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The RECOCA and BALTCOST models: integrated modelling to support cost-effective nutrient management in the Baltic Sea

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Reduction of Baltic Sea Nutrient Inputs and Cost Allocation within the Baltic

Nutrient abatement cost models for the Baltic Sea:

- ”BALTCOST”: developed through BNI and the Bonus RECOCA project
- ”The RECOCA model”: developed through the Bonus RECOCA project
- BALTCOST and RECOCA: Static models which use the inter-sea region nutrient transport matrix from the BNI SANBALT marine model. *Will be modified to handle the new BNI BALTSEM marine model with more sea-regions.*

What can the models be used for ?

- **Both models:**
  - quantify cost-effectiveness of N & P abatement measures
  - estimate the minimum total cost of achieving particular N & P load reductions for potential use in cost benefit analysis

- **Differences between the models:**
  - spatial resolution of terrestrial, riverine and marine physical processes and their associated natural science models
  - spatial resolution of minimum-cost abatement solutions

BALTCOST and RECOCA models

- Use spatially-specific data on physical parameters and pollutant sources to model and quantify the effects of N & P abatement measures
- Use spatially-specific cost functions to quantify the costs of N & P abatement measures
- Use non-linear optimisation to identify cost-minimised spatially-specific combinations of N & P abatement measures to achieve environmental targets: eg. N & P load targets for sea regions as specified under BSAP

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BALTCOST and RECOCA models

- Evolutionary developments from an earlier environmental-economic model of cost-effective N & P abatement for the Baltic
- BALTCOST and RECOCA models operate at different spatial resolutions
- BALTCOST models N & P abatement in 9 countries at main drainage basin resolution: 24 main drainage basins in total around the Baltic
- RECOCA models N & P abatement in 9 countries at 10x10 km grid cell resolution: 17533 grid cells in total around the Baltic

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BALTCOST

- **Moderate spatial resolution, covering all 9 Baltic coast countries draining into the 7 Baltic sea regions via 24 drainage basins.**
- **Well suited to identifying cost-effective combinations of abatement measures when nutrient load reductions are configured or allocated differently between countries and/or sea regions**

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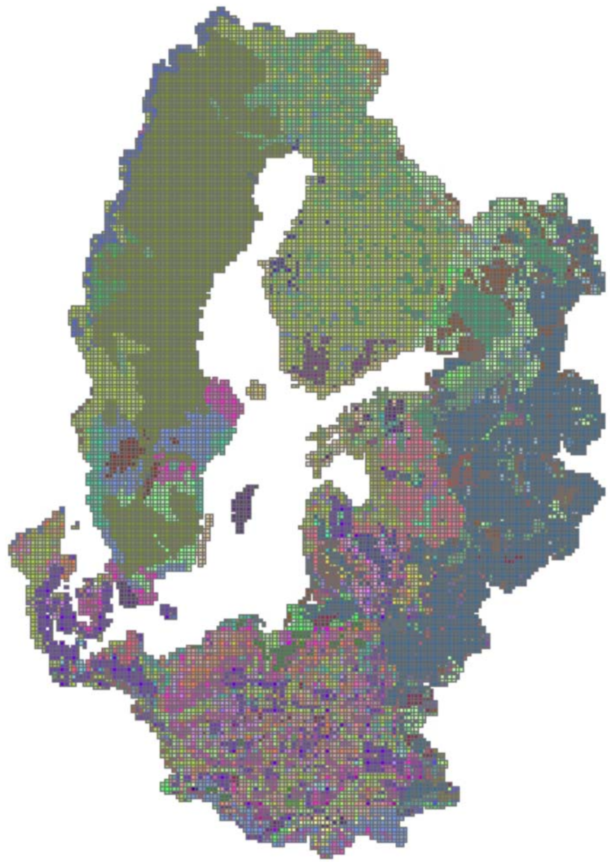
The RECOCA model

- High spatial resolution: 10 x 10km grid cell-specific modelling of natural processes – N & P retention in soil and surface waters, soil type and agricultural production etc.
- Well suited to modelling different spatial implementations of abatement measures within countries and terrestrial regions



N & P abatement measures – both models

- Improve waste water treatment (WWT)
- Restore wetlands and/or construct new wetlands
- Reduce fertiliser applications in arable agriculture
- Catch crops under spring cereals
- Reduce animal numbers in livestock farming
- Reduce NOx emissions from electricity generation and shipping
- For each measure:
  - model effectiveness (incremental effect, retentions etc.)
  - model cost (marginal and/or average costs)
  - assign maximum implementation capacity

  at the relevant spatial resolution
- Models minimise total cost by maximising cost-effectiveness

New data inputs for effectiveness modelling

- Soil types, agricultural cropping structure and livestock numbers
- Current fertilizer applications, arable crop yield functions
- Spatially-specific N & P retentions in soil and surface waters (via root zone loss function etc.)
- Households currently connected to different levels of WWT, location and level of existing WWT facilities
- Electricity generating plant: locations, capacities, emissions and deposition of airborne N
- Shipping traffic: category, transit frequency, emissions and deposition

BALTCOST & RECOCA abatement measures

Measures

- Wetland restoration
- Reduce fertiliser applications
- Catch crops

Costs and capacities

- Wetland: capacity estimated for constructed and re-established, costs modelled using data from Sweden and Denmark
- Data at 10x10 km grid on soils, crop types and fertiliser applications: yield functions used to estimate lost profits
- Grown under spring cereal: Danish costs - adjusted

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BALTCOST & RECOCA abatement measures

Measures	**Costs and capacities**
› Reduce livestock production	› max 20% livestock reduction: costs estimated as opportunity cost in terms of standard gross margin (country-specific)
› Improve WWT	› WWTP data from Poland and Denmark: cost functions quantify scale effect and elasticity of cost with respect to input prices: feasibility of WWT connection
› NOx reduction from power plants and ships	› Data from literature review, NECA assessment and DEHM model results on depositions

BALTCOST#1 illustration: modelling WFD- and MSFD-relevant emissions reductions

- The BALTCOST#1 used to identify cost-effective combinations of abatement measures when N & P reduction targets are formulated differently
- BALTCOST#1 is an earlier version of the BALTCOST model which used old models of the costs and effectiveness of abatement measures across 21 basins draining into 7 sea regions (Schou et al, Gren et al)
- Scenario 1: BSAP reduction allocations enforced separately for each country at its own coastline – reduction measures distributed cost-effectively within a country
- Scenario 2: BSAP targets enforced for each sea region around its coastline - reduction measures distributed cost-effectively between basins which drain into that sea region

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Scenario 1: BSAP reduction allocations enforced for each country

$$\min \sum_{i=1}^{i=21} \sum_{m=1}^{m=6} C_{im}(a_{im})$$

subject to:

$$\sum_{i=1}^{i \text{ within country}} \sum_{m=1}^{m=6} f_i^N(a_{im}) \geq T_{country\_N}$$

and:

$$\sum_{i=1}^{i \text{ within country}} \sum_{m=1}^{m=6} f_i^P(a_{im}) \geq T_{country\_P}$$

with

$$a_{im\_max} \geq a_{im} \geq 0$$

- *m* denotes the six abatement measures, *i* denotes separate drainage basins
- $C_{im}(\,)$ are the cost function for implementing measure *m* in drainage basin *i*
- a_{im} is abatement level by measure *m* in drainage basin *i*,
- $T_{country\_N}$ *and* $T_{country\_P}$ *are* the reduction allocations enforced per country
- $f_i()$ are transport coefficients specific to each drainage basin and pollutant
- a_{im_max} is the max potential for implementing measure *m* in drainage basin *i*

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Scenario 2: BSAP targets enforced for each sea region

$$\min \sum_{i=1}^{i=21} \sum_{m=1}^{m=6} C_{im}(a_{im})$$

subject to: $$\sum_{i=1}^{i \text{ into sea region}} \sum_{\mathrm{m}=1}^{\mathrm{m}=6} g_i^N(a_{im}) \geq T_{searegion\_N}$$

and: $$\sum_{i=1}^{i \text{ into sea region}} \sum_{\mathrm{m}=1}^{\mathrm{m}=6} g_i^P(a_{im}) \geq T_{searegion\_P}$$

with $$a_{im\_\max} \geq a_{im} \geq 0$$

- *m* denotes the six abatement measures, *i* denotes separate drainage basins
- $C_{im}()$ are the cost function for implementing measure *m* in drainage basin *i*
- a_{im} is abatement level by measure *m* in drainage basin *i*,
- $T_{searegion\_N}$ *and* $T_{searegion\_P}$ *are* the reduction targets enforced per sea region
- $g_i()$ are transport coefficients specific to each drainage basin and pollutant
- a_{im_max} is the max potential for implementing measure *m* in drainage basin *i*

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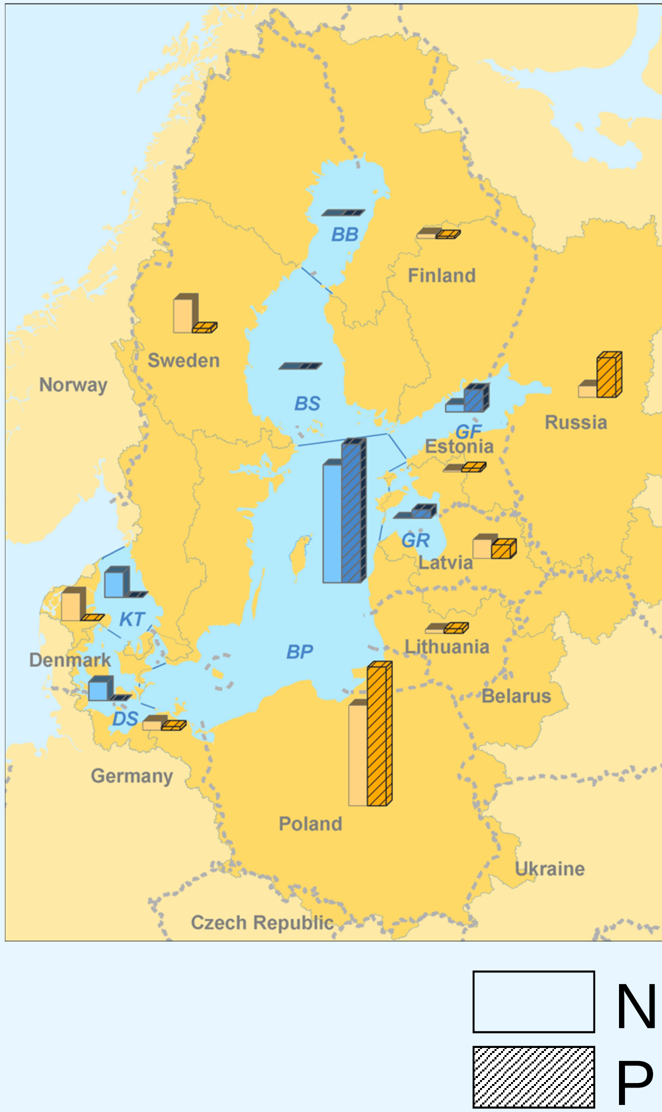
HELCOMs BSAP

Sea Region	Current loads (Tonnes)		Reduction targets (Tonnes)	
	Nitrogen	Phosphorous	Nitrogen	Phosphorous
Bothnian Bay	51440	2580	0	0
Bothnian Sea	56790	2460	0	0
Baltic Proper	327260	19250	94000	12500
Gulf of Finland	112680	6860	6000	2000
Gulf of Riga	78400	2180	0	750
Danish Straits	45890	1410	15000	0
Kattegat	64260	1570	20000	0

Helcom, 2007



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Cost-minimised N & P reductions under Scenarios 1 & 2 vs BSAP targets

Sea Region	Nitrogen reduction (Tonnes)		
	Scenario 1	Scenario 2	BSAP
Bothnian Bay	6187	0	0
Bothnian Sea	6218	0	0
Baltic Proper	87622	94000	94000
Gulf of Finland	11219	10687	6000
Gulf of Riga	4582	15008	0
Danish Straits	15913	15000	15000
Kattegat	14404	20000	20000

Sea Region	Phosphorous reduction (Tonnes)		
	Scenario 1	Scenario 2	BSAP
Bothnian Bay	300	0	0
Bothnian Sea	277	0	0
Baltic Proper	10244	12500	12500
Gulf of Finland	2098	2000	2000
Gulf of Riga	341	750	750
Danish Straits	212	0	0
Kattegat	43	185	0

- BSAP sea region targets may not be achieved when allocations are enforced per country (e.g. Scenario 1: Baltic Proper)
- Overfulfillment in some countries/sea regions for both P and N (e.g. Scenarios 1 & 2: N in Gulf of Finland, Scenarios 1 & 2: P in Kattegat)

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Scenario 1 & 2 illustration: N cost allocation

Country	Cost allocation, Million Euro (percentages of share of costs)	
	Scenario 1	Scenario 2
Sweden	125.56(26%)	76.07(16%)
Finland	7.31(2%)	0(0%)
Russia	53.45(11%)	42.77(9%)
Estonia	4.70(1%)	4.78(1%)
Latvia	4.47(1%)	16.47(3%)
Lithuania	8.95(2%)	44.28(9%)
Poland	200.02(41%)	216.67(41%)
Denmark	56.66(12%)	64.93(14%)
Germany	21.59(4%)	10.39(2%)
Totals	482.72	476.35

BALTCOST#1- illustration

As an illustration BALTCOST #1 investigated 2 scenarios:

1) nutrient load reductions allocated to individual countries
2) nutrient load reduction targets enforced at the coast of the individual sea-regions

- Scenario 1: suggests that country-based reduction allocations are unlikely to deliver the desired load reductions in all sea regions.
- Scenario 2: suggests that setting reduction targets for sea regions should deliver load reductions which meet requirements
- Scenario 2 is likely to be delivered at slightly lower total cost than Scenario 1
- Distribution of costs between countries differs under the two Scenarios

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Policy evaluations with BALTCOST

- Current BSAP per-country allocation of load reductions targets is not likely to be cost-effective
- Useful for policy evaluations related to the Water Framework Directive and the Marine Strategy Framework Directive: different targets, enforced across different spatial areas - WFD enforced at country level cf. MSFD enforced in the open sea
- The BALTCOST and RECOCA models will be used to investigate a number of other scenarios during the coming months

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Thank you for your attention!

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Appendix

› **Following slides are available if additional details are requested during the presentation**

The model sets and variables in the RECOCA model

- $n \in \{N, P\}$ – nutrients
- $r = 1..7$ – the Baltic Sea Regions
- t_r^n – target nutrient loadings to each region
- $m = 1..M$ – measures to be applied
- $g_r = 1..G_r$ – overland grid cells $\left(\sum_{r=1}^{R} G_r = 17533\right)$
- $q_{g_r m}$ – scale of application of measure m in grid cell g_r
- $\bar{q}_{g_r m}$ – potential (maximum scale) of application of measure m in grid cell g_r
- $l_{g_r}^n\left(q_{g_r m}\right)$ – reduction of nutrient n as a function of $q_{g_r m}$ (measured at the river mouth)
- $c_{g_r m}\left(q_{g_r m}\right)$ – cost of application of measure m in grid cell g_r as a function of $q_{g_r m}$

The cost-minimisation problem

- The cost minimization problem:

$$\min \sum_{r=1}^{R} \sum_{g_r=1}^{G_r} \sum_{m=1}^{M} c_{g_r m}\left(q_{g_r m}\right) \quad \text{s.t.} \quad \begin{cases} \underset{n\in\{N,P\}}{\forall} \; \underset{r=1..R}{\forall} \; \sum_{g_r=1}^{G_r} \sum_{m=1}^{M} l_{g_r}^{n}\left(q_{g_r m}\right) \geq t_r^n \\ \underset{r=1..R}{\forall} \; \underset{g_r=1..G_r}{\forall} \; \underset{m=1..M}{\forall} \; 0 \leq q_{g_r m} \leq \overline{q}_{g_r m} \end{cases}$$

- Search for a scale $q_{g_r m}$ to which each measure m should be applied in each grid cell g_r of each Baltic Sea region r so that the resulting N and P reductions are at least their targets for this region t_r^n and the costs are minimized