Baltic Sea Catchment Modelling

- BNI
  - Catchment characteristics and threads
    - CSIM model
  - Modelling eutrophication issues and N and P fluxes
    - Isotope studies in AMBER

- Christoph Humborg, Carl-Magnus Mörh, Erik Smedberg, Dennis P. Swaney
BNI History

• MArine Research on Eutrophication (MARE)
• Funded 1999-2006
• Aim: Define “critical loads” for Baltic eutrophication and illustrate “cost-efficient” ways to reach these loads
• Product: Decision Support System NEST
• “Institutionalized” in 2007 as Baltic NEST Institute (Swedish and Danish branch)
NEST can be used freely with any computer with Internet access from http://www.Balticnest.org
In order to reach the goal towards a Baltic Sea unaffected by eutrophication

WE AGREE on the principle of identifying maximum allowable inputs of nutrients in order to reach good environmental status of the Baltic Sea.

WE ALSO AGREE that there is a need to reduce the nutrient inputs and that the needed reductions shall be fairly shared by all Baltic Sea countries.

BEARING IN MIND that the figures are based on the MARE NEST model, the best available scientific information, and thus stressing the provisional character of the data WE ACKNOWLEDGE that the maximum nutrient input to the Baltic Sea that can be allowed and still reach good environmental status with regard to eutrophication is about 21,000 tonnes of phosphorus and 600,000 tonnes of nitrogen.

WE FURTHERMORE RECOGNISE that, based on national data or information from 1997-2003 in each sub-region of the Baltic Sea, the maximum allowable nutrient inputs to reach good environmental status and the corresponding nutrient reductions that are needed in each sub-region are as follows:

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Maximum allowable nutrient input (tonnes)</th>
<th>Inputs in 1997-2003 (normalised by hydrological factors)</th>
<th>Needed reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phosphorus</td>
<td>Nitrogen</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>Bothnian Bay</td>
<td>2,580</td>
<td>51,440</td>
<td>2,580</td>
</tr>
<tr>
<td>Bothnian Sea</td>
<td>2,460</td>
<td>56,790</td>
<td>2,460</td>
</tr>
<tr>
<td>Gulf of Finland</td>
<td>4,800</td>
<td>100,680</td>
<td>6,800</td>
</tr>
<tr>
<td>Baltic Proper</td>
<td>6,750</td>
<td>233,250</td>
<td>19,250</td>
</tr>
<tr>
<td>Gulf of Riga</td>
<td>1,430</td>
<td>78,400</td>
<td>2,180</td>
</tr>
<tr>
<td>Danish straits</td>
<td>1,410</td>
<td>30,890</td>
<td>1,410</td>
</tr>
<tr>
<td>Kattegat</td>
<td>1,570</td>
<td>44,260</td>
<td>1,570</td>
</tr>
<tr>
<td>Total</td>
<td>21,060</td>
<td>601,720</td>
<td>30,310</td>
</tr>
</tbody>
</table>

In order to diminish nutrient inputs to the Baltic Sea to the maximum allowable level WE AGREE to take actions not later than 2016 to reduce the nutrient load from waterborne and airborne inputs aiming at reaching good ecological and environmental status by 2021,
• 87 major catchments and 21 costal strips
• Hydrological data and nutrient fluxes for 1970-2006
• Landscape types, Population
  Agricultural data
  Atmospheric deposition
• PLC 5 based on national inconsistent approaches
Hydrological alterations and global warming affecting Si and C fluxes

Changes sewage cleaning and livestock densities affecting N and P fluxes
Figure 1. Modeled seasonal river discharge to the Baltic Sea from HEV-Baltic for present-day conditions (shaded) and four climate change scenarios. Shown are daily means over the 23-year modeling period. All plots are drawn to the same X and Y scales.

Graham 2004
Changes in lifestyles translates into N emissions

Y = 6.9 * ln(X) - 4.10548635
R² = 0.71
Now: fixed type concentrations
Future: Type concentrations = f(land use)

Mörth et al. 2007
Emission numbers and informations on MWWTPS, rural vs urban population, livestock densities, various retention coefficients in soils and river were used for **Scenario Analyses**

<table>
<thead>
<tr>
<th>Country</th>
<th>Milk cows</th>
<th>Other cattle</th>
<th>Slaughter pigs</th>
<th>Sows</th>
<th>Humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belarus</td>
<td>N</td>
<td>P</td>
<td>N</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>47.4</td>
<td>9.8</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Czech republic</td>
<td>63.0</td>
<td>11.8</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Germany</td>
<td>96.1</td>
<td>16.1</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
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<tr>
<td>Denmark</td>
<td>74.2</td>
<td>13.3</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
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<tr>
<td>Estonia</td>
<td>94.3</td>
<td>15.9</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
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<tr>
<td>Finland</td>
<td>84.8</td>
<td>14.6</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
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<tr>
<td>Lithuania</td>
<td>63.5</td>
<td>11.9</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
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<tr>
<td>Latvia</td>
<td>62.2</td>
<td>11.7</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
</tr>
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<td>Norway</td>
<td>101.6</td>
<td>16.8</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Poland</td>
<td>63.0</td>
<td>11.8</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Russia</td>
<td>47.4</td>
<td>9.8</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Sweden</td>
<td>101.6</td>
<td>16.8</td>
<td>34.0</td>
<td>4.5</td>
<td>8.8</td>
</tr>
</tbody>
</table>
Simulated (validation period vs. measured) streamflow, TN and TP loads

Mörth et al. 2007

Fig. 5. A multiannual fit of simulated and measured data for the validation period (1990–1994): (a) streamflow, (b) Tot-N, and (c) Tot-P.
Seasonal simulations of an eutrophied (Oder) and unperturbed system (Råne)

Mörth et al. 2007
Future plans

• Forcing data update
• Type concentrations = f(soil types, specific runoff, crop type, livestock density, manure handling etc.)
• Riverine Retention = f (TI, HL)
HELCOM data on hot spots and sewage

HELCOM Municipal Hot Spot List

PLC-4 MWWTP List
Watershed Nutrient Budgets as a solid base for the scientific and economic analyses

NANI=Net Anthropogenic Nutrient Input

Howarth et al. 1996; Boyer et al. 2002
NANI = Food and Feed budgets + N-fixation + Fertilizer Use + Atmospheric Deposition

**Figure 6.** Net anthropogenic N inputs (kg N km⁻² yr⁻¹) vs riverine N exports to the Baltic Sea (kg N km⁻² yr⁻¹) of 36 major Swedish watersheds.
Dynamic description of retention

Y = 0.014 * X + 0.033
R-squared = 0.844
Modelling of the Baltic Sea catchment

Validation by multiple stable isotopes

- Cultivated land in catchment [%]
- Load weighted $\delta^{18}$O-NO$_3$ [%]
- Load weighted $\delta^{15}$N-NO$_3$ [%]

$\text{r}^2 = 0.67$
$n=7$
$p<0.05$

$\text{r}^2 = 0.769$
$n=11$
$p<0.001$

- Terrestrial DOM
- Marine DOM
- Marine sediment
- Marine algae
Tundra and Taiga (Podzol Zone) C-Budgets as linked to Hydrology

- Polar amplification of global warming
- 450 Pg C stored
- ~ 70 annual anthropogenic emissions
- Boreal/subarctic Baltic unperturbed rivers as model systems
Figure 1. Modeled seasonal river discharge to the Baltic Sea from HEV-Baltic for present-day conditions (shaded) and four climate change scenarios. Shown are daily means over the 23-year modeling period. All plots are drawn to the same X and Y scales.
DOC increases up to mid latitudes in Sweden

Trend analysis
30 years
Monitoring data
With monthly Resolution

Humborg et al., 2007
HESS
RV Maria S. Merian
28 feb 2006 – 17 mars 2006
Conservative mixing of TOC in the Baltic?

TOC

Humic Substances

Wedborg et al., 1997

Fonsellius, 1995
Conservative mixing of TOC in the Baltic?

Degradation patterns can not be seen by just comparing TOC/Salinity

Discrimination between terrestrial and marine TOC has to be made
How to use isotopic signatures

Terrestrial source (end member)  
$\delta^{13}C = -28 \%\text{o}$

Marine source (end member)  
$\delta^{13}C = -21 \%\text{o}$

$\delta^{13}C = -25 \%\text{o}$  
57 % terrestrial DOC 43 % marine
Methods

- Ultra filtration (cross flow filtration) used to up-concentrate DOM

- Natural stable isotopes, specific value of each source – each end member

DOM-concentrates from Bothnian Sea and Bothnian Bay
Results of $\delta^{13}$C analysis of the DOM

Terrestrial signature:
-28‰

Marine signature:
-21‰

Estuarine production:
about -24‰

Normal terrestrial signal

Too little difference from the total terrestrial sample to make a quantification of terrestrial input.
Results of $\delta^{34}$S analysis of the DOM

Terrestrial signature: 6.9‰

Marine signature: 18.1‰

Still not a total marine signature

Terrestrial end member

7.0‰

10.3‰

12.5‰

13.7‰
End points of the two isotope signatures correspond well
Terrestrial fraction of DOC
Bothnian Bay
River input: 760

Bothnian Sea
River input: 550

~50% to sediments and/or respired

N. Baltic proper
Kton C/yr

Simple box model
-fluxes of terrestrial DOC

DOC= 87% terrestrial
-410

DOC= 75% terrestrial
-420

DOC= 75% terrestrial

DOC= 67% terrestrial

36 50 River input: 55074 50 Kton C/yr

~50% to sediments and/or respired