2007 Peer Review

Stressor-Response Relationships for Nutrients:
Comparative Systems Approach for Development of Nitrogen Load-Eelgrass Response Models for Estuaries
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AGENCY PROBLEM

Nutrients are a major cause of water quality impairments in estuaries, leading to low dissolved oxygen, fish kills, overabundance of nuisance macrophytes, loss of beneficial macrophytes, likely increased sedimentation, and detrimental species shifts of both flora and fauna. The Agency needs to provide tools to assist states and tribes in developing nutrient criteria for estuaries.

Decline of seagrass beds is one of the damaging effects of nitrogen overenrichment. Excess nitrogen leads to a variety of system changes that tend to favor growth of phytoplankton and macroalgae over SAV, leading to a decline in the spatial extent of seagrass.

One of several approaches outlined by U.S. EPA to assist a state or authorized tribe to develop nutrient criteria is the "effects-based" approach, which relies on nutrient load-response models using the following procedure:

• Establish numeric criteria for response variables such as eelgrass extent
• Adopt a procedure to quantitatively address causal parameters (i.e., nitrogen and phosphorus) and determine nutrient loads in specific water body segments that will achieve the response variable criteria (step 1).

This procedure could be a mathematical loading-response model that is referenced in the state or tribal water quality standards as a "translator" for water quality parameters. This translator procedure, together with numeric criteria for response variables, provide a state or authorized tribe with the means to set targets for permit limits, assessment, and total maximum daily loads.

EPA needs to provide approaches and methods to develop and apply nutrient criteria that will support designated uses for aquatic systems.

Specifically, EPA needs to define quantitative and causal relationships between varying levels of nutrients and the ecological responses of aquatic ecosystems and the resulting services such systems provide.

RESEARCH GOALS

The goal of AED's nutrient effects research program is to construct quantitative relationships between nitrogen loads to estuaries (nitrogen is the limiting nutrient in most estuarine systems) and important estuarine ecological responses for application by the Office of Water, the states and authorized tribes as "translators" in effects-based criteria. This poster describes our research concerning the relationship between the spatial extent of eelgrass (*Zostera marina*) and nitrogen loads in small to medium-sized estuaries in Southern New England.

Objective:
To construct nitrogen load-ecological response models for estuaries of the East Coast, beginning with southern New England.

Specific steps:
• Estimate nitrogen load to estuaries
• Determine eelgrass extent metrics along N gradient
• Estimate residence time
• Construct and revise nitrogen load-ecological response models using residence time or other factors to minimize uncertainty

METHODS

2001 systems
☐ Systems Used in Model
☐ Other Systems Considered
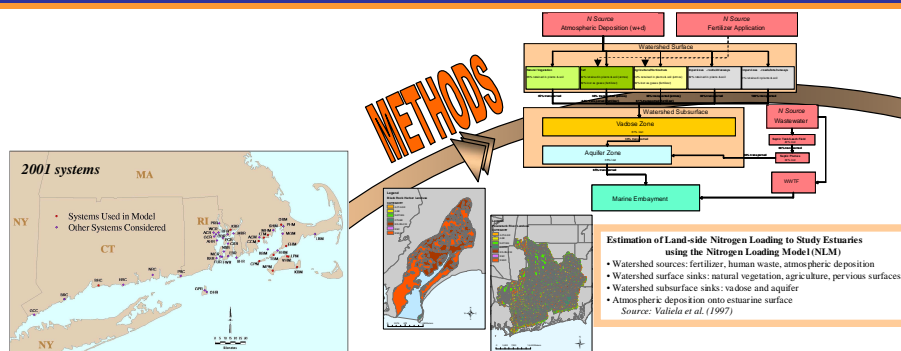
Study System Selection
• Selected 40 systems in 2001
• Sampled 13 systems in 2002 for eelgrass indicator
• Added 9 systems in 2006
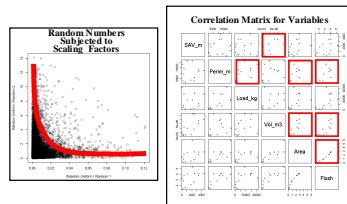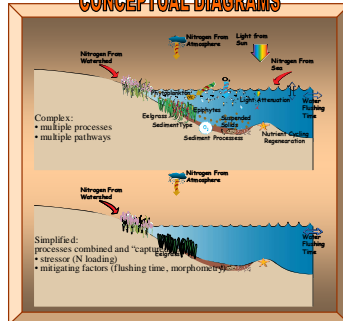• Adding 20 more systems in 2007

Assumptions
• Whole estuary *Zostera* extent is a good system-level indicator sensitive to nitrogen loading
• Initially, *Zostera* linear extent is a good proxy for areal extent (subsequently abandoned when new data became available)
• All other factors would cause additional variance in the ideal model but are not so severe as to require explicit inclusion for this class of estuary (e.g., light intensity, sulfide levels, substrate type, currents)
• Average nitrogen loading to estuaries is reasonably estimated from watershed loading model
• Flushing time is reasonably estimated using an empirical model and can be estimated using estuarine area

Summary
• The approach is based on comparative systems ecology
• Measured response indicators in many estuaries along a nutrient gradient
• mitigating factors (flushing time, morphometry)

Hypothesis: ecological responses will be observable and that they vary according to the level of nutrient inputs

Estimation of Land-side Nitrogen Loading to Study Estuaries using the Nitrogen Loading Model (NLM)
• Watershed sources: fertilizer, human waste, atmospheric deposition
• Watershed surface sinks: natural vegetation, agriculture, pervious surfaces
• Watershed subsurface sinks: vadose and aquifer
• Atmospheric deposition onto estuarine surface
  Source: Valiela et al. (1997)

N Source Atmospheric Deposition (w+d)
N Source Fertilizer Application
Watershed Surface
Watershed Subsurface
Vadose Zone
Aquifer Zone
N Source Wastewater
Marine Embayment

Airplane derived Eelgrass images collected in 2002
• Desired 40% endlap between images; 30% sidelap
• Morning flights with low sun angle
• Wind less than 10 knots
• Tide: ~ 2 hrs. low
• Cloud cover < 5%
• Acquisition at or near 'peak biomass'
• Altitude – 500 ft. (AED specific)
  Source: Finkbeiner et al. (2001) C-CAP protocol

Rock Weed
Deep SA

Eelgrass linear indicator
• Required because of inadequate photo/sampling
• System-level indicator not bed-level
• Proxy for areal measures
• Exploring traditional areal measures

CONCEPTUAL DIAGRAMS

Nitrogen From Watershed — Light from Sun — Nitrogen From Atmosphere — Nitrogen From Sea

Complex:
• multiple processes
• multiple pathways

Simplified:
processes combined and "captured"
• stressor (N loading)
• mitigating factors (flushing time, morphometry)

Empirically Derived Estuarine Flushing Time
• Literature values for flushing time of 11 estuaries
• Estuarine surface area explained 89% variance
• Power-law functionality applied to EPA systems
  Source: Dettmann (2002)

APPROACH

Correlation Matrix for Variables

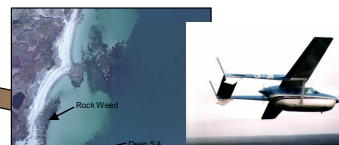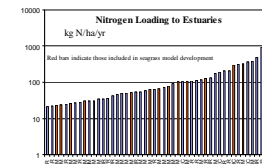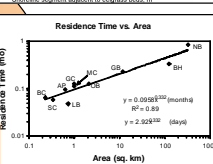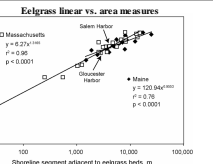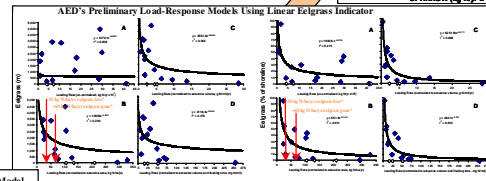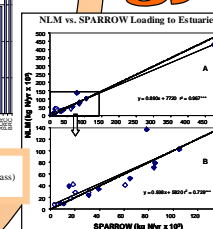### Random Numbers Subjected to Scaling Factors

The use of ratios in the X and Y axes can lead to X-Y cross-correlation:
• Scaling factors (as ratios), if used in both the X and Y variables, may introduce a pattern on the data
• Ideally, data should show minimal co-dependence between X and Y variables or their scaling factors

$$\frac{\text{Eelgrass Length, m}}{\text{Total Shoreline, m}} \quad \text{versus} \quad \frac{\text{(Loading, mg/d) (Flushing Time, d)}}{\text{Volume, m}^3}$$

Flushing Time = f (estuarine area) = f (total shoreline, depth)
Eelgrass length, m = f (estuarine volume)

RESULTS

Eelgrass linear vs. area measures
☐ Massachusetts
◆ Maine
Salem Harbor
Gloucester Harbor
$y = 0.27x^{1.603}$
$r^2 = 0.96$
$p < 0.0001$
$y = 120.94x^{0.6920}$
$r^2 = 0.76$
$p < 0.0001$

Residence Time vs. Area
$y = 0.0956^{0.5593}$ (months)
$R^2 = 0.89$
$y = 2.929^{0.559}$ (days)

Nitrogen Loading to Estuaries
kg N/ha/yr
Red bars indicate those included in seagrass model development

Nitrogen Loading from NLM to Embayments
• Ranged from 20 – 5,000 kg N/ha/yr (20-325 for eelgrass)
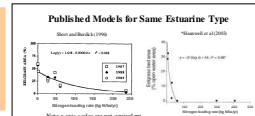• Compared favorably with SPARROW estimates

NLM vs. SPARROW Loading to Estuaries
SPARROW (kg N/yr x 10⁶)

AED's Preliminary Load-Response Models Using Linear Eelgrass Indicator

Preliminary Load-Response Model using Area (State of MA data)
◆ 2001
■ 1995
$y = -91.75 \ln(x) + 428.15$
$R^2 = 0.6259$
Loading Rate (kg N/ha/yr)
Note x-axis scales are not equivalent in all normalized models

Derived Nitrogen Load-Eelgrass Response Model
• Estuaries varied in size and loading rate
• Scaling factors for eelgrass extent and nitrogen loading were used to increase variance explained by model
• Similar shape and ranges as other studies
• Preliminary normalized model was significant at 95% CI and $R^2 = 0.82$

Published Models for Same Estuarine Type
Short and Burdick (1996)
Hauxwell et al.(2003)
Note x-axis scales are not equivalent

IMPACTS

Nitrogen load-eelgrass response models can be used by the states/tribes in southern NE as part of weight of evidence to determine critical nitrogen loading limits protective of designated uses.

Process:
1. Select response value for criteria
2. Apply load-response model
3. Set nitrogen limit based on model output

Advisors to/collaborators:
• EPA LIS Study
• EPA OW National Nutrient Coordinator
• EPA OW National Estuarine Experts Workgroup
• EPA Regions 1, 2
• NOAA NCCOS
• States of RI, NH, CT

OUTCOMES

The load-response translator, together with numeric criteria for response variables, provide a state or authorized tribe with the means to set targets for permit limits, assessment, and total maximum daily loads which will improve water quality in estuaries.

Expected outcomes:
• Improved water column light intensity from nitrogen causes
• Improved light intensity at leaf from reduced epiphytes
• Stable or increased eelgrass extent from nitrogen causes

FUTURE DIRECTIONS

• Develop estuary eelgrass-based indicators that are not subject to cross-correlation
• Increase number of estuaries in model
• Validate model with other estuaries in same class
• Expand to other estuarine classes (by working with NOAA-NCCOS and other partners)

KEY REFERENCES

Dettmann E (2002) Empirical Estimation of Water Residence Times of Non-Riverine Embayments, US EPA/ORD/NHEERL/Atlantic Ecology Division

Finkbeiner M, Stevenson B, Seaman R (2001) Guidance for Benthic Habitat Mapping: an Aerial Photographic Approach. Report No. 0/NOAA/CSC/20117-PUB, U.S. NOAA Coastal Services Center, Charleston, SC

Hauxwell J, Cebrián J, Valiela I (2003) Eelgrass Zostera marina loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae. marine Ecology Progress Series 247:59-73

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Short FT, Burdick DM (1996) Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. Estuaries 19:730-739

Valiela I, Collins G, Kremer J, Lajtha K, Geist M, Seely B, Brawley J, Sham CH (1997) Nitrogen loading from coastal watersheds to receiving estuaries: new method and application. Ecol Appl 17:358-380