Nitrogen-Eutrophication Dynamics in Estuaries

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Key Estuarine Nutrient Issues

• Primary production in estuarine waters is largely N limited; however some systems are N & P co-limited or P limited

• N (& P) Over-enrichment linked to eutrophication

• Sources, forms and proportions of N loading are changing
  e.g. point & non-point surface runoff, atmospheric deposition, groundwater

• Ammonium is increasing as a N source
  Hypoxia, Increased wastewater loads, Ag runoff

• Ecological Effects?*
  * nuisance algal blooms, toxicity, hypoxia/anoxia, food web alterations
Nutrient limitation in the Chesapeake Bay

(Fisher et al. 1998)

Seasonal & Spatial Patterns of Nutrient Limitation in Chesapeake Bay

(Fisher et al. 1998)

Phytoplankton Responses to N and P Patuxent River Estuary

adapted from D’Elia et al. 1985

Fisher et al. 1998
Nutrient limitation dynamics in the Neuse R. Estuary, NC

Gallo 2004

Neuse R. Estuary
Nitrate and Ammonium Concentrations in the Neuse R. Estuary, NC

Paerl et al. 2005; ModMon Project
Relative uptake of Ammonium, Nitrate and Urea in the NRE

Twomey et al. 2005
Conclusions (For Neuse R. Estuary)

- All forms of N are readily utilized
- Uptake of various N forms reflects their availability & concentrations
Ammonium is often a preferred N source, and it is increasing. What are the effects on phytoplankton community structure?

Twomey et al. 2005
Control Nitrate Ammonium
0 3 6 9 12 15

Chl a

Treatment
Control Nitrate Ammonium

Concentration (mg m⁻³)

Alloxanthin

Zeaxanthin

Diatoms

Cryptophytes

All phytos

Bogue Sound Bioassay

Paerl et al. 2006

August, 1996
N source can affect cyanobacterial dominance: Lake Njupfatet, Sweden

Blomqvist et al. 1994
Lake Taihu 3rd largest lake in China. Increased N loads (dominated by ammonium). Blooms have grown to "pea soup" conditions within a decade.
Freshwater discharge and residence time matter as well.

Hydrologic controls of chlorophyll-a (chl-a) production and composition: SeaWiFS (SAS II) during low flow ('95) and high flow ('96) years.

Sources:
- Harding et al. 2006
Chesapeake Bay phytoplankton composition by CHEMTAX – contrasting flow years

Adolph et al 2007
Nutrient cycling and food web implications

Linkages Between Nutrient Inputs, Hydrology, Phytoplankton Community Composition, Grazing, Hypoxia and Fisheries Habitat

Nutrient and Hydrologic drivers

PHYTOPLANKTON COMMUNITY

FORM of Limiting Nutrient (NO₃⁻, NH₄⁺, DON)
Nutrient Ratios, Residence Time

Grazed Phytoplankton Species

Nuisance / Toxic Phytoplankton Species
Some Dinoflagellates Cyanobacteria

Grazing and Water Column Carbon Recycling

Carbon Deposition (POC)

DECREASED O₂ Depletion Potentials

INCREASED O₂ Depletion Potentials

Nutrient Regeneration
Decomposition of POM

OXIC CONDITIONS

HYPOXIA ANOXIA

HYPOXIA

Grazing and Water Column Carbon Recycling

Mixing PHYSICAL CONTROLS
Stratification
Management Implications

- In most estuaries, including regions of the SFO Bay N, plays role as limiting nutrient.
- DIN utilization reflects supply rates: However, some forms (e.g., ammonium) may be preferred.
- Sources of N influence algal composition: Potential food web and biogeochemical implications.
- Light-N interactions may be important, especially in turbid waters.
- Hydrology (storms, floods, droughts) and residence time are important interactive variables, especially for slower growing phytoplankton like cyanobacteria.
- Develop appropriate in situ response assays and indicators to assess responses and impacts.
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Effects of Ammonium or Nitrate (10 μg N L⁻¹) additions (+P) on phytoplankton biomass in eutrophic Lake Erken, Sweden

Blomqvist et al. 1994
Lake Okeechobee, Florida: Nutrient enrichment, water withdrawal, drought conditions. Lots more ammonium.
Expansion of Cylindrospermopsis Raciborskii

Why?
Nutrient/light strategies of *Cylindrospermopsis raciborskii*

- **High P uptake and storage capacity**
  (Isvanovics *et al* 2000)

- **N₂ Fixer**

- **High NH₄⁺ uptake affinity**
  - N additions (NH₄⁺ NOₓ) often significantly increase growth (chl a and cell counts) and productivity (Presing *et al* 1996)

- **Tolerates low light intensities**
  - “Tracks” eutrophication (expand in waters w/ increasing turbidity)
  - Can coexist in water column with other cyanoHABs (Fabbro and Duivenvoorden 1996)
N stimulation of primary production in the Coastal W. Atlantic Ocean

Paerl et al., 1999
N (+P) stimulation of primary production in the brackish Baltic Sea

Baltic Sea 2000, Bioassay A
Primary Productivity

Baltic Sea 2000, Bioassay A
Chlorophyll
Phytoplankton functional group responses

Distance Downstream (km)

Chlorophytes (µg L⁻¹)

Cyanobacteria (µg L⁻¹)

Dinoflagellates (µg L⁻¹)

River Discharge (m³ s⁻¹)


Bertha
Fran
Bonnie
Dennis
Floyd
Irene
Isabel
What do the data show?

DIN Loading vs. primary production in a range of N. American and European estuaries

\[ \log PP = 0.442 \log \text{DIN} + 2.332 \]
\[ r^2 = 0.93 \]

Primary production, g C m\(^{-2}\) yr\(^{-1}\)

DIN input, mol m\(^{-2}\) yr\(^{-1}\)

(Nixon 1996)
N loading and algal production in the Neuse R. Estuary

Salinity (psu)

NO$_x$ (ug L$^{-1}$)

chl a (ug L$^{-1}$)