A Global Perspective of Nutrient Overenrichment and Mitigation in Large Marine Ecosystems

- Emilio Mayorga, University of Washington, Seattle, USA
- Sybil Seitzinger, International Geosphere-Biosphere Program (IGBP), Stockholm, Sweden
Oxygen depletion hotspots in coastal waters, linkage to nutrients

Land use change, urbanization, climate change, hydrological engineering, sediment fluxes
Production of Food and Energy

Have > doubled input of fixed N to terrestrial ecosystems
Positive Effects
Increased Food Production

Synthetic fertilizer → Crop production

Positive Effects include:
- Increased Food Production
- Synthetic fertilizer
- Crop production

Meat production
Rivers Transport Excess Nitrogen to Coastal Waters

- Algal Blooms
- Anoxia (loss oxygen)
- Fish kills
- Biodiversity
- Habitat Loss

Groundwater/Rivers
Drinking Water Degradation
Integrated Approach: Global NEWS 2 Model
Hindcast (1970), contemporary (2000), & scenarios

Nutrient Export from Watersheds

**Nutrient Sources**
- **Natural**
  - N\(_2\)-Fixation
  - P Weathering
- **Anthropogenic**
  - Non-Point
    - Fertilizer (by crop type)
    - N\(_2\)-fixation - crops
    - Manure (by animal species)
    - Atmos. Dep. N
  - Point
    - Sewage (pop.; treatment level)

**Hydrology & Physical Factors**
- Global Watersheds
- Water Runoff
- Precip. Intensity
- Land-use
- Slope

**In-River Nutrient Removal**
- Rivers & Reservoirs
- Consumptive Water Use

Nutrient Loading to Coastal Waters
- At ~ 6000 river basin mouths
- Annual fluxes of multiple nutrients & nutrient forms

Seitzinger et al. 2005, 2010, GBC; Mayorga et al. 2010, EMS
Global NEWS 2 output, basin yields for Year 2000

Exports normalized by basin area

<table>
<thead>
<tr>
<th>Nitrogen (kg N km^{-2} yr^{-1})</th>
<th>15</th>
<th>40</th>
<th>70</th>
<th>110</th>
<th>190</th>
<th>350</th>
<th>570</th>
<th>880</th>
<th>&gt; 1220</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus (kg P km^{-2} yr^{-1})</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>50</td>
<td>100</td>
<td>500</td>
<td>&gt; 2000</td>
</tr>
<tr>
<td>Carbon (kg C km^{-2} yr^{-1})</td>
<td>50</td>
<td>100</td>
<td>500</td>
<td>1000</td>
<td>2000</td>
<td>4000</td>
<td>8000</td>
<td>&gt; 20000</td>
<td></td>
</tr>
</tbody>
</table>
Different elements dominated by different forms:

- **N**: DIN & PN
- **P**: PP
- **OC**: DOC & POC

*Mayorga et al., 2010, Env. Model. Soft.*
Nutrient export trajectories
2000 - 2030 - 2050

Includes social, economic, policy, and ecological considerations

http://www.millenniumassessment.org
Global NEWS 2, Integrated Scenario Development

Global NEWS 2, Integrated Scenario Development

1. MEA Scenarios

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2. IMAGE:
   Land Use, Climate,
   Nutrient Management,
   Energy, Wastewater
Global NEWS 2, Integrated Scenario Development

1. MEA Scenarios

2. IMAGE:
   Land Use, Climate, Nutrient Management, Energy, Wastewater

3. WBM$\text{\textsubscript{plus}}$:
   Hydrology and River Discharge
Focus on two contrasting scenarios

<table>
<thead>
<tr>
<th></th>
<th>Worst Case</th>
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<th>Better Case</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Global</td>
<td>Orchestration</td>
<td>Adapting</td>
<td>Mosaic</td>
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<tr>
<td>Envir. Approach</td>
<td>reactive</td>
<td></td>
<td>proactive</td>
<td></td>
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<tr>
<td>Income</td>
<td>high</td>
<td></td>
<td>medium</td>
<td></td>
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<tr>
<td>Population Increase</td>
<td>lower</td>
<td></td>
<td>higher</td>
<td></td>
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<tr>
<td>Fertilizer Use</td>
<td>high</td>
<td></td>
<td>moderate</td>
<td></td>
</tr>
<tr>
<td>Nutrient Management</td>
<td>not optimal</td>
<td></td>
<td>efficient</td>
<td></td>
</tr>
<tr>
<td>Meat Consumption</td>
<td>high</td>
<td></td>
<td>moderate</td>
<td></td>
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<tr>
<td>Sewage Treatment</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Access</td>
<td>full</td>
<td></td>
<td>constant %</td>
<td></td>
</tr>
<tr>
<td>N removal</td>
<td>high</td>
<td></td>
<td>moderate</td>
<td></td>
</tr>
</tbody>
</table>

Specifics vary by region and country

Bouwman et al., Van Drecht et al., 2009 GBC
Change in Global River Export: N, P, C

Export to Oceans N, P or C Tg yr⁻¹

1970 - 2000 - 2030

% Changes

1970-2000
DIN: 35%
DIP: 29%
DON, DOP, DOC (& DSi): 2 to 5%
PN, PP, POC: 10 to 18%

2000-2030
DIN: -6 to 18%
DIP: 19 to 48%
DON, DOP, DOC (& DSi): -5 to 6%
PN, PP, POC: -8 to -11%

Seitzinger et al, 2010, GBC
Change in Global River Export: N, P, C

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Seitzinger et al, 2010, GBC

Export to Oceans N, P or C Tg yr⁻¹

a. Change in global river export (Tg yr⁻¹)

b. Change in global river export (Tg yr⁻¹)

c. Change in global river export (Tg yr⁻¹)
Impacts of policy options on future nutrient inputs to Coastal Waters

- Nutrient Sources from Food and Energy
- Nutrient Export at River Mouth
- Policy Options & Costs
- Coastal Effects (algae blooms; anoxia; fisheries; etc.)
Contrasting Regional Trajectories 1970-2050, Global Orchestration
Change DIN river export
South Asia, 2000-2030

Global Orchestration

Seitzinger et al. 2010 GBC
Change DIN river export
South Asia, 2000-2030
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Seitzinger et al. 2010 GBC
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Global Orchestration

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Change DIN river export
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Global Orchestration

DIN Export to Oceans

Adapting Mosaic

Seitzinger et al. 2010 GBC
Contribution to river DIN export
South Asia

How were improvements achieved?

• Sewage connectivity constant %
• Technological NOx controls
• Lower meat consumption
• Efficient nitrogen management in agriculture

Seitzinger et al. 2010, GBC
Contribution to river DIN export
South Asia

How were improvements achieved?
- Sewage connectivity constant %
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- Lower meat consumption
- Efficient nitrogen management in agriculture

Other nutrients?
- Greater role for sewage inputs on DIP
- Reservoir retention impact on particulates and dissolved silica
Change DIN Export
GO 2030 vs Climate Change

A simple model examination

Global DIN Export
Change vs. 2000

Global Orchestration

Seitzinger, Mayorga, et al. unpubl.
Integrated nutrient scenarios: Some conclusions

- Ramifications of continued socioeconomic expansion in developing countries, without nutrient mitigations
- Differential impact of drivers on nutrient forms
- Direct human perturbations to basins may dominate over climate change impacts on nutrient exports through 2030-2050. BUT:
  - Amplifications and interactions
  - Role of extreme events, changed climate distribution, (sub)seasonal variability
  - High uncertainty
- Greater control, options and benefits from policy impacting direct regional perturbations, vs. climate inertia
TWAP LME: Nutrient Impact & Eutrophication Risk

- Aggregate river nutrient exports into LME's
- Ecosystem state and trends based on generalized nutrient impact indicators
- Projections to 2030 & 2050, based on one MEA scenario (Global Orchestration)
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- Aggregate river nutrient exports into LME's
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**Merged nutrient risk indicator incorporating:**

1. *Nutrient load* (DIN as most appropriate proxy)
2. *Nutrient ratios* (N, P, Si) leading to algal community perturbations

Weighted sub-indicators based on expert knowledge, with greater weight on N load
TWAP LME: Nutrient Impact & Eutrophication Risk
TWAP LME: Nutrient Impact & Eutrophication Risk

Merged Indicator

Year 2000 [66]  Risk:
1 [27]  Very low
2 [13]  Low
3 [13]  Moderate
4 [5]  High
5 [5]  Very high

LME NEWS Basins
Majority (63%) of LME's are currently in very low or low risk for coastal eutrophication.
Most LME's in high to very high risk are in W. Europe, S & SE Asia.
Increase in risk will occur largely in S & SE Asia, and also in S. America & Africa.
Bay of Bengal LME: A more detailed analysis of river nutrient inputs

“Second-level”, more detailed examination of nutrient alterations and exports to an LME

Seitzinger, S.P., S. Pedde, C. Kroeze and E. Mayorga. Understanding nutrient loading and sources in the Bay of Bengal Large Marine Ecosystem. Final Report for the BOB LME Project, 22 May 2014

Ability to examine sub-LME variability by nutrient (P, N, Si), nutrient form (dissolved vs particulate), and sources

3 largest rivers vs. Total LME
Basin area: 58%
Discharge: 66%

Large % of inputs, but coastal areas exposed to wide range of conditions
Bay of Bengal LME: A more detailed analysis of river nutrient inputs

Nutrient Sources

Seitzinger et al. 2014, BOB LME Report
Bay of Bengal LME: A more detailed analysis of river nutrient inputs

Nutrient Sources

Largest source of DIP exported to BOB LME; year 2000 and Global Orchestration scenario for 2030 & 2050

Seitzinger et al. 2014, BOB LME Report
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- BOB LME Project support
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