or impaired conditions are unlikely to occur and therefore protect designated uses

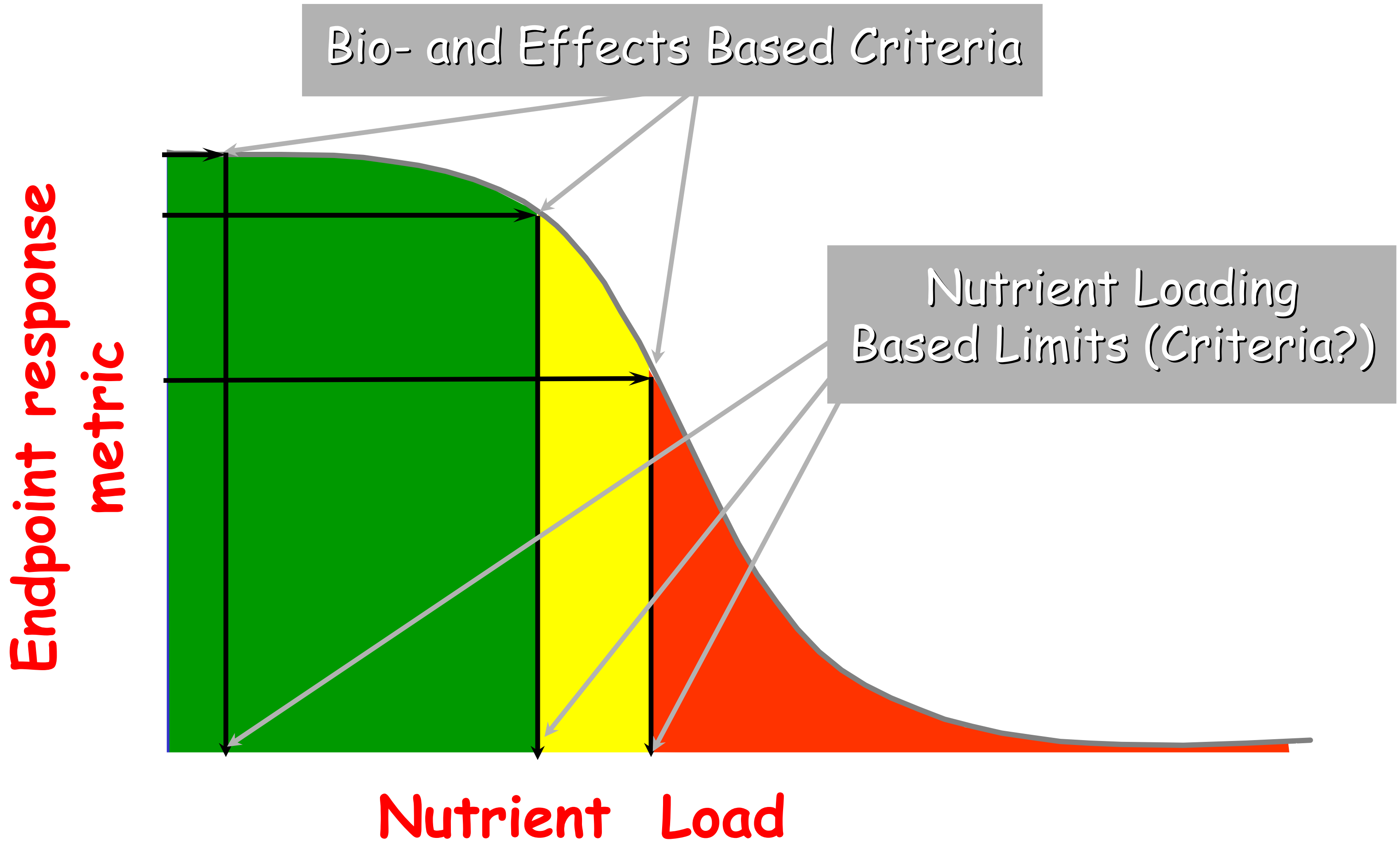
…reduce anthropogenic component of nutrient over-enrichment to levels that maintain designated uses or prevent nutrient pollution in the first place



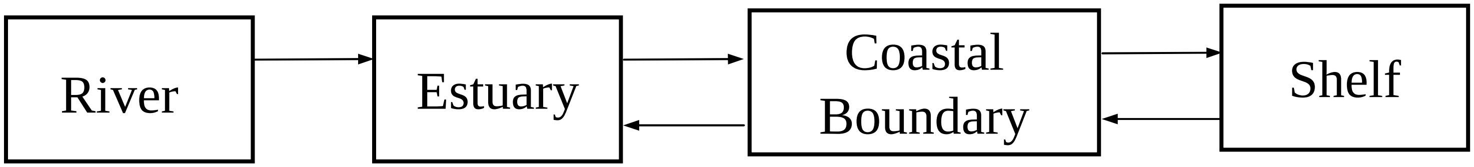



From Latimer , 2005

## Conceptual Approach to Using
## Load – Response Models to Establish Nutrient Criteria/Limits




From Latimer , 2005




Factors that control the effects of nutrients in aquatic ecosystems.

## Physico-chemical factors

**Sources:**
Atmospheric Deposition
Watershed/Land use NPS input
Point-source and Riverine input

**Reactive substances:**
TN, TP, DIN, DIC, DOC, POP, DIP, DO, DOC, TSS, DOM

**Modifying factors:**
Dissolved & Particulate Material, DO, Temperature, Hardness, Hypsography, etc.

**Residence Time:**
Freshwater Inflow
Surface Area
DCP/PRE

## Biological components

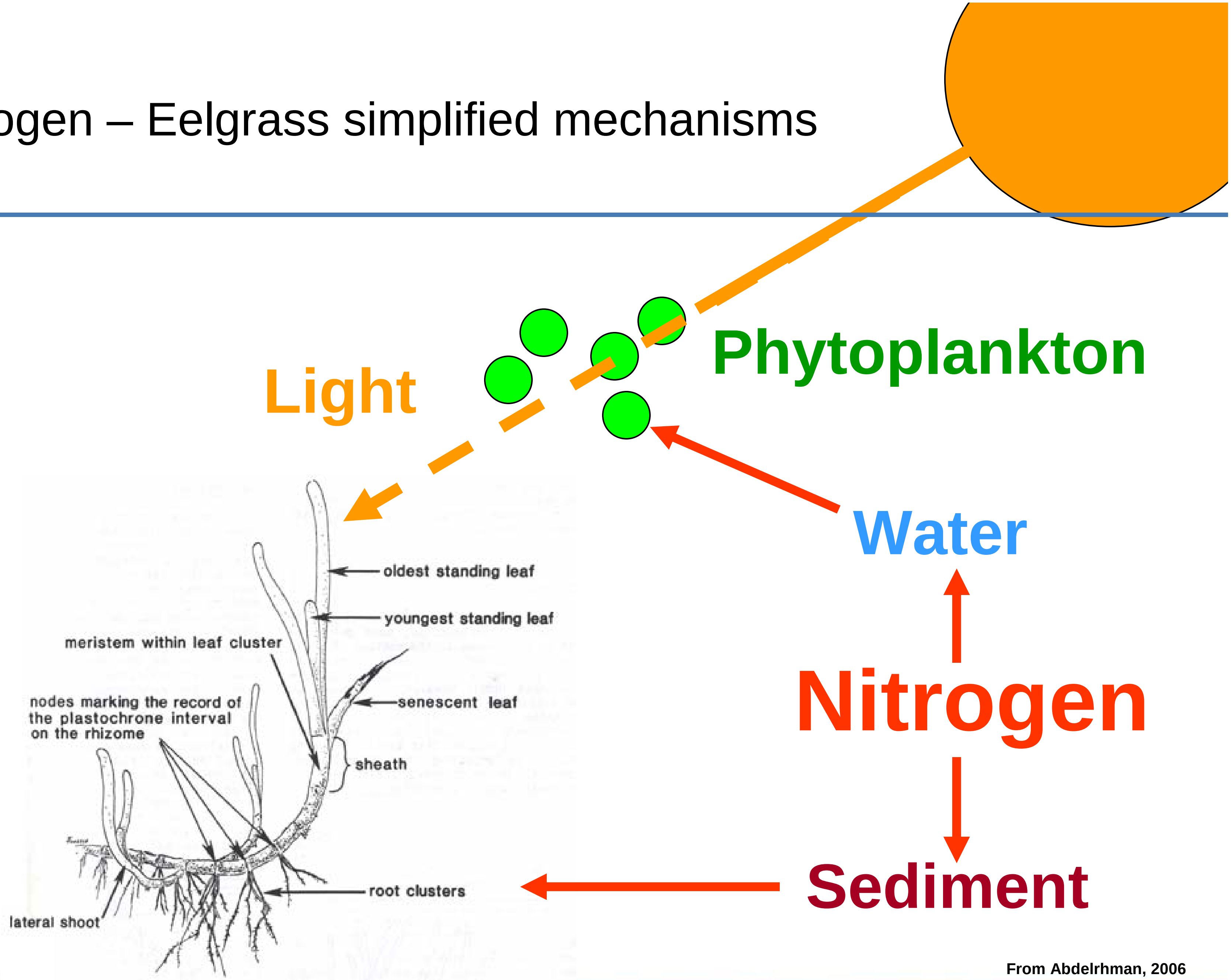
**Producers:**
- Macrophytes
- Phytoplankton

**Bacterial Processes:**
Denitrification,
N fixation, etc.

**Consumers:**
- Zooplankton
- Planktivorous Fish
- Benthic suspension feeders, deposit and interface feeders
- Top Predators
- Benthivorous Fish

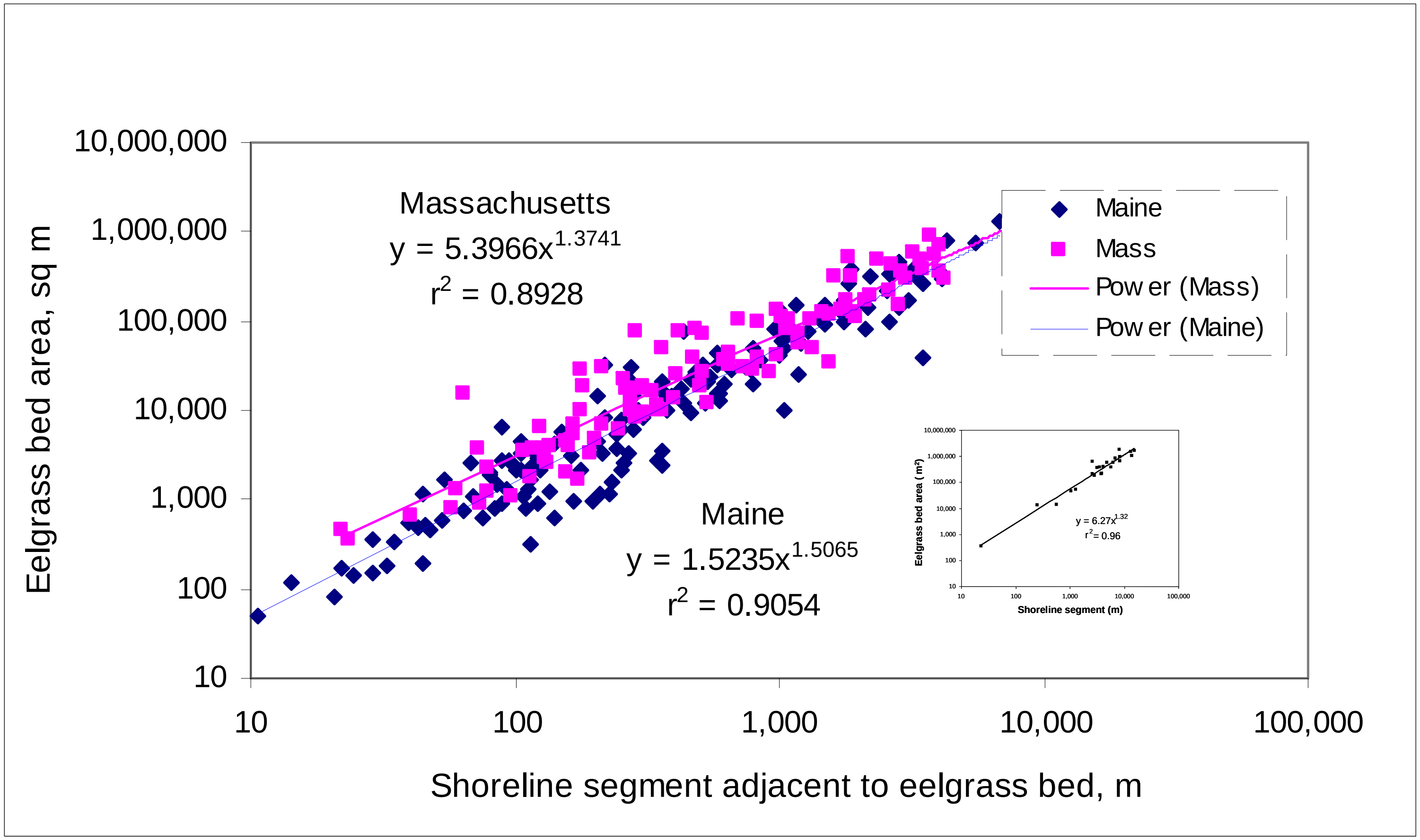
From Campbell et al. , 2006

# Nitrogen – Eelgrass simplified mechanisms



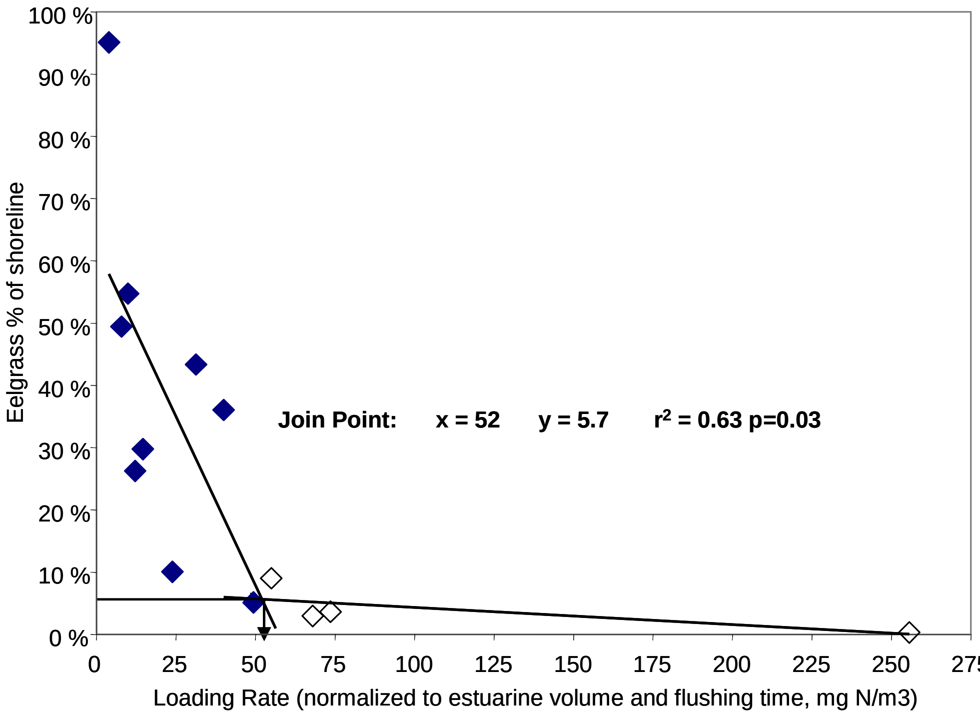

From Abdelrhman, 2006

## System-level indicator for SAV:
## Developed for small area and regional applicability tested

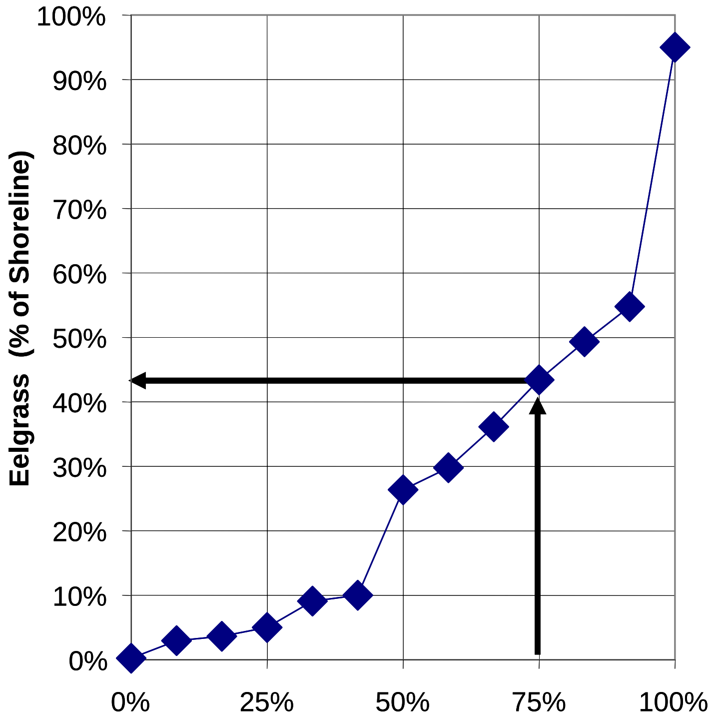



**(from Pesch et al., 2006).**

# Application of stressor-response for criteria




*Analysis of the nitrogen load-response model using a segmented regression analysis to determine a statistically rigorous threshold (arrows represent the determination of generic load limits associated with eelgrass extent join point).*

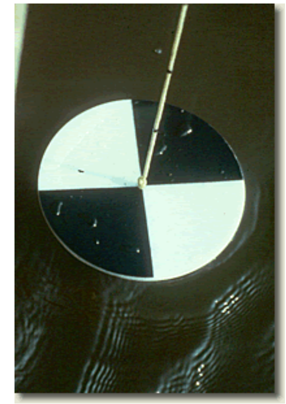



*Cumulative distribution curve for eelgrass extent data for current study systems. Arrows indicate the 75th percentile which yields a value of 43% eelgrass as % of shoreline.*

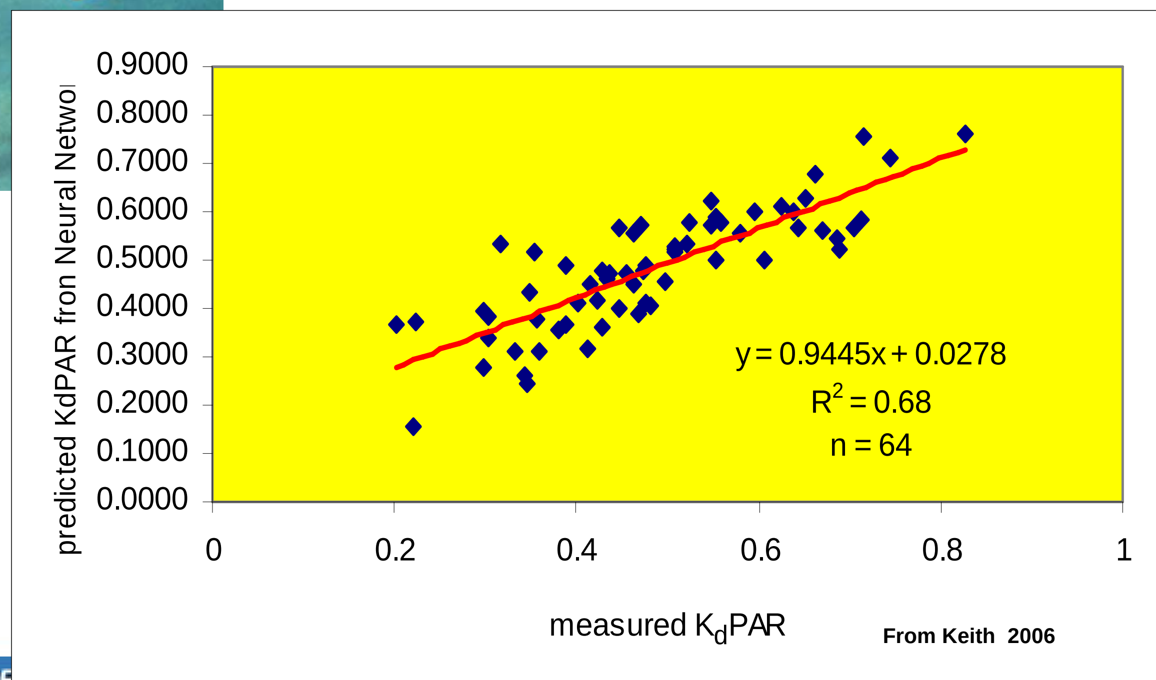
**From Latimer et al. , 2006**

*Develop empirical relationships that allow efficient collection of data at multiple scales*

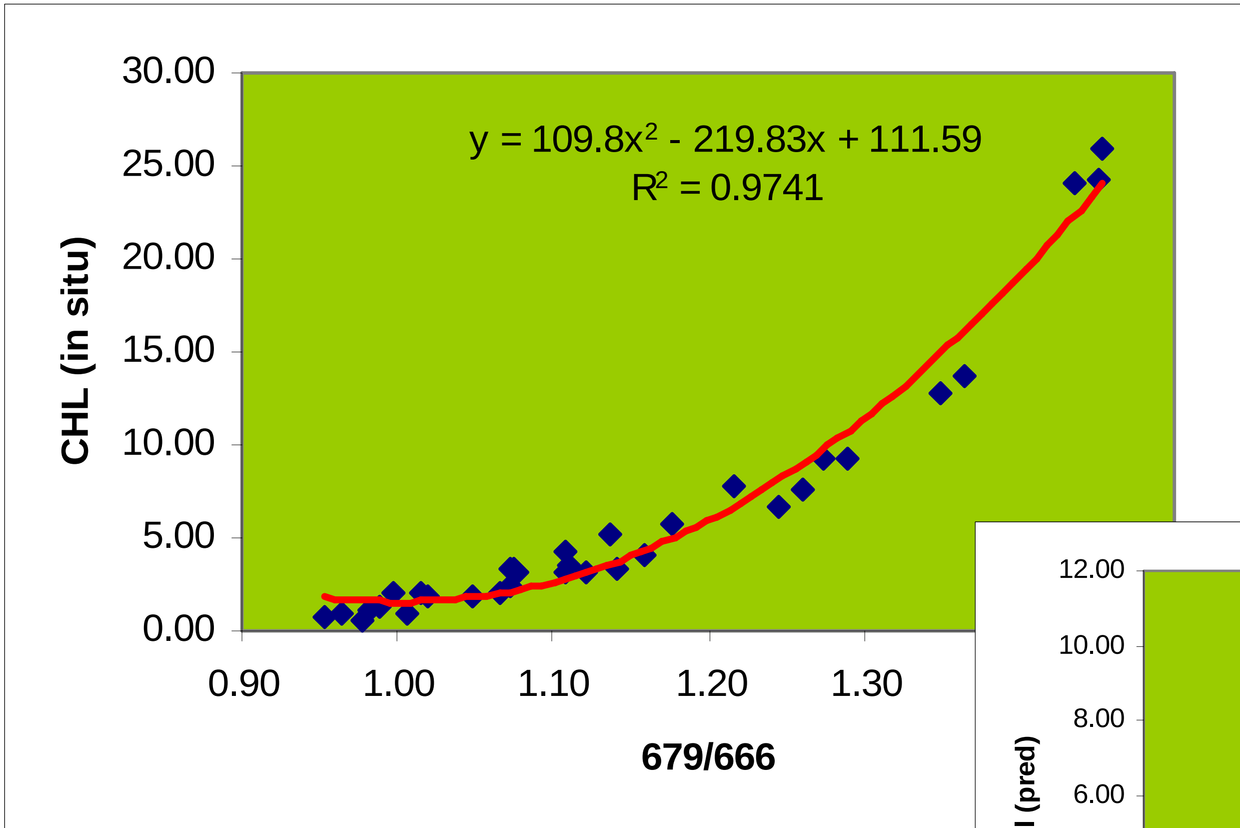
estuarine water color and water clarity using spectral data and a Neural Network

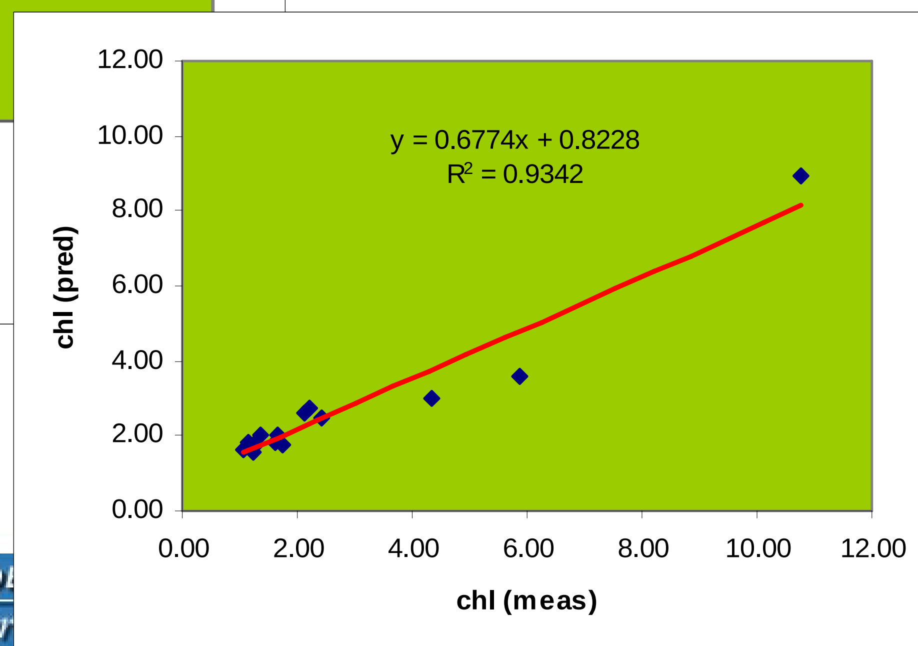


Future Directions:
- ➢Detect water clarity
- ➢Detect salinity
- ➢More accuracy using hyperspectral sensors
- ➢Detect Phytoplankton Functional Group



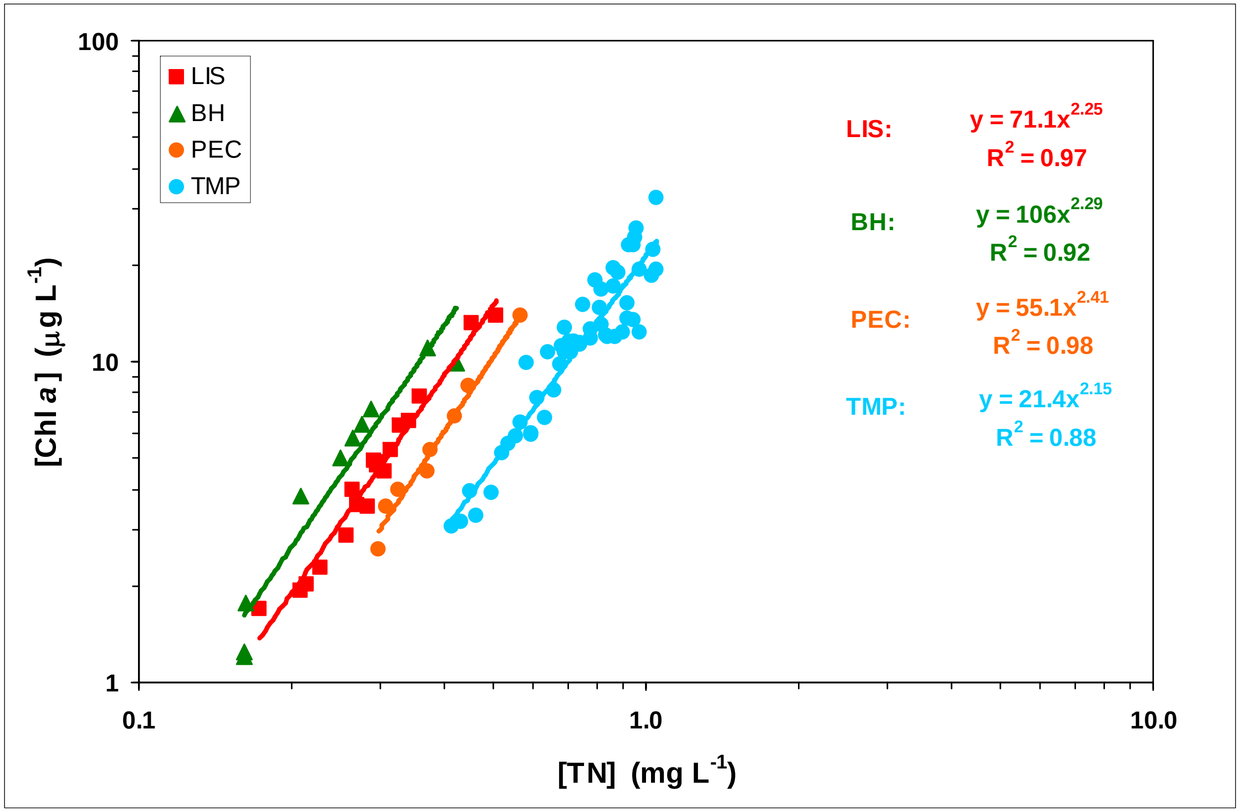
# Preliminary Regional Model and Results for Chl-a




From Keith et al. , 2006

# Chl-a to N relationships in larger estuaries: similar and offset by TSS

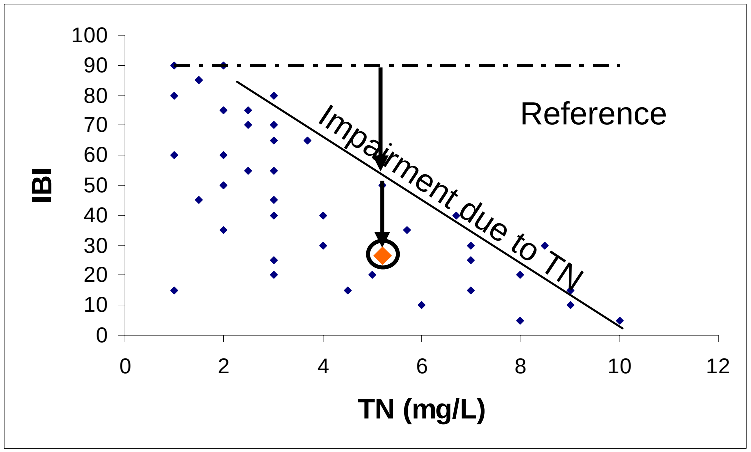


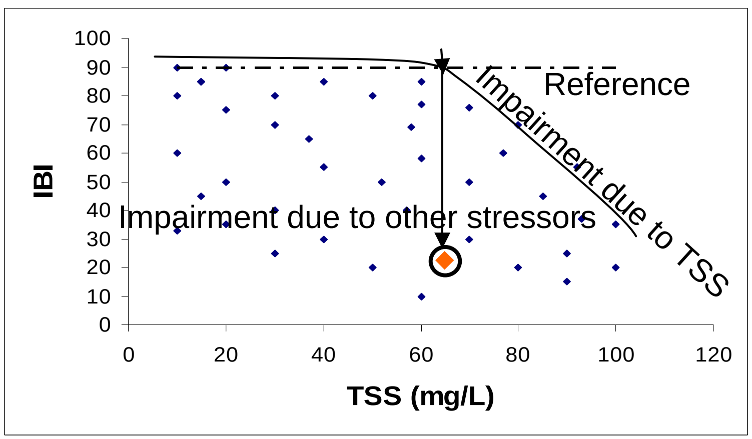

***Mean long-term summer concentrations of TN vs. chlorophyll a at individual stations in Long Island Sound, Boston Harbor, the Peconic Estuary, and Tampa Bay. Also included are***

***regression lines for individual systems.***

**From Dettmann et al. , 2006**

## *Use stressor-response relationships to identify cause and allocate among causes*



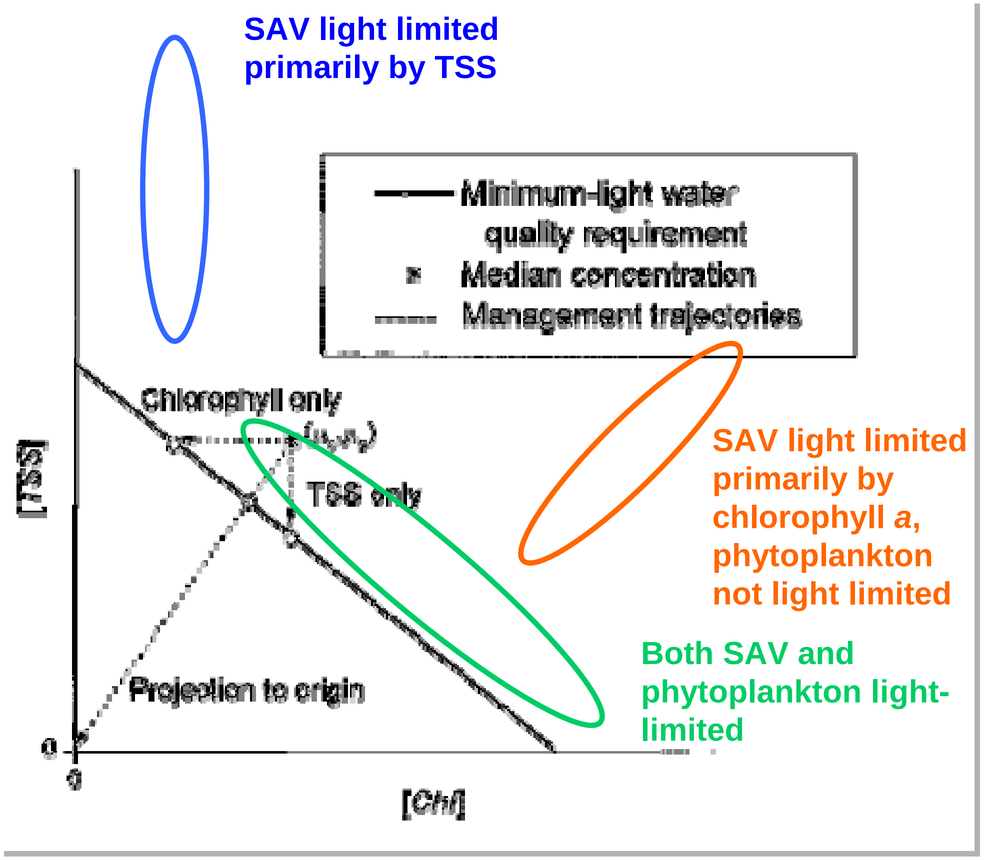

- Along upper envelope, observed response is due to identified stressor

- Below upper envelope, other stressors are contributing to response

  - **Issue**
    - Many impaired waters have more than one potential stressor present
  - **e-Estuary will provide**:
    - Fits to upper envelope (quantile regression) to support criteria
    - Weight of evidence
    - Allocation of cause among stressors

From Detenbeck et al. , 2006

# *Diagnostic tools for evaluating multiple stressors*



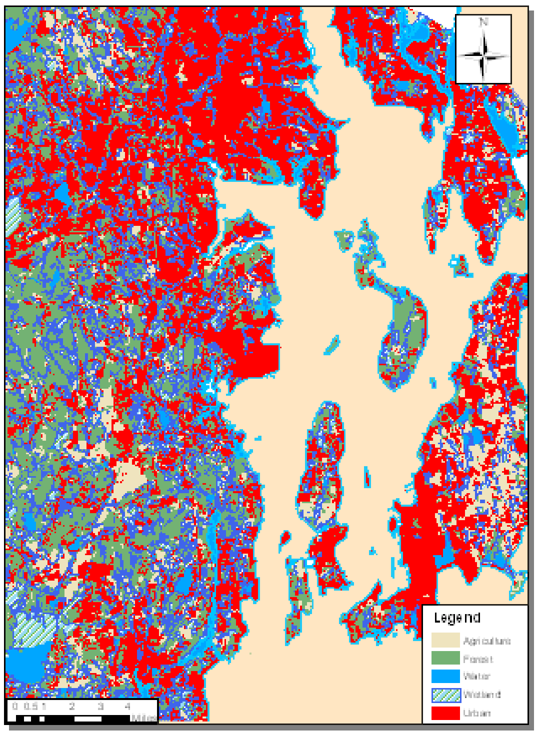

From Gallegos (2001)

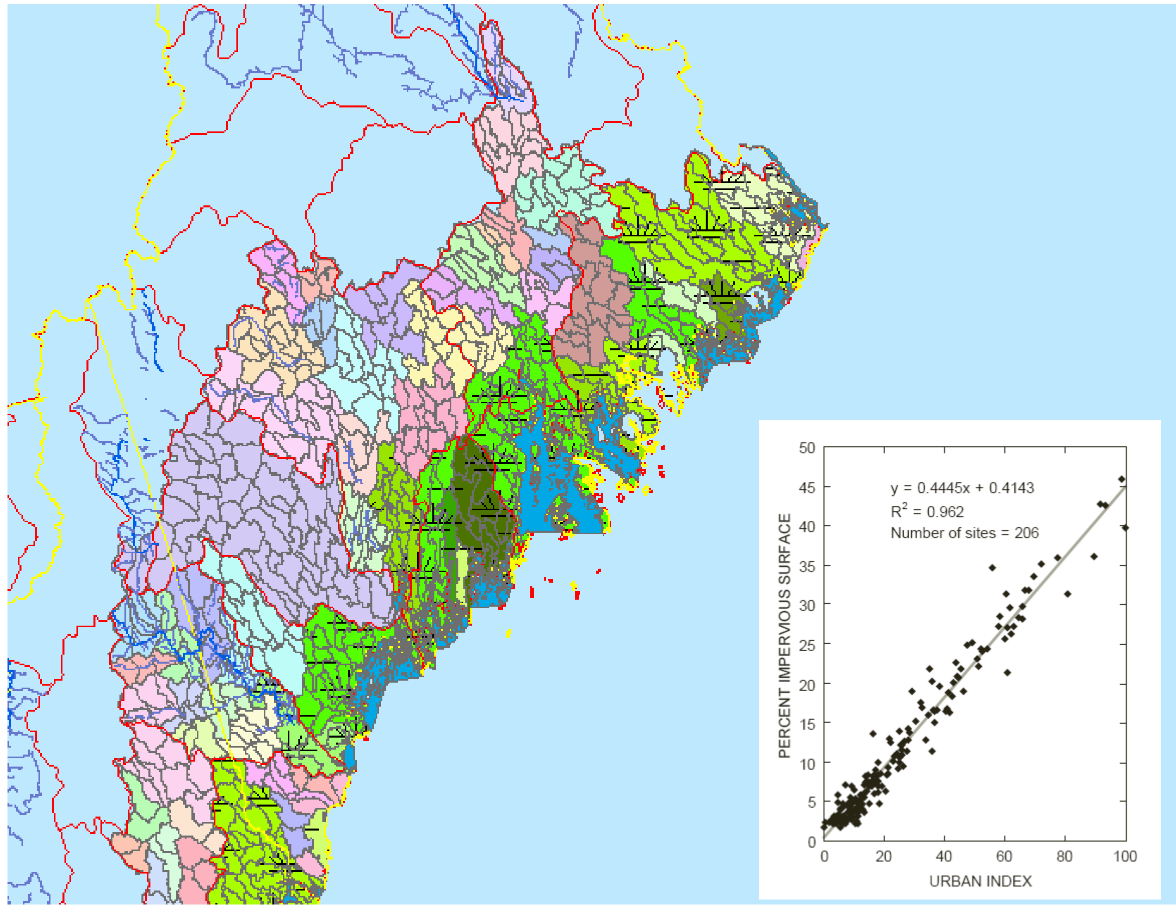
- **Issue**
  - Current WQ standards target single stressors; site-specific criteria need additional information
- **e-Estuary will provide**:
  - Regionalization of chemical criteria based on site specific guidance
  - Regionalized coefficients for light-limitation models to protect water clarity from multiple stressors

From Detenbeck et al. , 2006

# Regionalized loading estimates for multiple scales

- **Issue**
  - Loading estimates are not readily available for estuaries nationwide or at sub-watershed scales

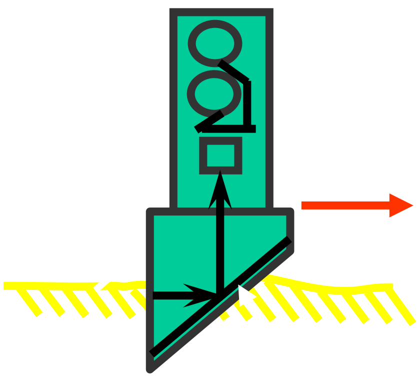


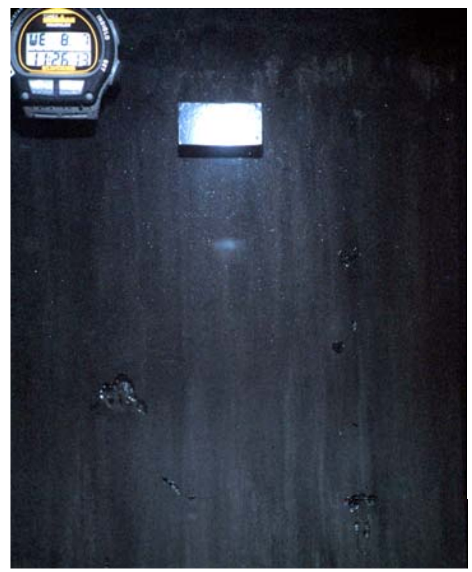

From Detenbeck et al. , 2006; Cole et al., 2004

# Sediment Profile Cameras and Images

Sediment Profile Imagery (SPI) analysis can provide a quicker, faster and inexpensive method to assess the spatial and temporal quantification of benthic community condition and effectiveness of remedial actions.



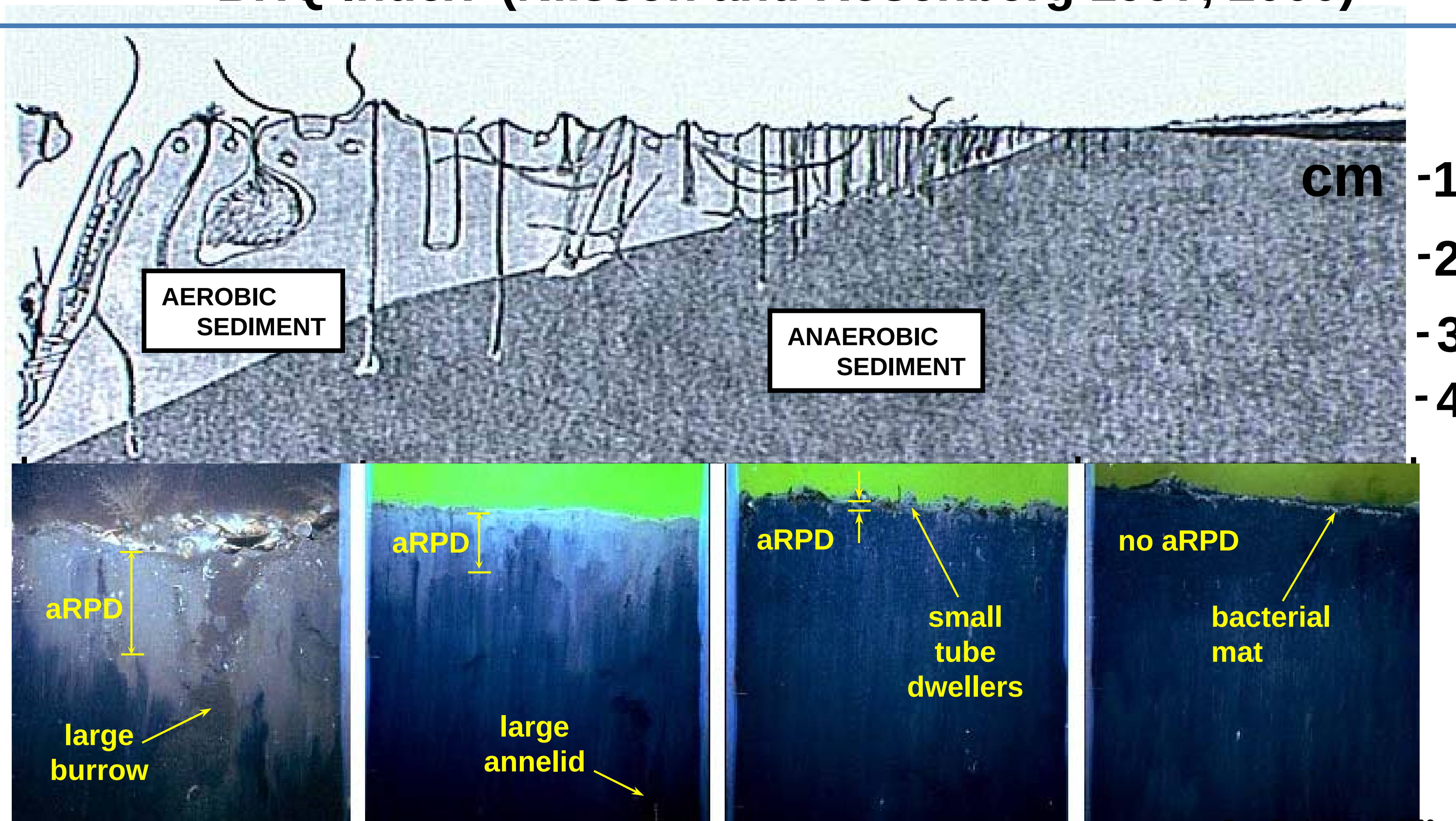
**no apparent oxidized sediment or infauna**



**Healthy, oxygen present**

From Bergen; from Cicchetti; 2006

# Two indices of infaunal condition based on images:
## OSI (Rhoads and Germano 1986)
## BHQ Index (Nilsson and Rosenberg 1997, 2000)

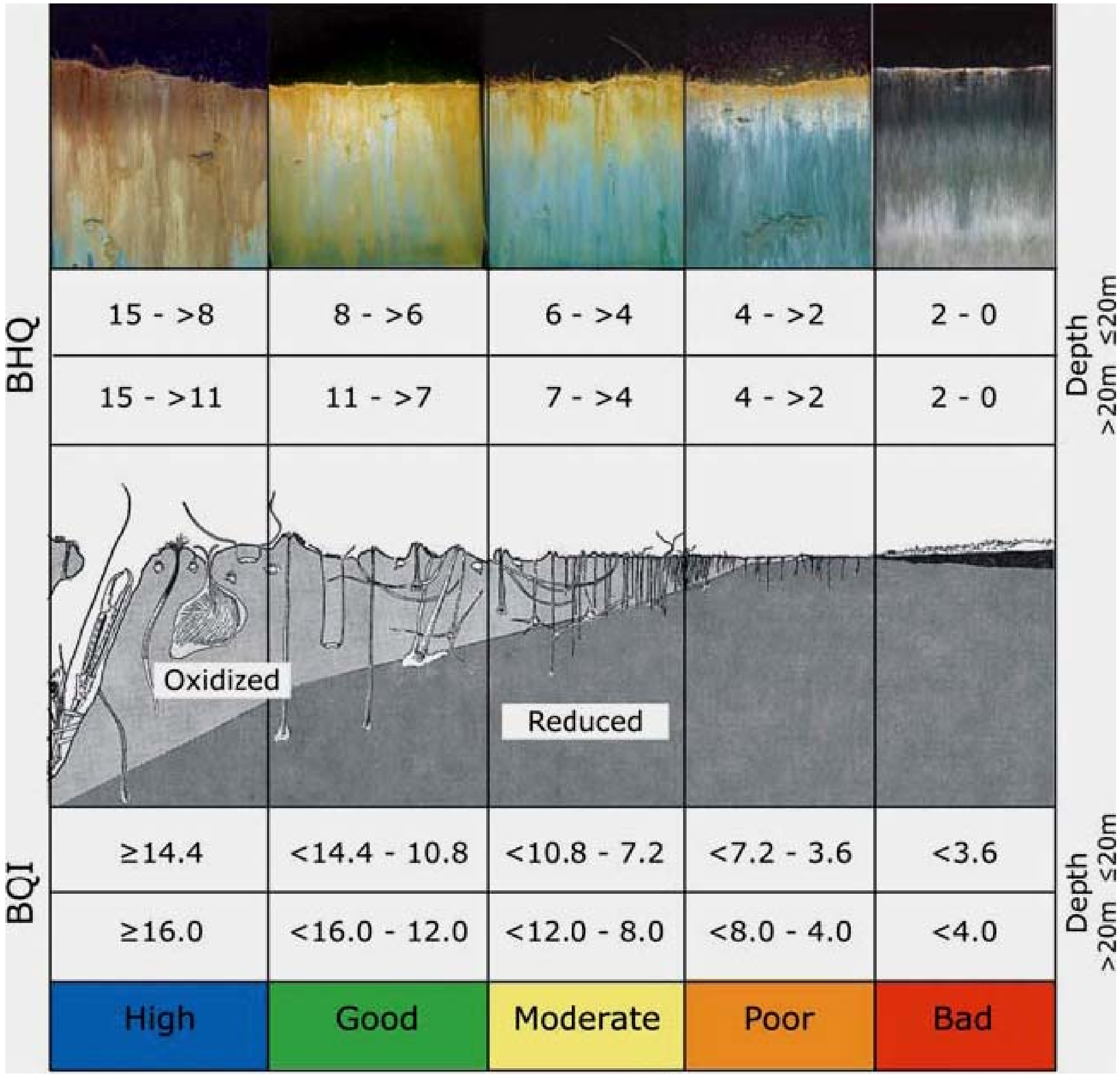



From Cicchetti et al. , 2006

# Sediment profile cameras and assessment:

**The European Water Framework Directive.**

**(Rosenberg et al 2004)**

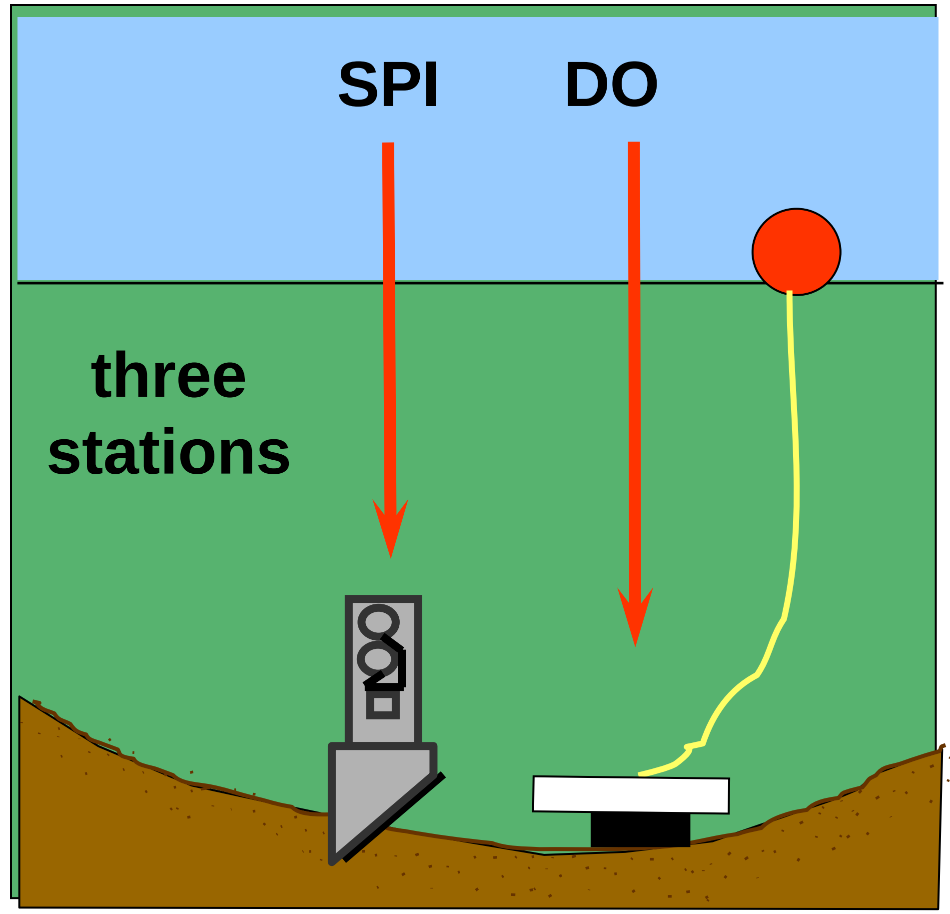



From Cicchetti et al. , 2006

# How does the camera see low DO as a stressor in NE estuaries?

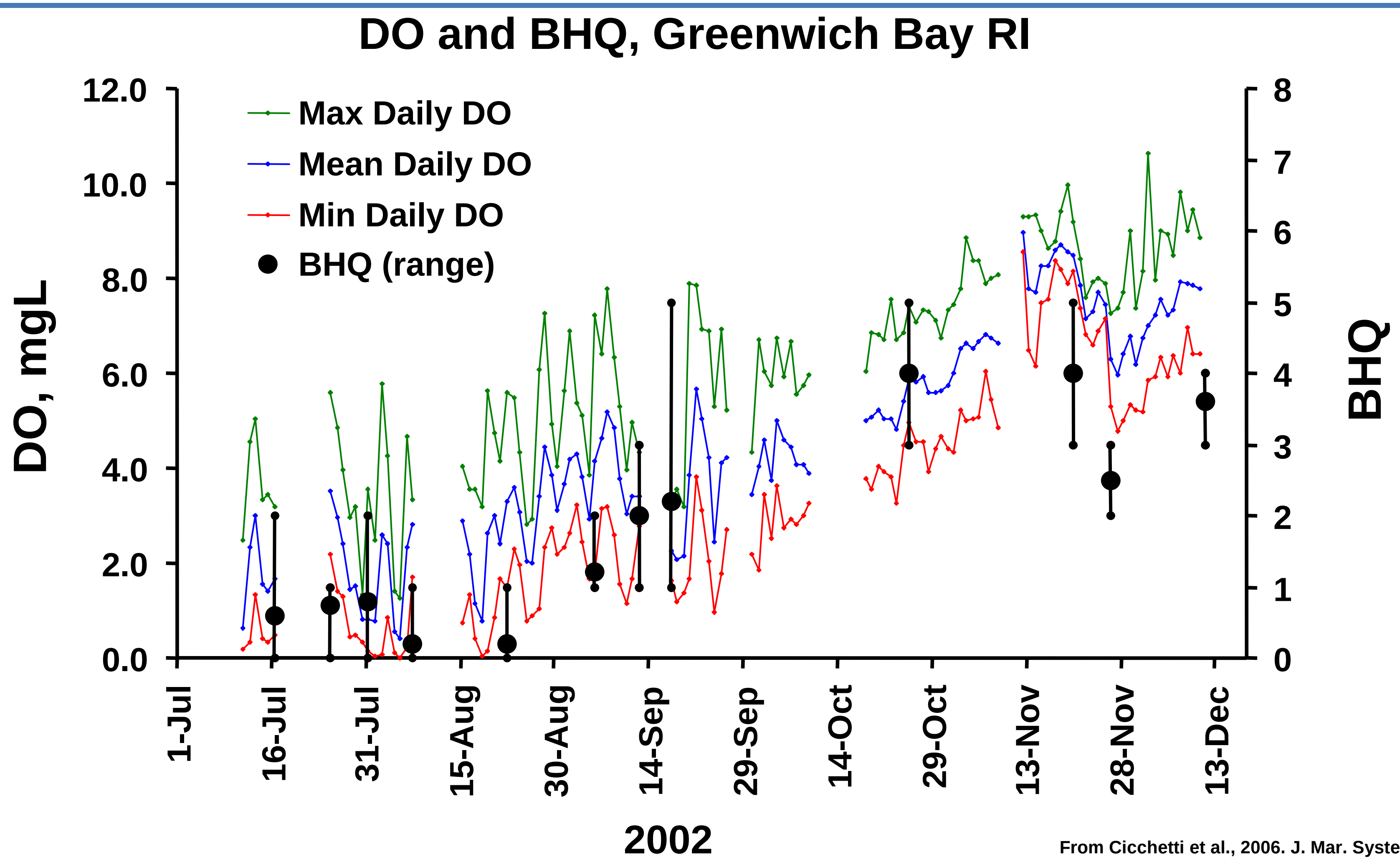
Moor DO loggers at 3 stations
over a few sediment types and DO regimes.

Deploy cameras biweekly for a season.



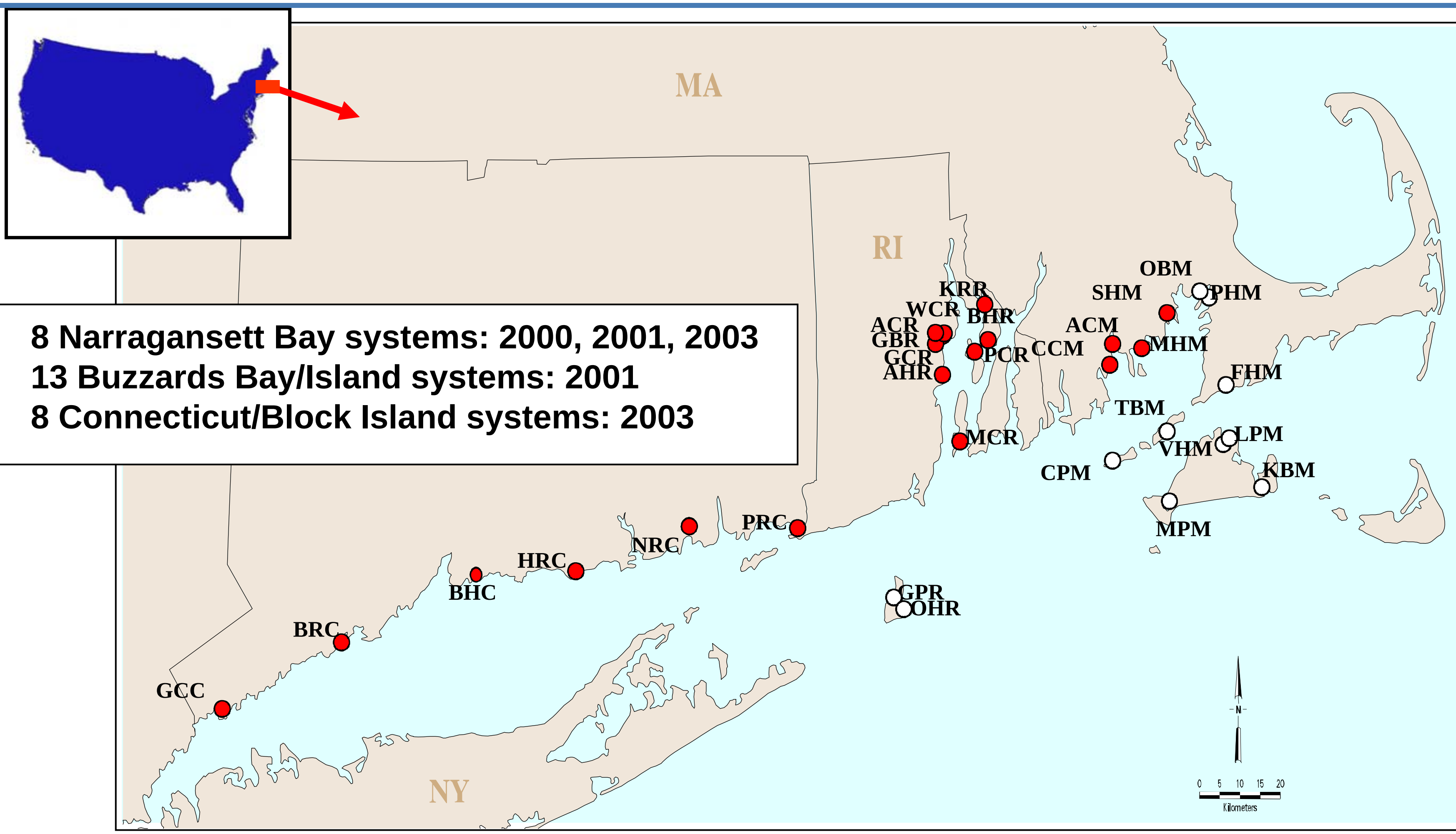

From Cicchetti et al. , 2006

**Indices "see" function, correlate to DO & other stressors . . .**



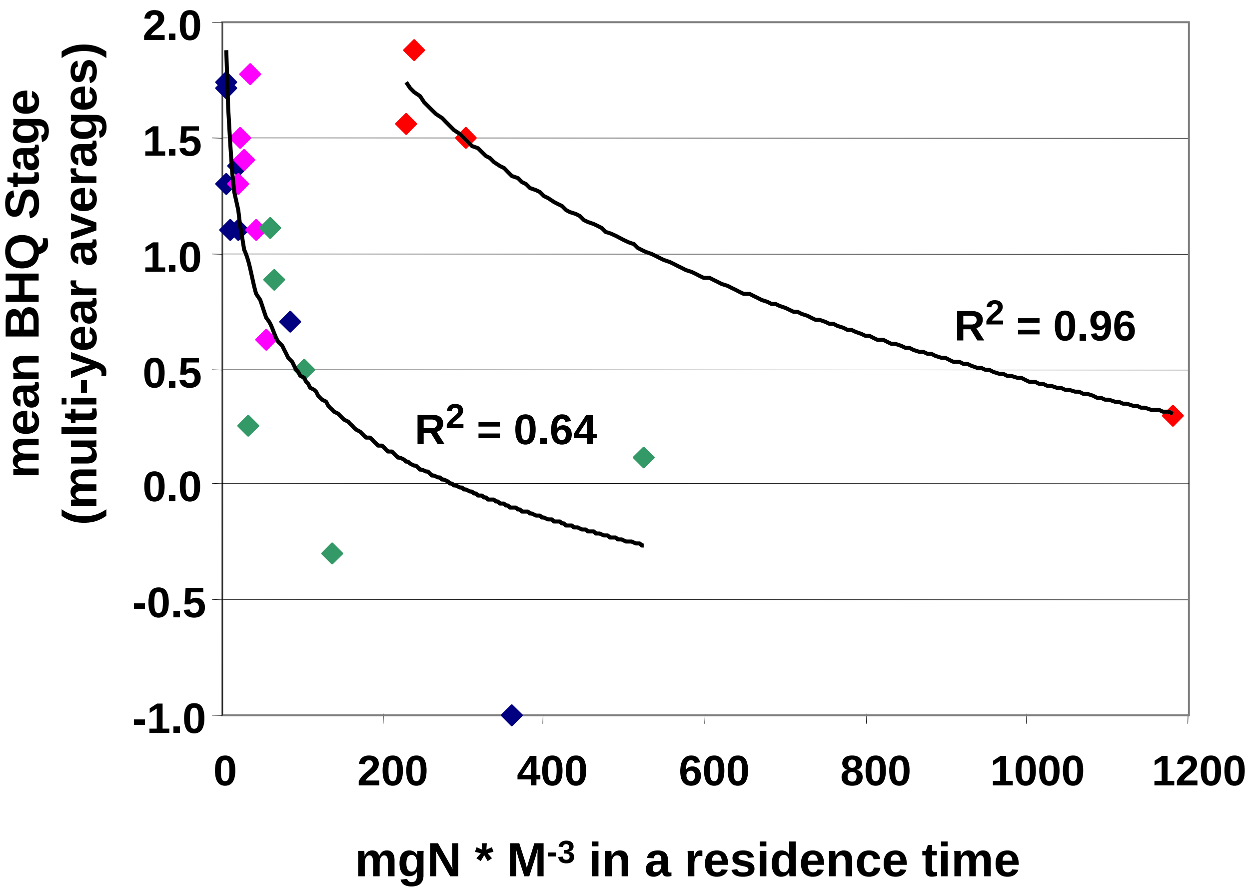

From Cicchetti et al., 2006. J. Mar. Systems.

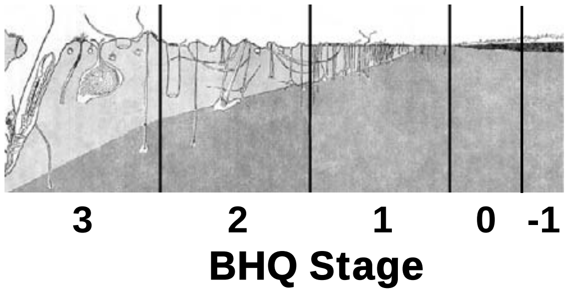
# Benthic Response: 29 coves & sub estuaries, NE USA




8 Narragansett Bay systems: 2000, 2001, 2003
13 Buzzards Bay/Island systems: 2001
8 Connecticut/Block Island systems: 2003

# Preliminary model:
# benthic response vs. nitrogen load




**Severely restricted systems and recreational boater havens removed**

From Cicchetti et al. , 2006

# Stratification of stressor-response for criteria development

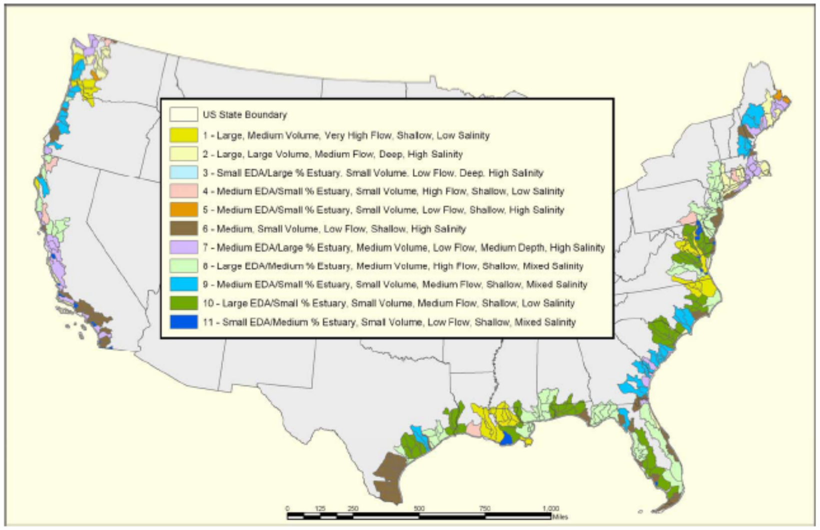
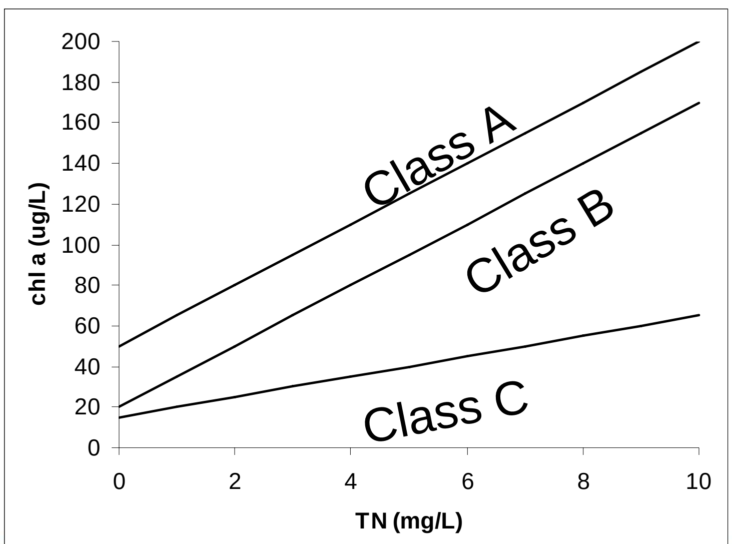



Figure ES- 3. Estuarine areas classified through cluster analysis of physical and hydrological variables.




- **Issue**
  - Stressor-response relationships from nationwide data sets are too noisy to support criteria development
- **e-Estuary will provide**:
  - Identification of ‘reference watersheds/estuaries within a class
  - Strata for applying criteria
  - Stratified stressor-response relationships as a basis for criteria

Classification Framework for Coastal Systems, US EPA 2004

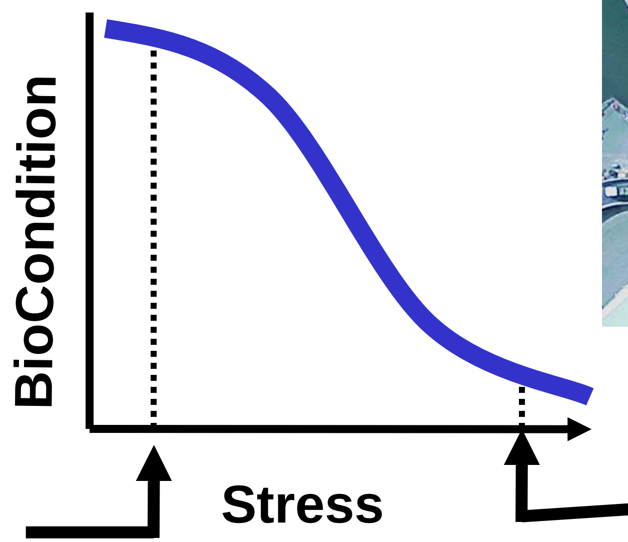
Detenbeck and Pelletier, 2006

**From Detenbeck et al. , 2006**

# TALU = Tiered Aquatic Life Uses

***A scientific framework for determining tiers of biological response to anthropogenic stress towards better environmental management***

Minimally disturbed, forested watershed

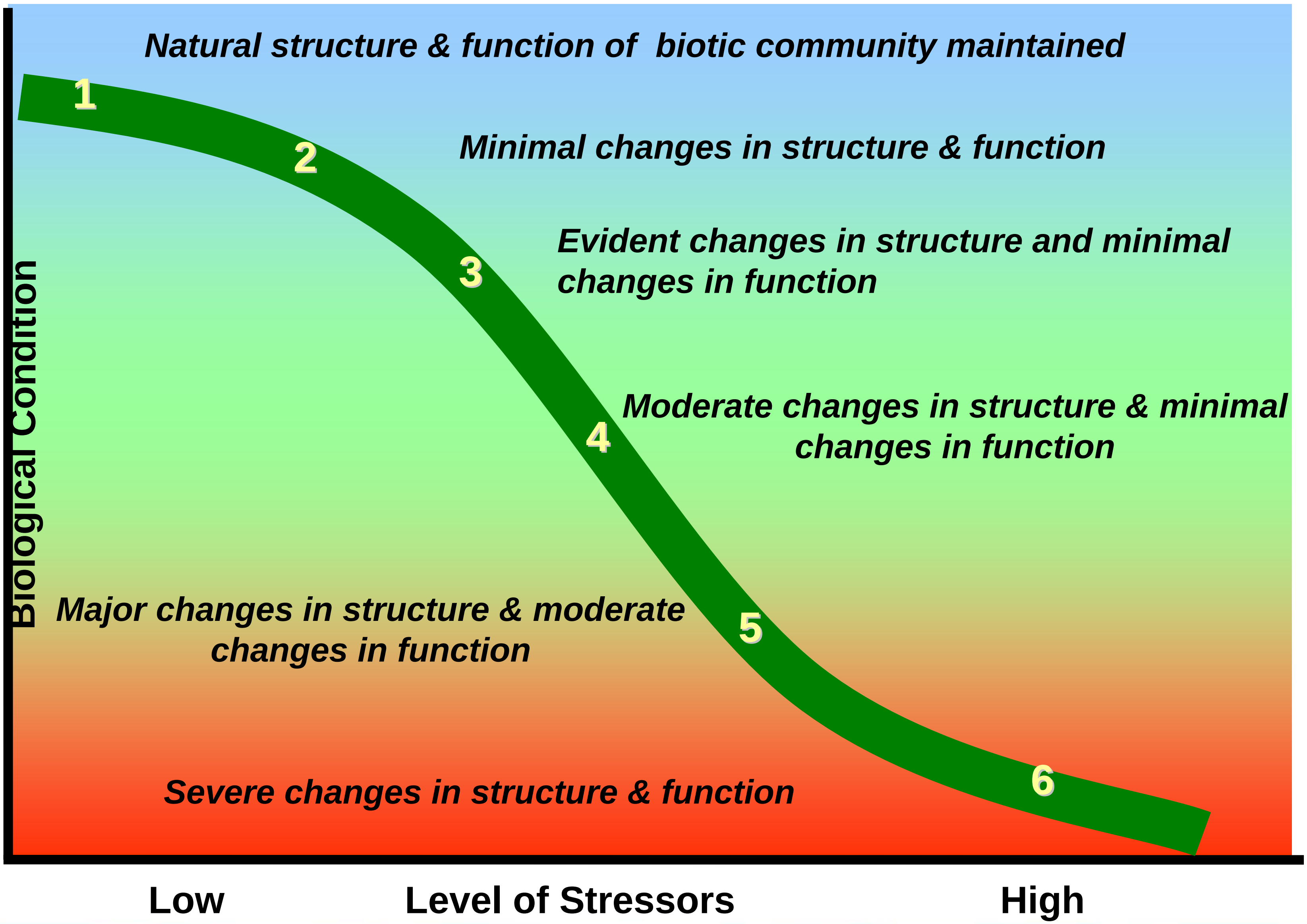



Urban estuary, industrial watershed,

***Used in streams***
***Being developed for estuaries***

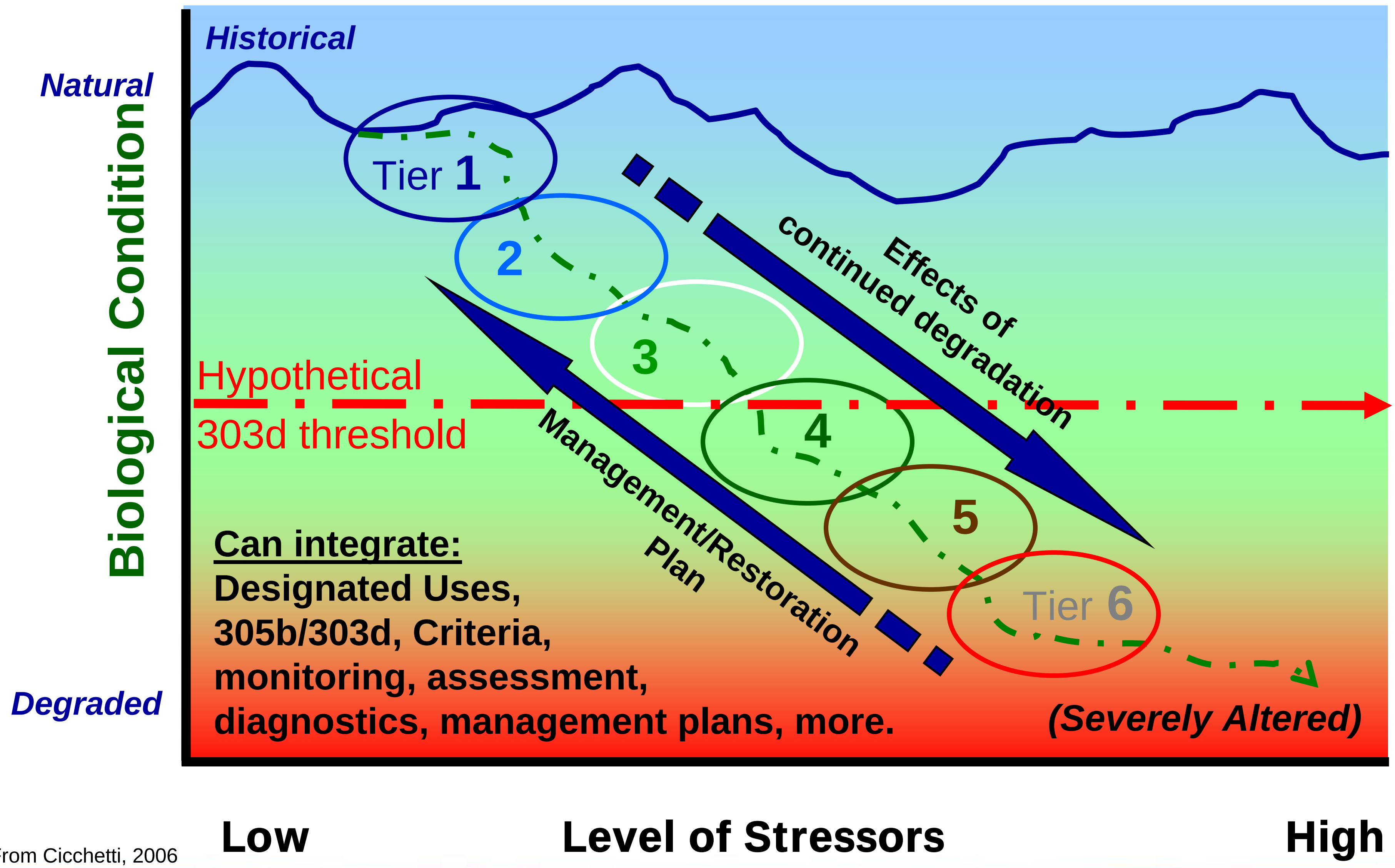
US EPA 2005. Use of biological information to better define designated aquatic life uses in state and tribal water quality standards: Tiered Aquatic Life Uses.

## TALU biological condition gradient:




From Cicchetti, 2006

## TALU provides an integrating scientific framework for assessment and management




From Cicchetti, 2006

# *Indicators*

- One size does not fit all
- Simpler is better
- Consider needs for application at multiple scales
- Need to fit regulatory scale
- Quantify and communicate uncertainty and variability
- Let the question define the indicator
- Build on existing and/or easily expandable data sets
- Must be feasible/ manageable

Habitat mosaics and TALU: Premise –

Maps of living habitats or *biotopes* can be related to stressors and used to describe biological condition.

## Pressure → Biological Condition Gradient → Faunal Guilds

**Human disturbance**

(Anchors Tier 1 at zero human impact)

Numeric indices of:
- land-use N-load
- shoreline development
- human population
- dischargers
- other impacts

**Altered biotope landscapes**

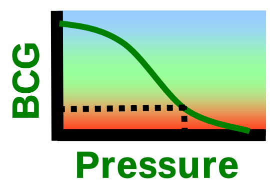
(Allows bioassessment to Tiers, links to Designated Uses)

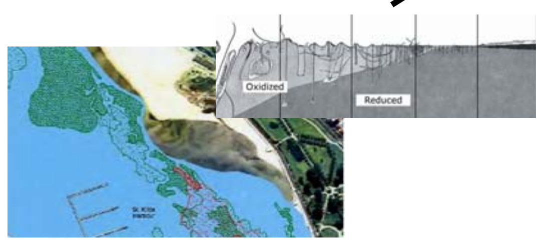
Altered biotope map with numeric indices that integrate:
SAV
distinct benthic communities
marsh
shellfish reef
etc.

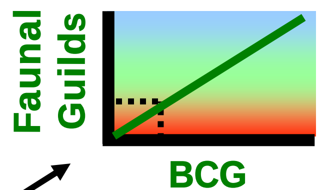
**Ecological / Societal / Economic value of identified critical guilds**

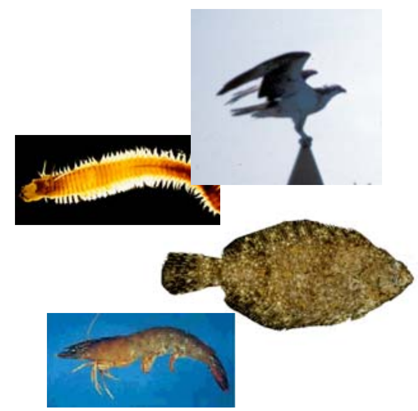
(Refines & communicates Designated Uses, engages stakeholder interest)

Links can be derived via expert consensus, or can be quantitative.



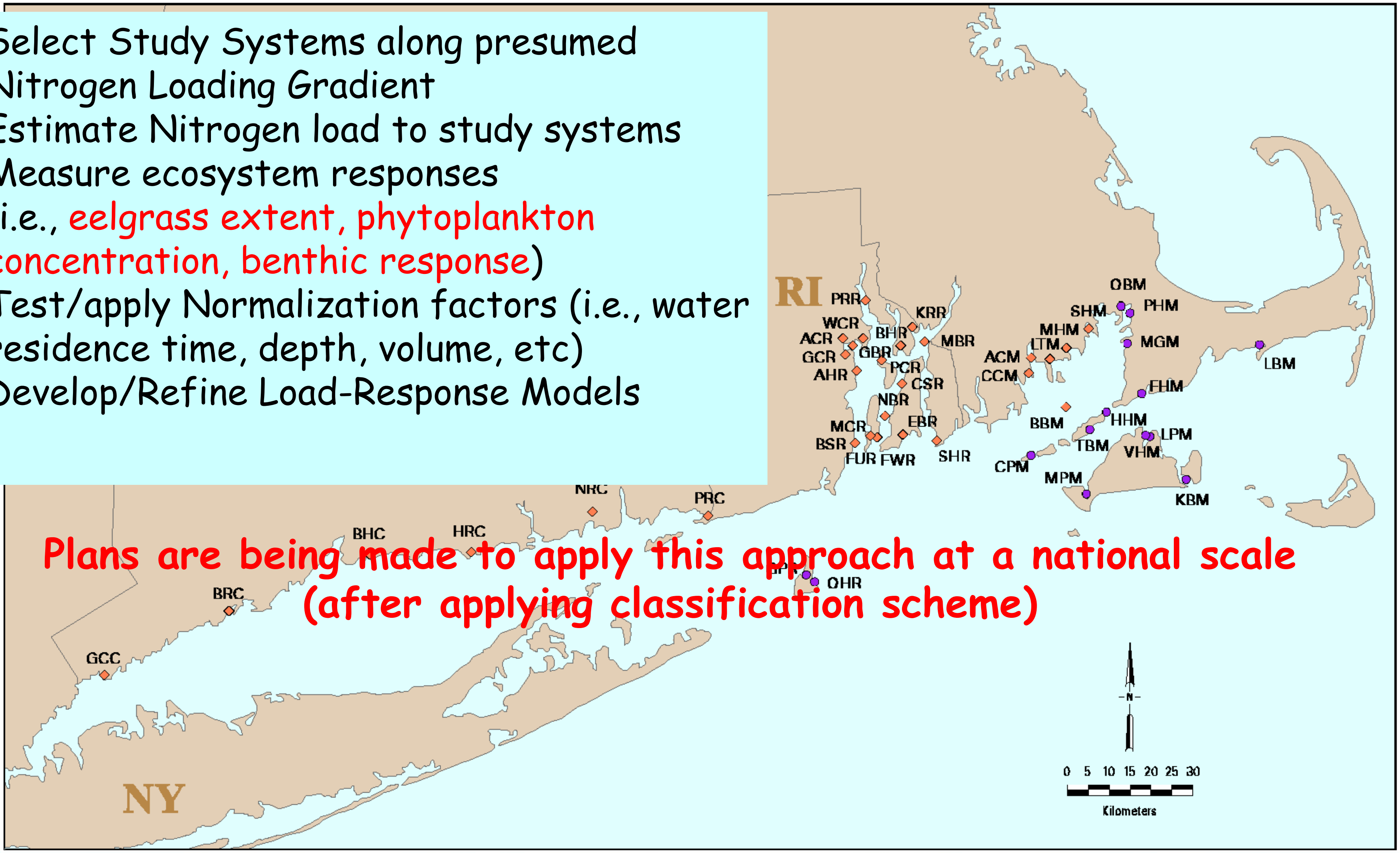



From Cicchetti et al. , 2006

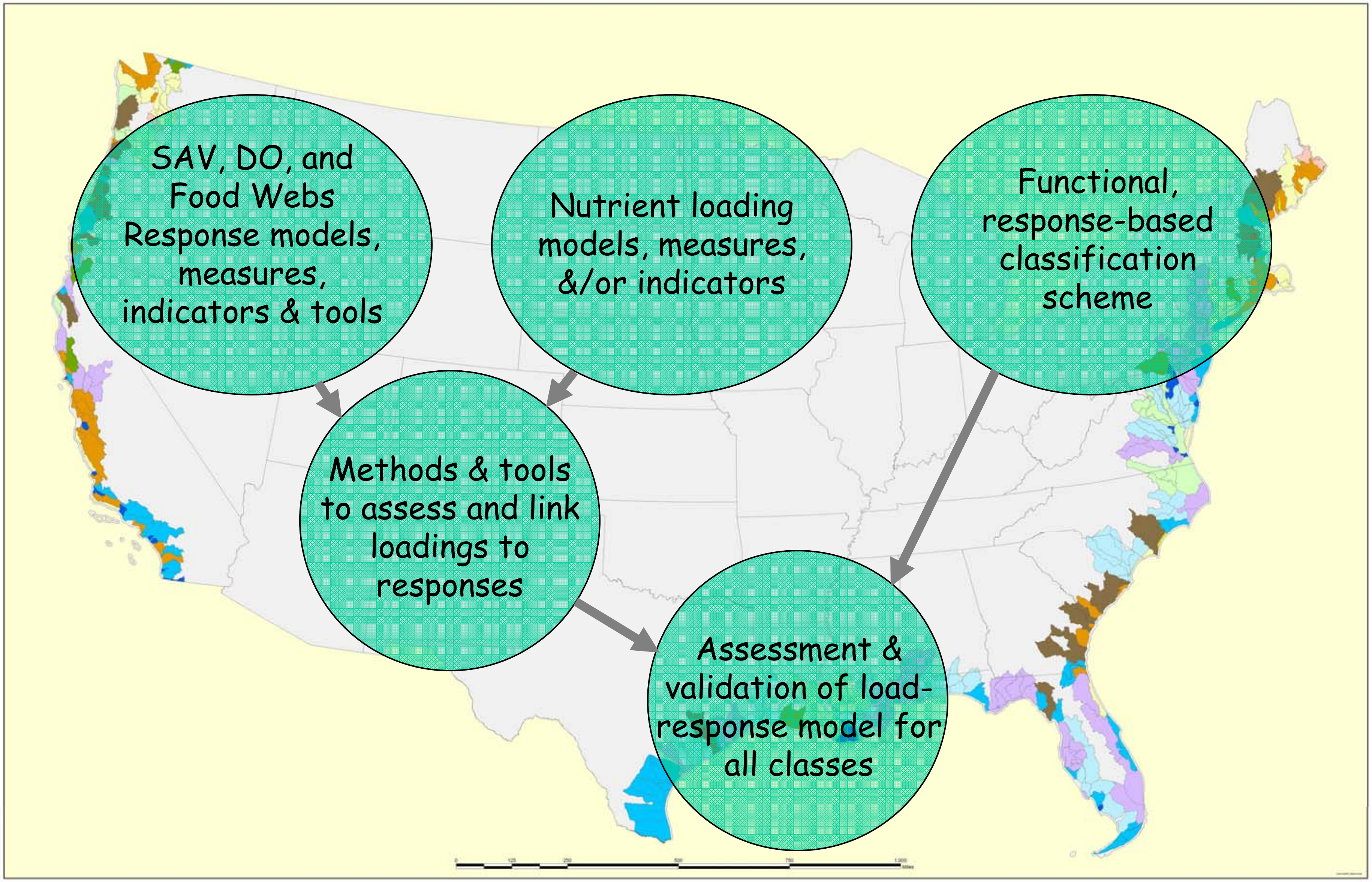
## *Research Design:*
## *Multiple System Comparative Approach*

- Select Study Systems along presumed Nitrogen Loading Gradient
- Estimate Nitrogen load to study systems
- Measure ecosystem responses (i.e., eelgrass extent, phytoplankton concentration, benthic response)
- Test/apply Normalization factors (i.e., water residence time, depth, volume, etc)
- Develop/Refine Load-Response Models

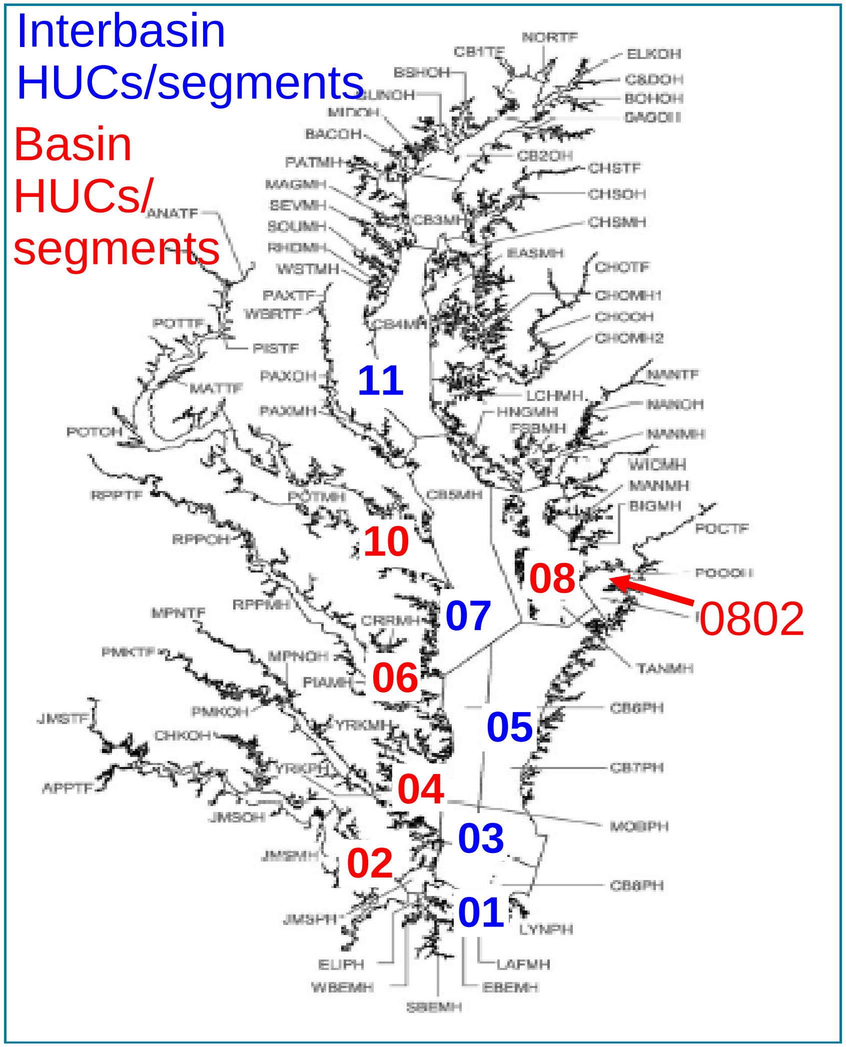



**Plans are being made to apply this approach at a national scale (after applying classification scheme)**

# Research Elements of the Critical Path



## *Determining scales for assessment & listing*




2003 Chesapeake Bay Segmentation Scheme

Source: Chesapeake Bay Program.

- **Issue**
  - No common protocol for determining 303(d) listing segments
- **e-Estuary will provide**: - Segmentation by local residence time
  - Hierarchical coding scheme
    - Estuary "address"
    - Flexible aggregation
    - Link to appropriate watershed scale

# ***Stressor-response as approximations***

- Detailed mechanistic models vs. simple but useful approximations

- A conceptual model of stressor actions and interactions, developed and published under the Aquatic Stressors Framework (US EPA 2006) and stressor interaction, forms the basis for an approach to evaluating multiple stressors. In conjunction with the conceptual model, classification schemes have been developed and are currently being refined to capture regional and ecosystem class-specific differences in retention time, factors influencing effective concentration of pollutants, and processing rates (US EPA 2004, Engle et al. 2006). Under the aegis of the Typology Group of the US EPA National Estuarine Experts Workgroup (NEEW), refinements to a classification scheme explaining differences in estuarine response to nutrients will include specific tests of whether addition of modifying factors (water color, turbidity) can improve nutrient-response models. Regional and local demonstrations will be performed to evaluate usefulness of these tools. Similar work on classification of habitat needs for fisheries (NOAA, 2005) can also be utilized for multiple-stressor considerations.

# *Example of indicators*

- For classification into grouped response

- For presence/absence
- For continuum response
- For condition – put on a St-R model
- For accountability (do regs work? ID cause? For valuation?)

- Integrative stress indicators
- Variability indicators
- Population level, individual level, environmental
- …. NOT DONE!

## *Incorporation into management tools*

- Predictive models
  – ecosystem response
  - population response
- Risk assessment
- Extrapolation (stressor; location)
- Multiple stressor
- Sensitivity

- NOT DONE

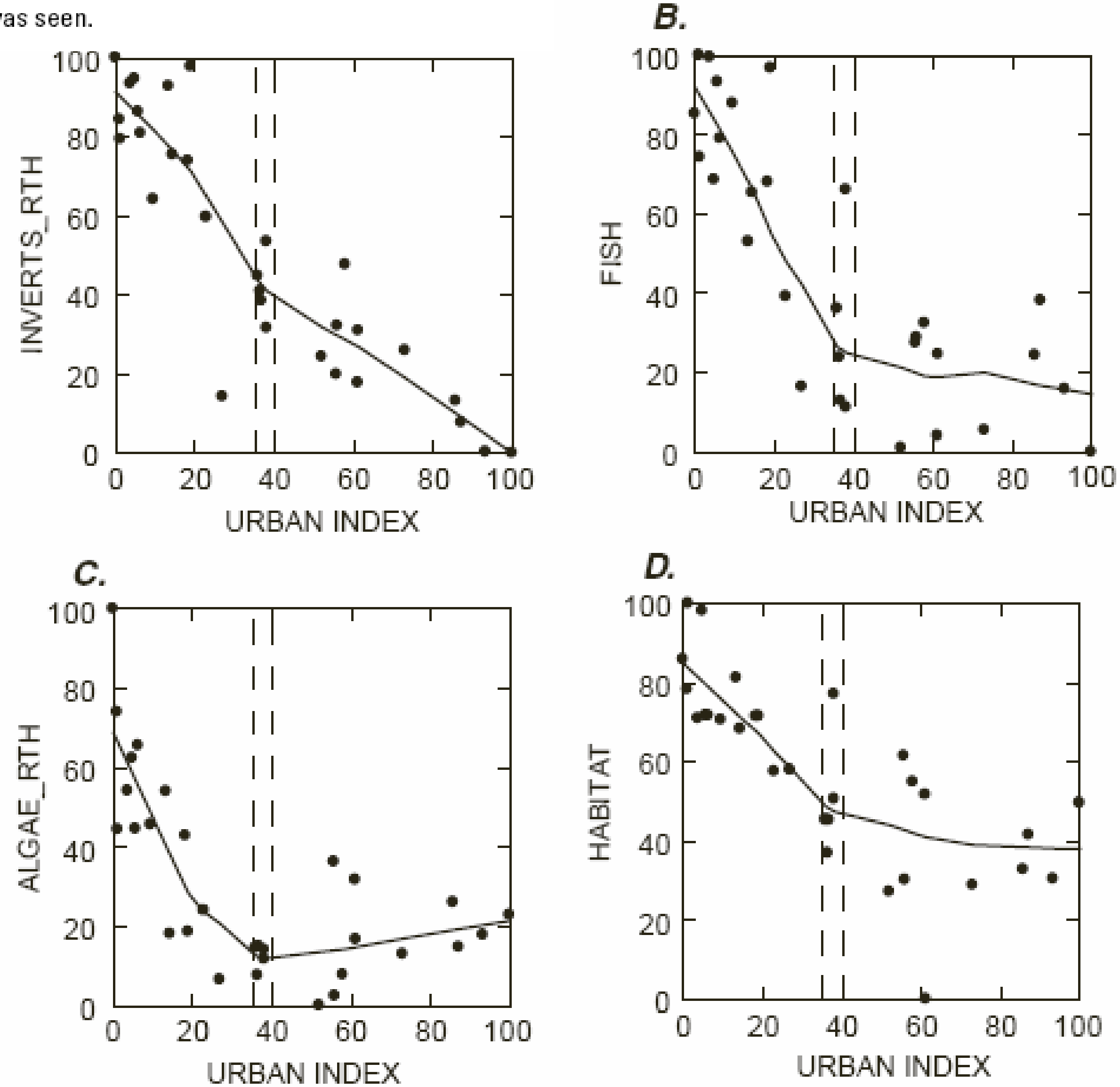
## *NHEERL Aquatic Stressors Research on Nutrients*

- Focused on coastal receiving waters (Great Lakes, estuaries and near coastal waters influenced by large rivers)
- Goal – improve the scientific basis for developing and supporting nutrient criteria in the Nation's waters <u>by defining nutrient load-ecological response relationships</u>

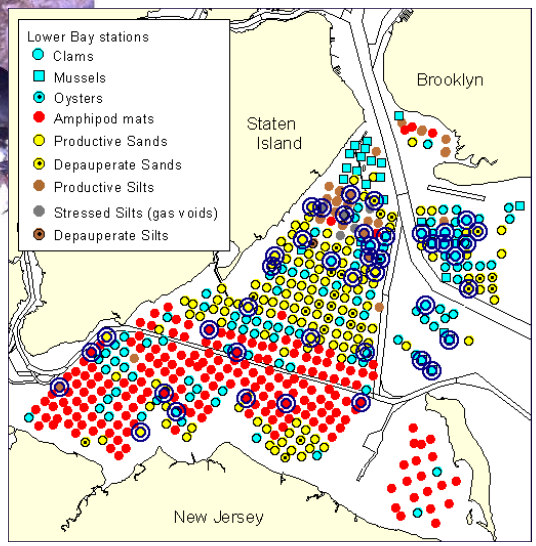

# *Issues of resolution*

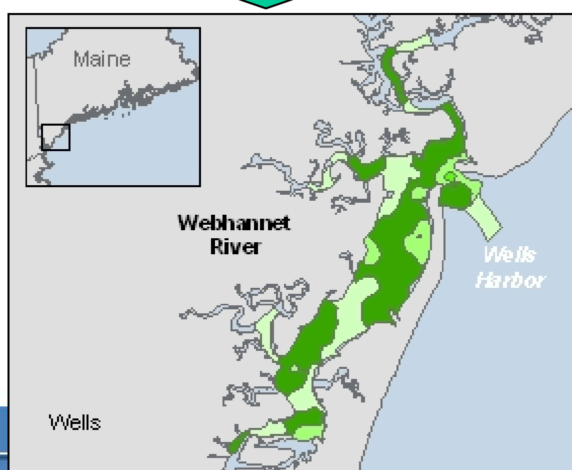
- Screening
- Natural variability in time/space/ biological response
- Technical capability or capacity
- Feasibility  (time, money, complexity)
- Fitting regulatory scale

**Figure 3.** The response of biological communities and habitat ordinations in relation to the urban index, with the LOWESS (SPSS, 1998) regression smoother used to indicate trends. The vertical dashed lines represent urban index values between 35 and 40, which was the most consistent region where a threshold was seen.



# Factoring habitat quality constraints into WQ standards




- **Issue**
  - Not all constraints on biological condition are captured in WQ standards => needed for Tiered Aquatic Life Uses
- **e-Estuary will provide**:
  - Interpolation of point data to continuous coverages
  - Refinement of localized designated use (e.g., habitat use zones (CBP))
  - Input to Habitat Suitability models
  - Basis for comparing existing/ potential habitat across estuaries

## *Initial Analytical Tools*
## *supporting multiple Programs*

- Waterbody segmentation
- Localized residence time (susceptibility scores)
- Habitat use zones (designated use methods)
- Load calculations for multiple stressors
- Comparative estuary tool ('reference estuaries')
- Tools to partition effects among stressors
- Classification tools (allow application to multiple scales)
- Data aggregation tools
- Parameterization of 'outside' models
- Benthic guild calculations (from species database)

Goal #1: Determine Chlorophyll *a* Concentrations in New England Estuarine and Coastal Waters Using Multispectral Remote Sensing From Low-Flying Aircraft

Rationale: Using remote sensing data from blue-green portion of the spectrum offers the capability to estimate chlorophyll *a* concentrations at local and regional scales over long time periods

Approach: Use the SeaWiFS Ocean Color 4 v.4 algorithm to process remotely sensed reflectance data into chlorophyll values.

Goal #2: Develop a regionally tuned algorithm to estimate chlorophyll *a* concentrations in New England estuarine and coastal waters using hyperspectral remote sensing from low-flying aircraft

Rationale: To reduce the variability in chlorophyll a estimates by using the chlorophyll fluorescense peak in the red-NIR portion of the visible spectrum.

Approach: To concurrently collect hyperspectral and chl *a* data from Narr. Bay, RI Sound, Buzzards Bay, and LI Sound

**Goal #3: From hyperspectral remote sensing data , determine phytoplankton groups.**

**Rationale: Phytoplankton may be diagnostic of estuarine health and responsive to changes in nutrient levels**

**Approach: Accumulate hyperspectral signatures of various phytoplankton groups under controlled conditions to determine pigments present and confirm with water samples collected concurrently for HPLC pigment analysis.**

**Goal #4: Continue to derive EMAP/NCA/OW indicators of water quality when possible from multispectral and hyperspectral aircraft and satellite signatures of southern New England coastal waters**

**Rationale: The ability to monitor and apply water quality indicators at a variety of spatial and temporal scales will create opportunities for hindcasting and forecasting environmental conditions.**

**Approach: Combine environmental information from aircraft, spacecraft, and monitoring stations into an Integrated Ocean Observatory System (IOOS) to monitor at local to regional scales.**