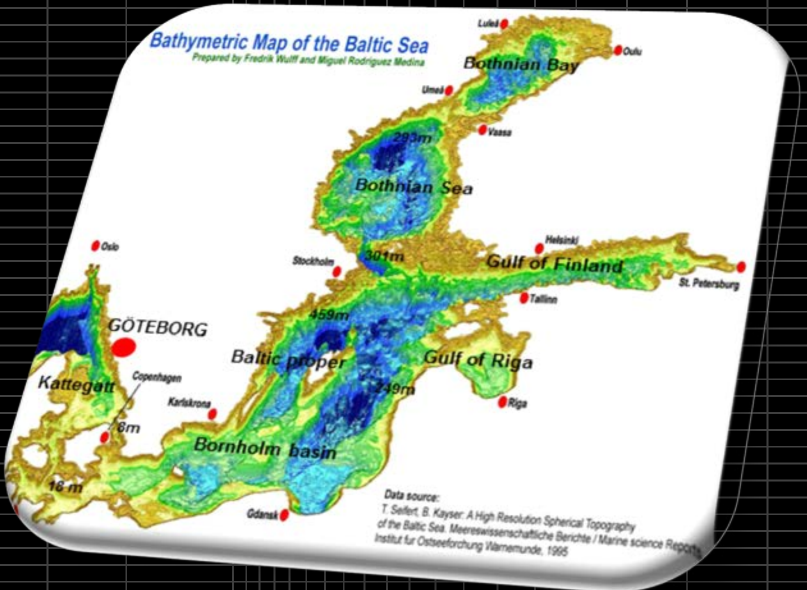
Understanding the Baltic Sea nutrient cycling



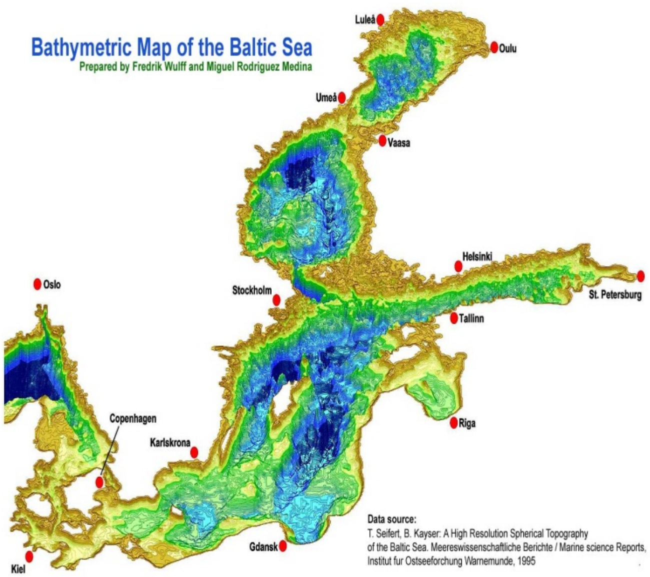
Baltic Earth

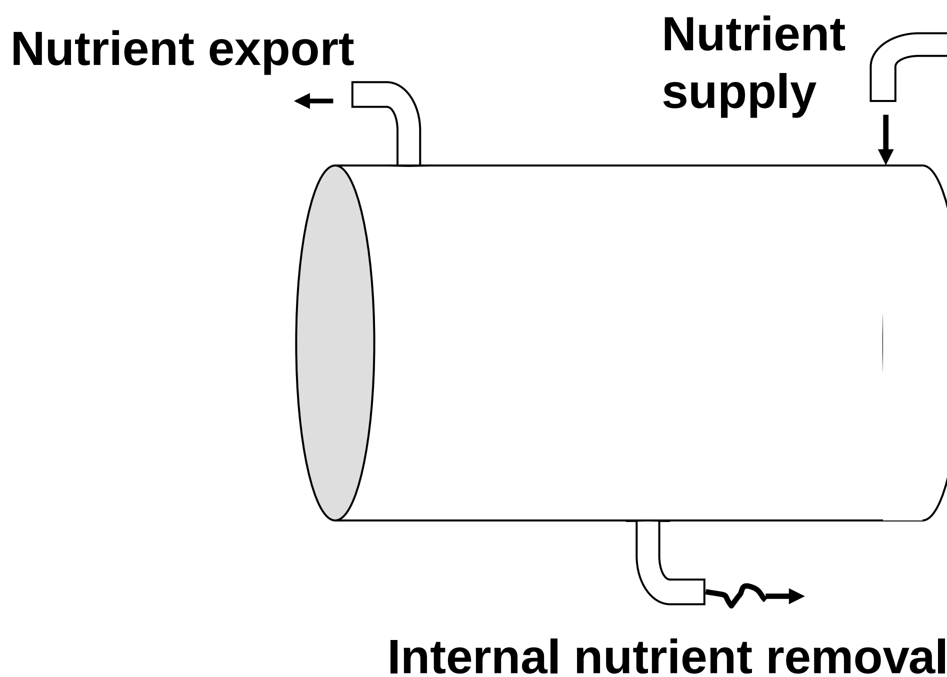
Sopot workshop 2013

Presentation: **Kari Eilola SMHI**

Swedish Meteorological and Hydrological Institute
E-mail: kari.eilola@smhi.se

Biogeochemical reactor





1. **External nutrient input.**
2. **Internal nutrient cycling.**
3. **Internal nutrient removal.**
4. **Net nutrient export.**

- **Sink efficiency**

The fraction of the supply that is removed in the Baltic.

The Baltic Sea Nutrient Cycling

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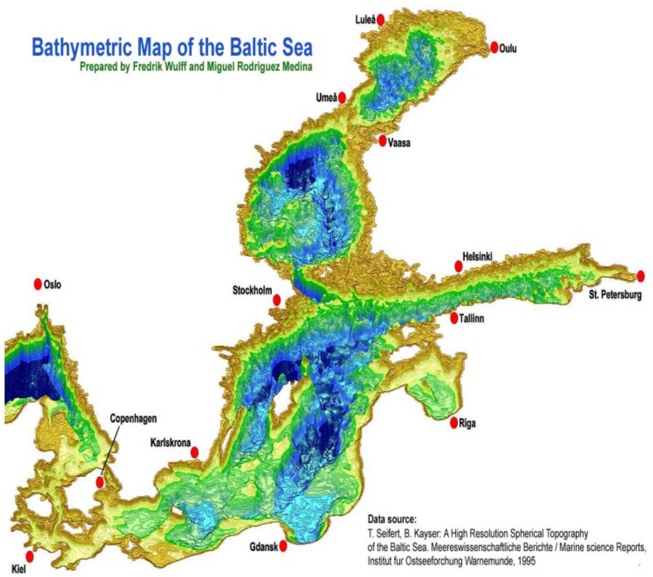
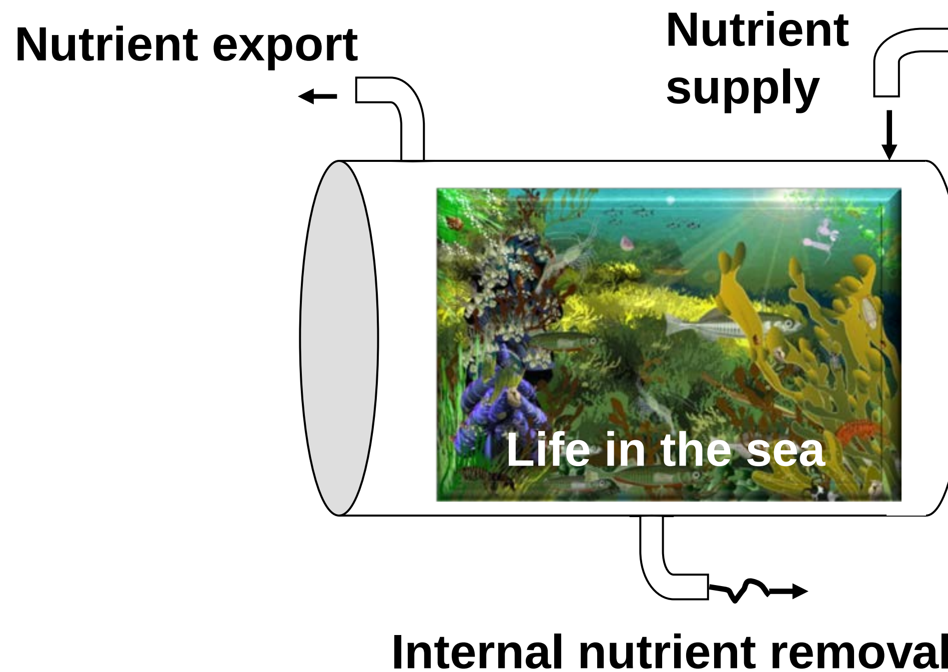
Biogeochemical reactor





1. External nutrient input.
2. Internal nutrient cycling.
3. Internal nutrient removal.
4. Net nutrient export.

- **Sink efficiency**

The fraction of the supply that is removed in the Baltic.

Litoral ecosystem figure from:

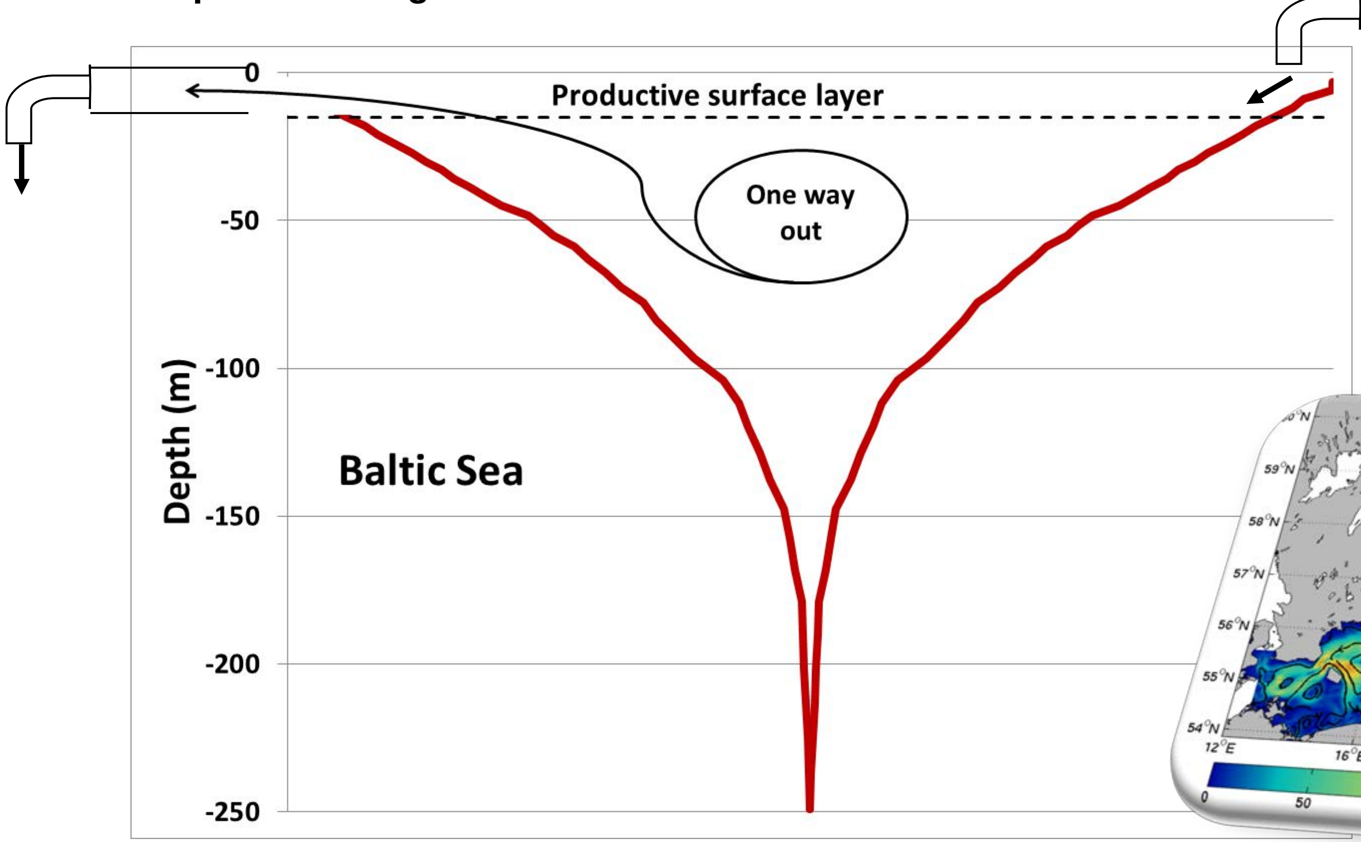
Merentutkimuslaitos
Havsforskningsinstitutet
Finnish Institute of Marine Research

- **Surface concentrations**

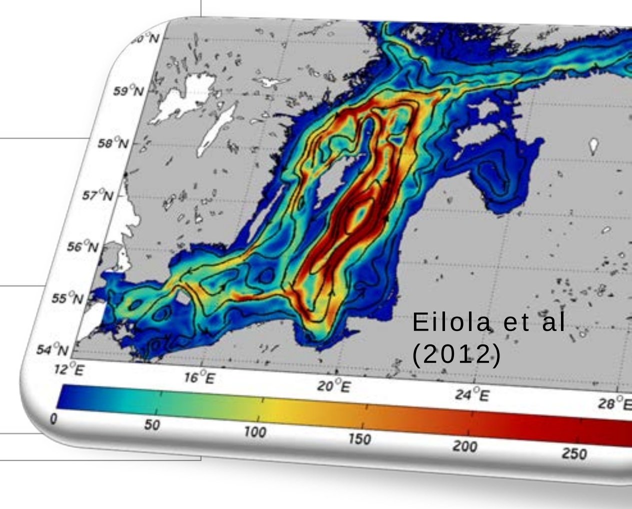
depends on the amount of nutrients we must export out of the Baltic Sea

Nutrient export = Average surface concentration x **volume flow**

Nutrient supply

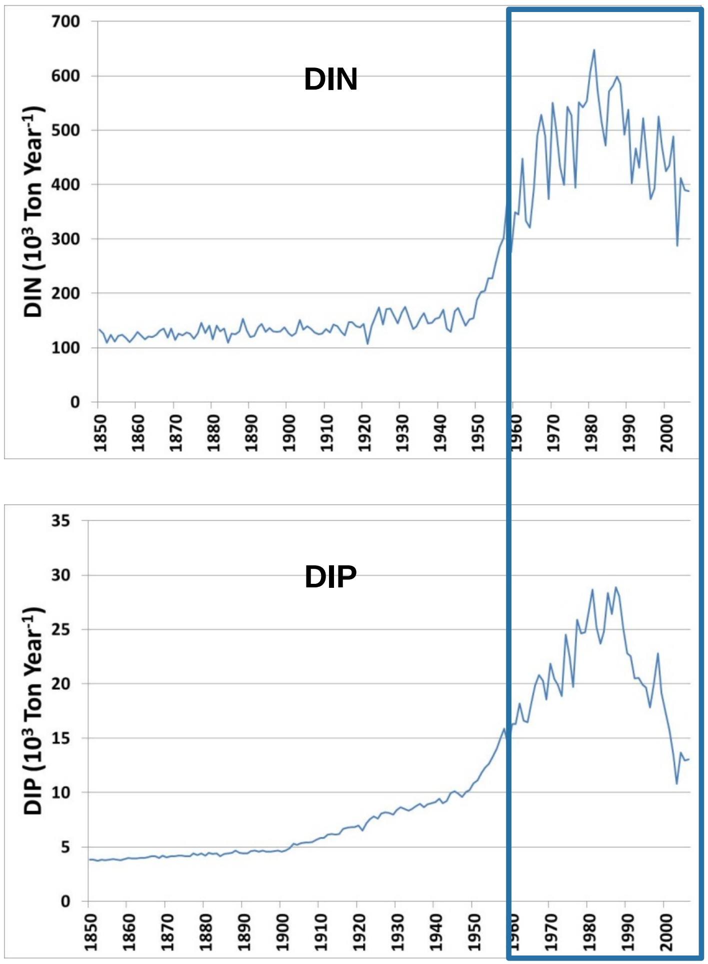


Horizontal spreading by transport systems

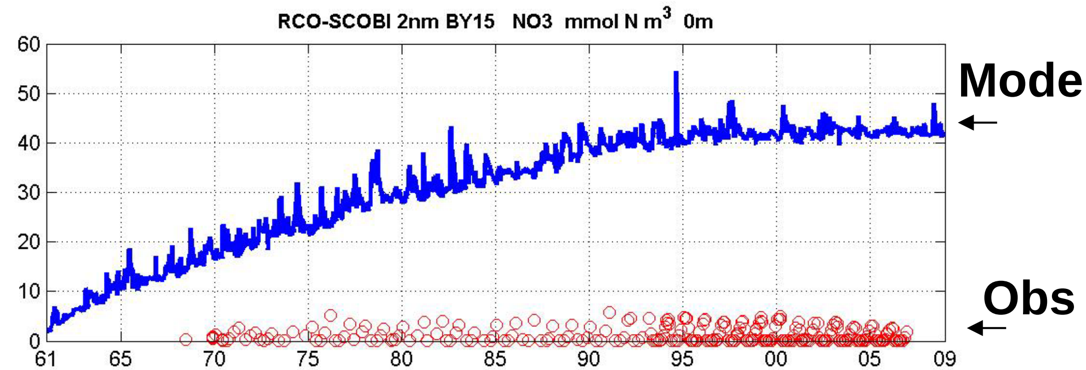


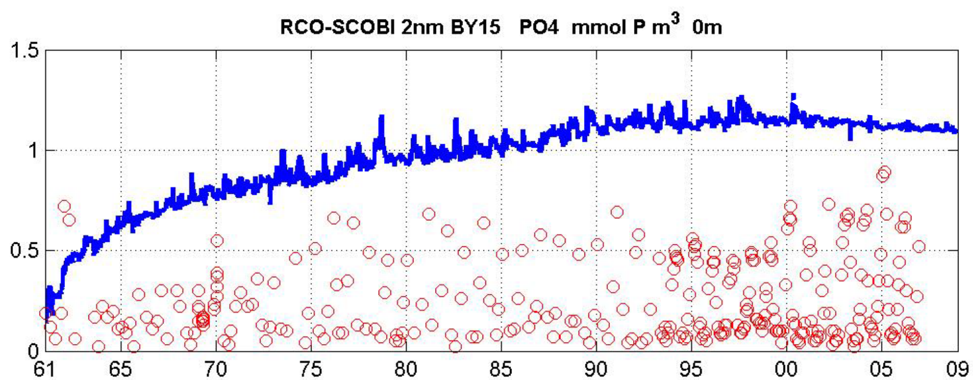
Eilola et al (2012)

- **Nutrient supply 1850-2006**



- **Sink efficiency = 0** **(i.e. no SCOBI)**
- **All supplied nutrients must be exported**





- ***RCO-SCOBI 2nm model (No SCOBI)***
- ***Surface observations SHARK BY15***

The Baltic Sea Nutrient Cycling

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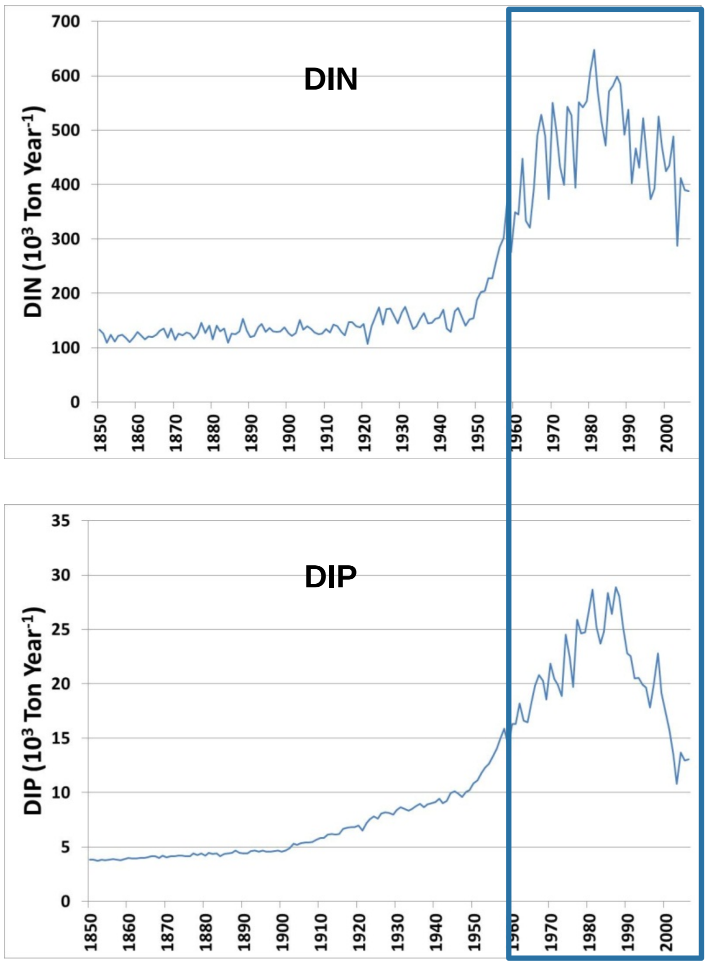
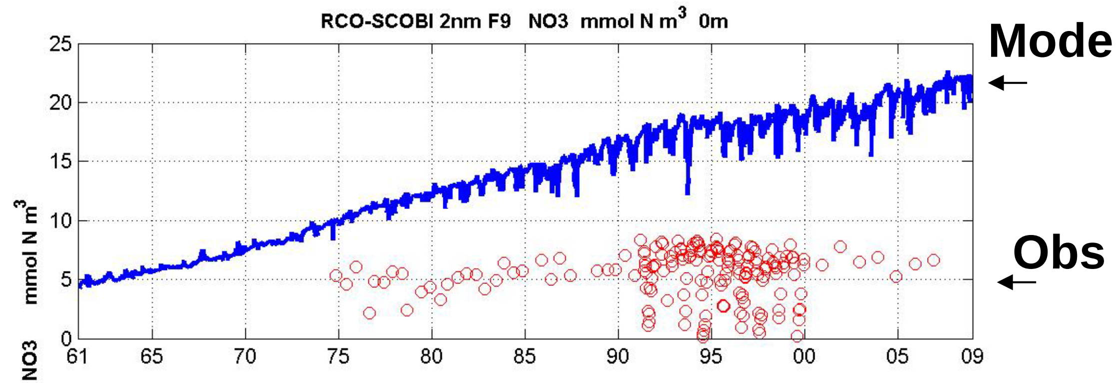
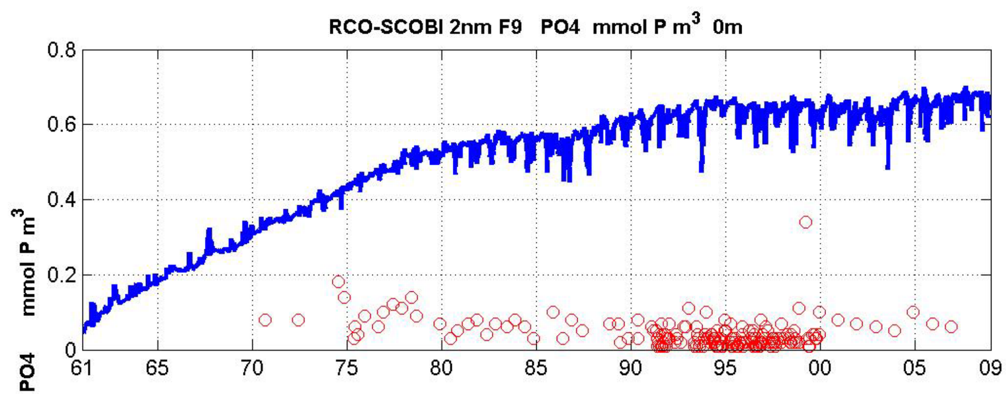
- **Nutrient supply 1850-2006**



- **Nutrients distributed by internal transports between the Baltic Sea sub basins**





- ***RCO-SCOBI 2nm model (No SCOBI)***
- ***Surface observations SHARK Bothnian Bay F9***

Challenges from a modeling point of view

- **Understand changes in nutrient cycling from the pre-industrial conditions to the present and define realistic future developments.**

Require understanding on systems (and regional) level about:

a. **How much nutrients are supplied to the Baltic Sea.**

b. **How much nutrients are there inside the Baltic Sea.**

c. **How much nutrients are removed in the Baltic Sea.**

Nutrient Budgets

SMHI

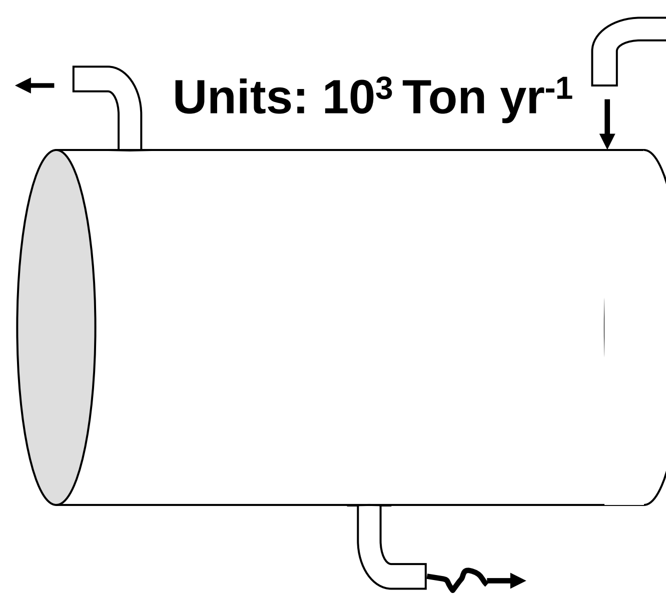
Ecosupport model ensemble
Meier et al. (2012a)

- **N and P budgets 1978-2007**
  The control period

Sink efficiency

- **N= 97% of supply removed**
- **P= 85% of supply removed**

Nutrient export	**Nutrient supply**
23 N	**835 N**
6 P	**39 P**



Internal nutrient removal

Nutrient Budgets

SMHI

Ecosupport model ensemble
Meier et al. (2012a)

- **N and P budgets 1978-2007 and 2069-2097 (REF)**

	Nutrient export	**Nutrient supply**
1978-2007	**23 N** **6 P**	**835 N** **39 P**
2069-2097 (REF)	**37 N** **13 P**	**819 N** **39 P**

Sink efficiency

- **N= 97% (95%)**
- **P= 85% (67%)**

Changing P sink efficiency

- **21% weaker internal P sink efficiency in future climate scenario.**
- **Similar nutrient supply, but increased nutrient export due to the reduced sink efficiency**

REFerence (REF):
Current riverine nutrient concentrations and current atmospheric deposition

Nutrient Budgets

Ecosupport model ensemble
Meier et al. (2012a)

- **N and P budgets 1978-2007 and 2069-2097 (REF, BAU)**

	Nutrient export		Nutrient supply	
	23 N		835 N	
	6 P		39 P	
	REF	BAU	REF	BAU
N	37 N	69 N	819 N	1108 N
P	13 P	19 P	39 P	51 P

Sink efficiency

- **N= 97% (95%, 94%)**
- **P= 85% (67%, 64%)**

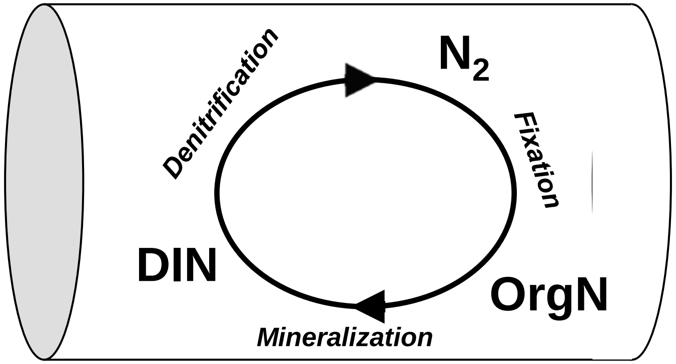
Changing P sink efficiency

- **21% and 25% weaker internal P sink efficiency in future climate scenarios.**
- **Still, almost all N and about 2/3 of the P supply are removed inside the Baltic Sea.**

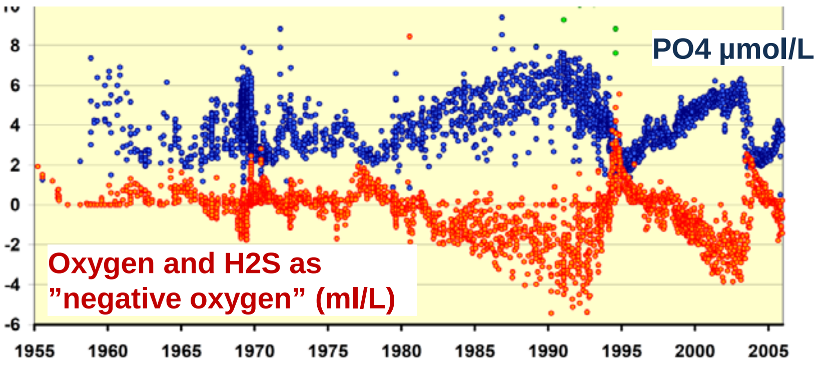
Business-As-Usual (BAU): Increased nutrient concentrations in rivers assuming an exponential growth of agriculture in all Baltic Sea countries and current atmospheric deposition.

Nutrient Budgets

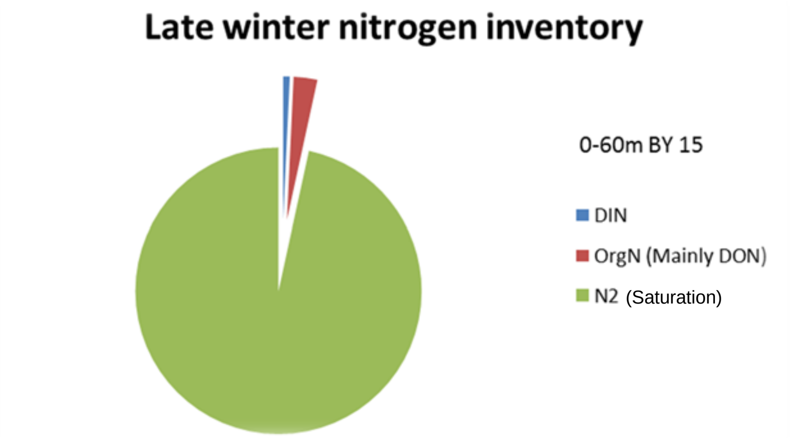
- ***No net internal sources, only possible sinks!***

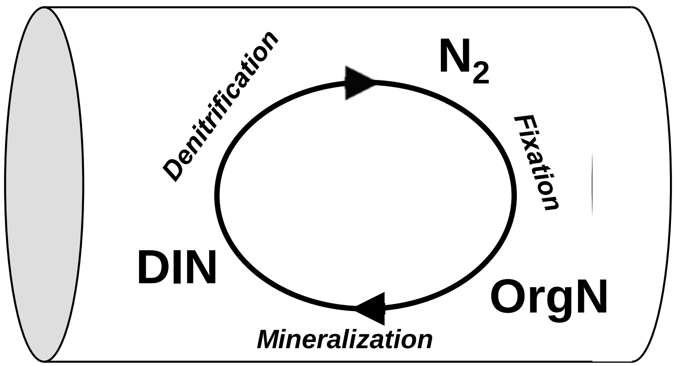


- **Nutrient input from nitrogen fixation and sediment release are:**
- **parts of the <u>internal nutrient cycling</u> that transfer the elements between different pools of nutrients inside the reactor**



Internal nitrogen cycling, example





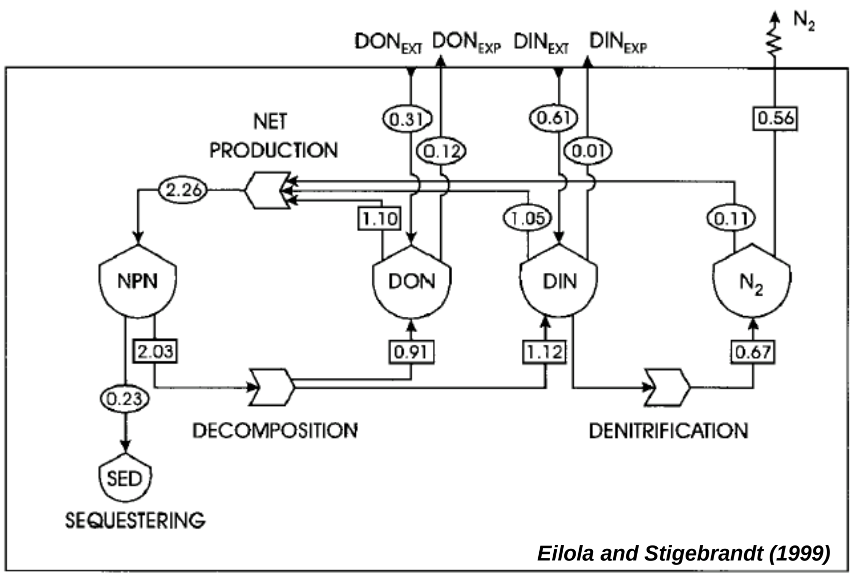
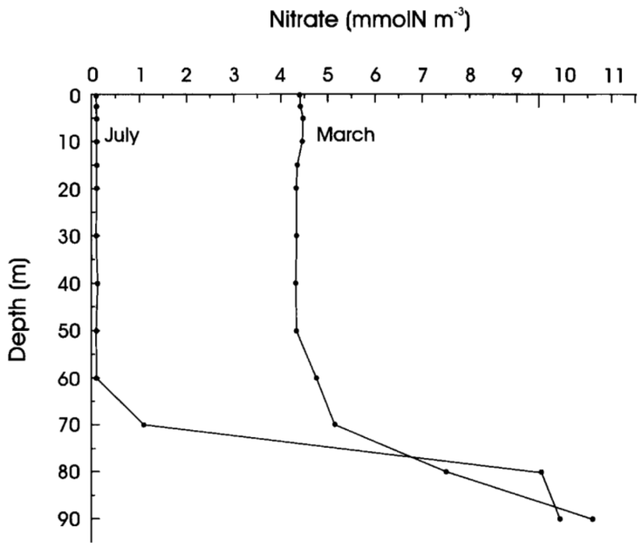
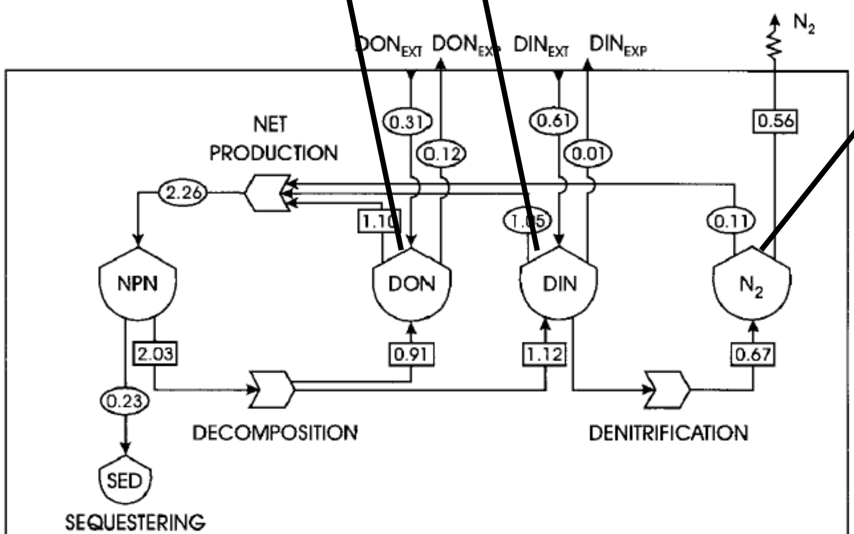


Figure 4. Flow chart for nitrogen in the Baltic proper biogeochemical reactor according to our model. As further explained in the text, numbers (in Mton N yr^{-1}) in ovals are considered known and numbers in squares are computed by the model using $\eta = 0.55$.



Internal nitrogen cycling, example

N2 Yesterday 0.1 ?



Eilola and Stigebrandt (1999)

Figure 4. Flow chart for nitrogen in the Baltic proper biogeochemical reactor according to our model. As further explained in the text, numbers (in Mton N yr^{-1}) in ovals are considered known and numbers in squares are computed by the model using $\eta = 0.55$.

Internal nitrogen cycling, example

N2 Today 0.8 ?

0.80

DON Today ?

Future ?

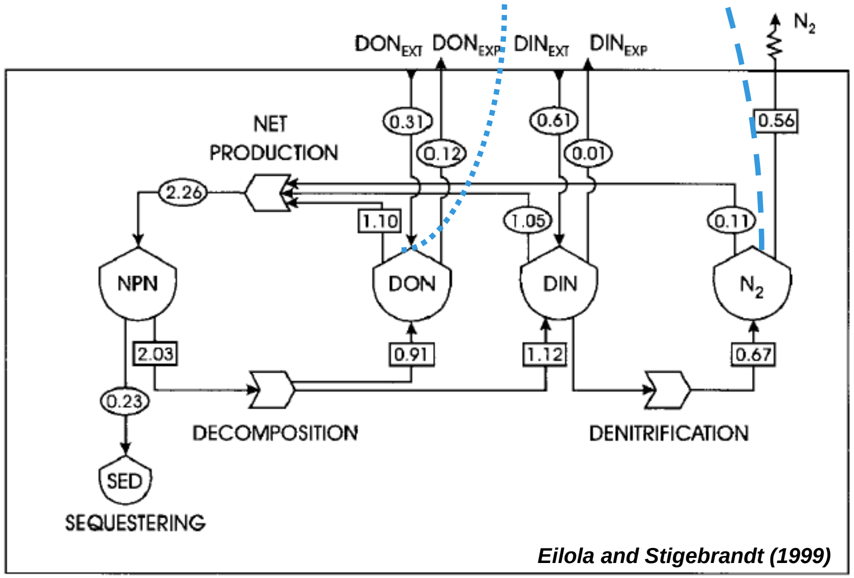
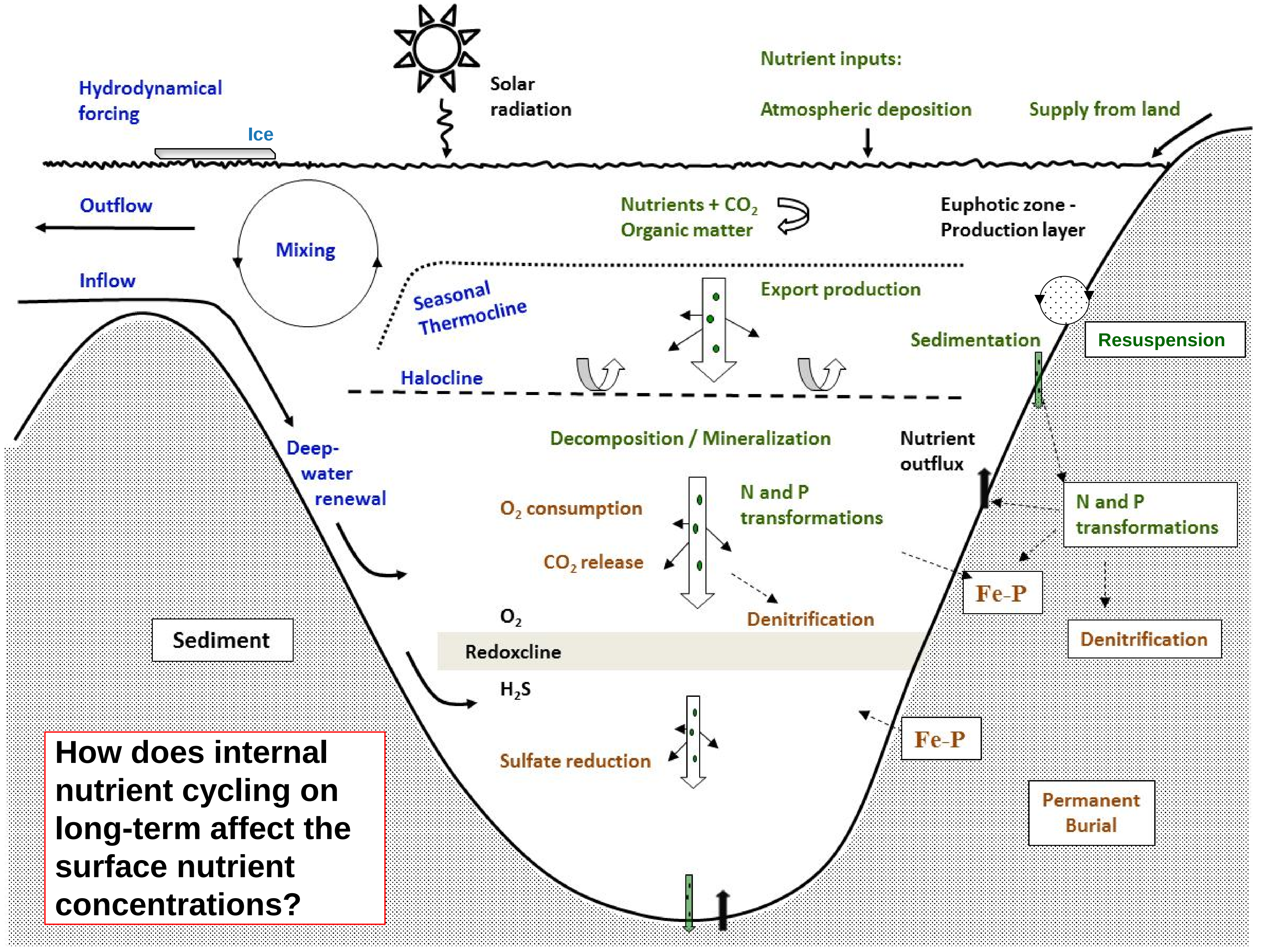


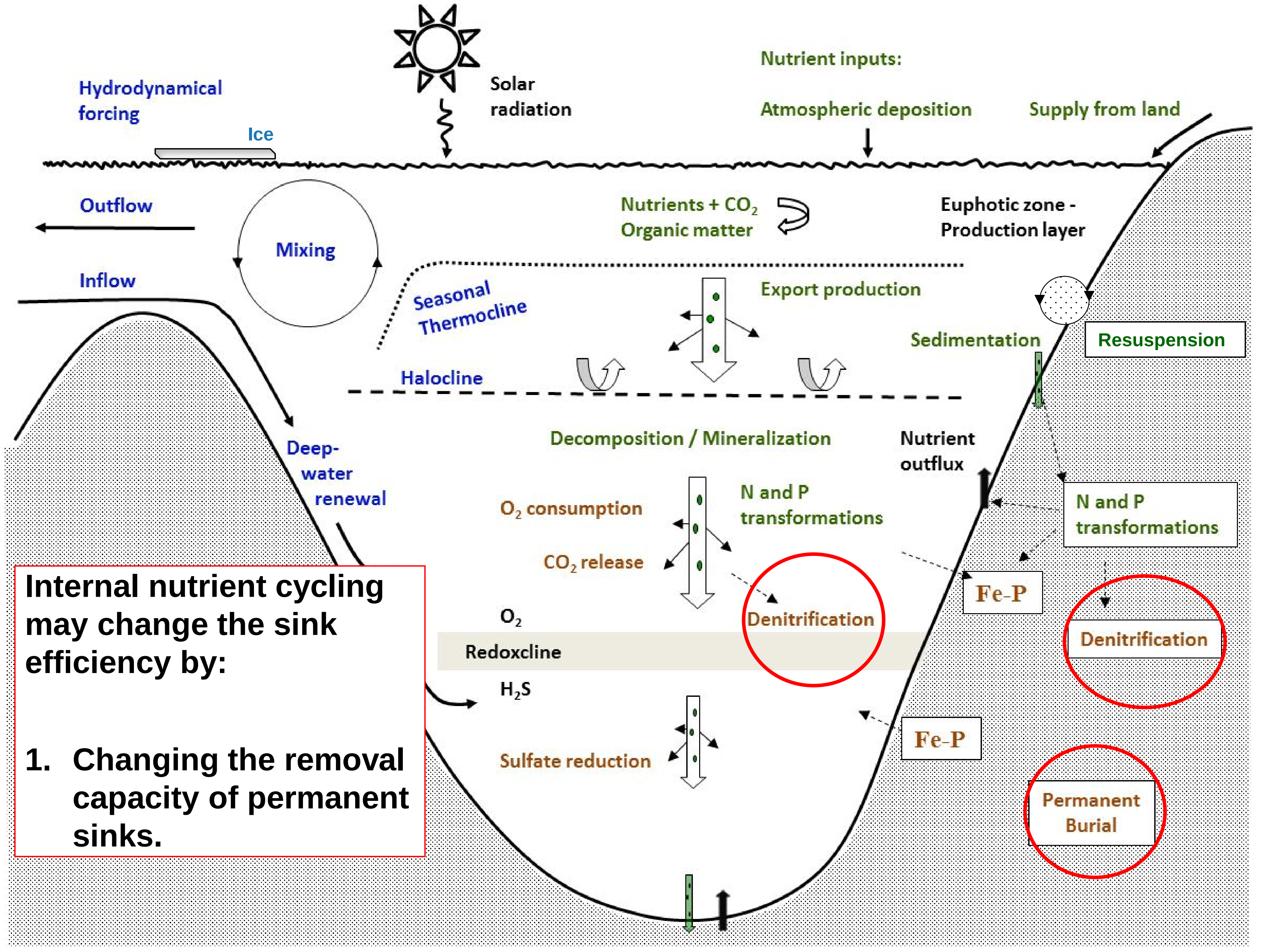
Figure 4. Flow chart for nitrogen in the Baltic proper biogeochemical reactor according to our model. As further explained in the text, numbers (in Mton N yr^{-1}) in ovals are considered known and numbers in squares are computed by the model using $\eta = 0.55$.

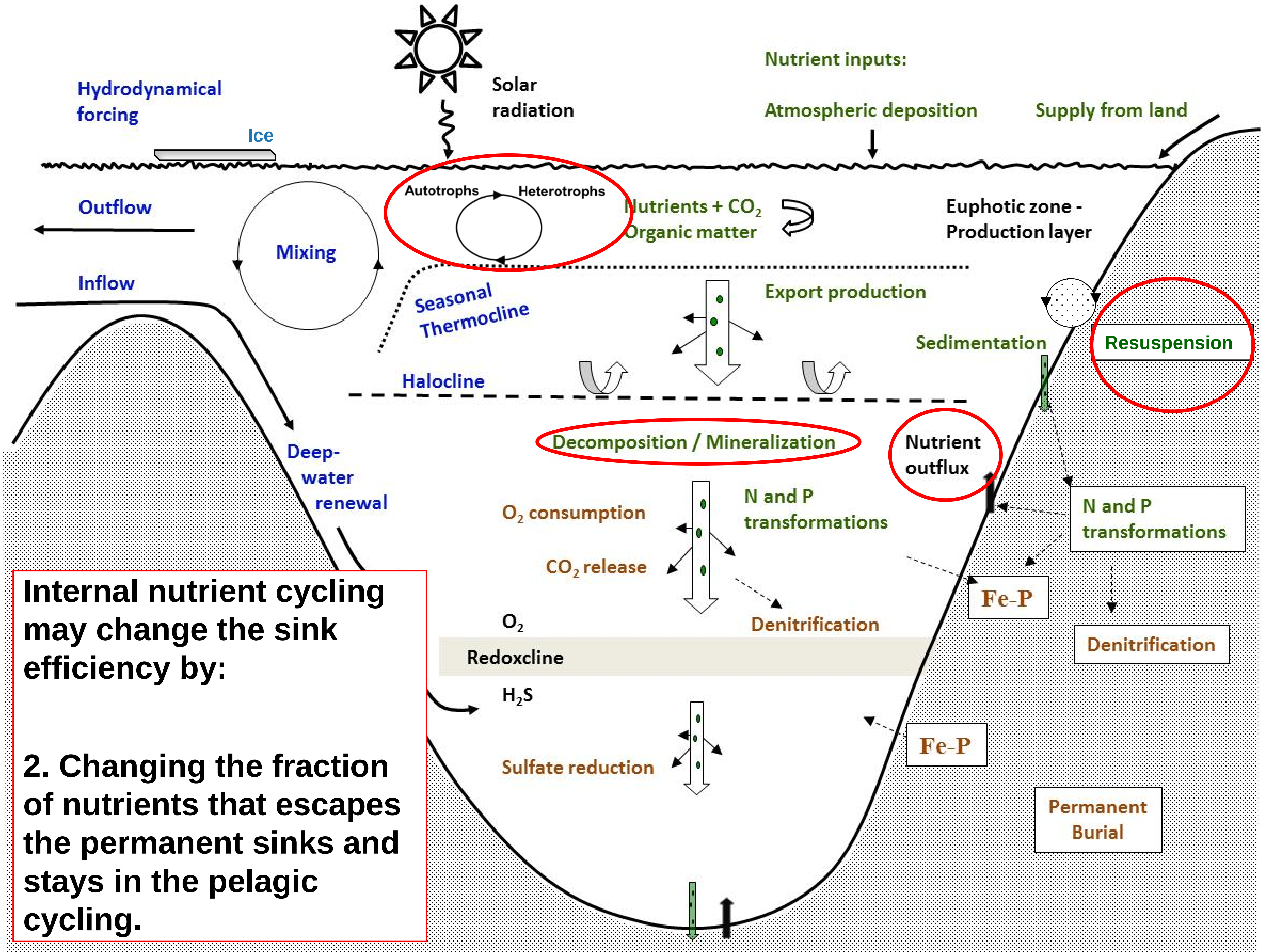


How does internal nutrient cycling on long-term affect the surface nutrient concentrations?

Internal nutrient cycling may change the sink efficiency by:

1. Changing the removal capacity of permanent sinks.





Internal nutrient cycling may change the sink efficiency by:

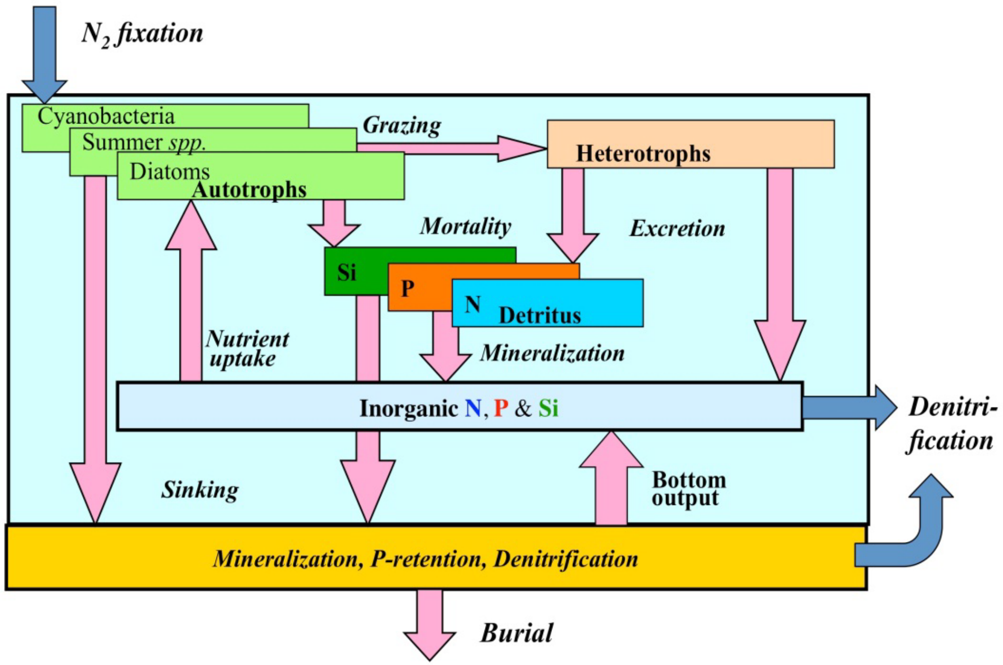
2. Changing the fraction of nutrients that escapes the permanent sinks and stays in the pelagic cycling.

State of the art models

SMHI

ECO SUPPORT | Baltic Nest Institute | Leibniz Institute for Baltic Sea Research Warnemünde IOW

Biogeochemical models
Simplified description from BALTSEM.



Coupled physical-biogeochemical models

1. RCO-SCOBI	(3D, 2nm)	SMHI	Sweden
2. BALTSEM	(1D, 13 basins)	BNI	Sweden
3. ERGOM	(3D, 3nm)	IOW	Germany

Key differences

- Representation of dead organic matter
- Sediment P dynamics
- Resuspension and sediment transport
- Horizontal resolution
- Vertical resolution

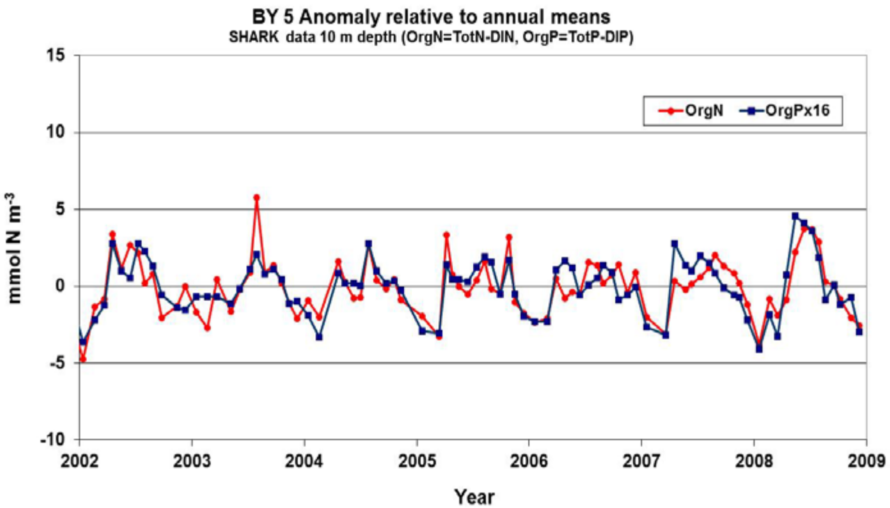
N, P and O_2 dynamics

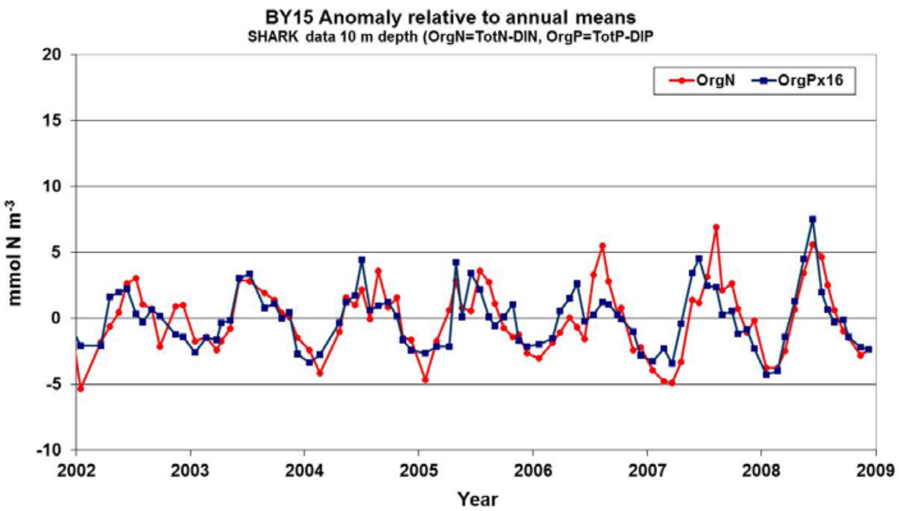
- Inorganic and organic
- Sediment dynamics
- Redfield plankton dynamics

Eilola et al. (2011) Evaluation of biogeochemical cycles in an ensemble of three state-of-the-art numerical models of the Baltic Sea.

Plankton model

- Redfield plankton model (N:P=16:1) simple visualization based on simultaneous N and P observations in the central and southern Baltic Sea.
- Calculate **OrgN** (TotN-DIN) and **16xOrgP** (TotP-DIP)
- Plot anomaly relative to annual mean in each year





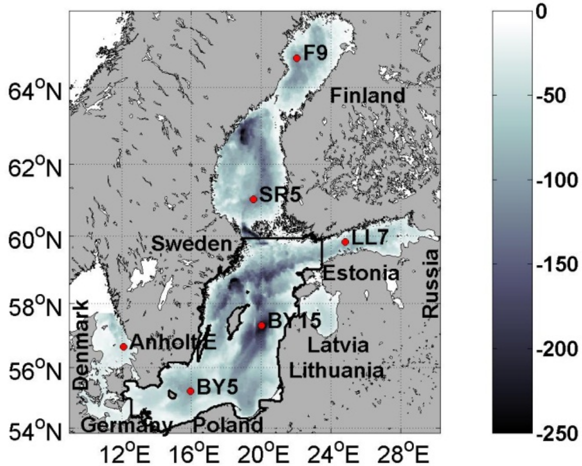
Data from Bornholm basin
10 m depth

Data from Gotland deep
10 m depth

SMHI

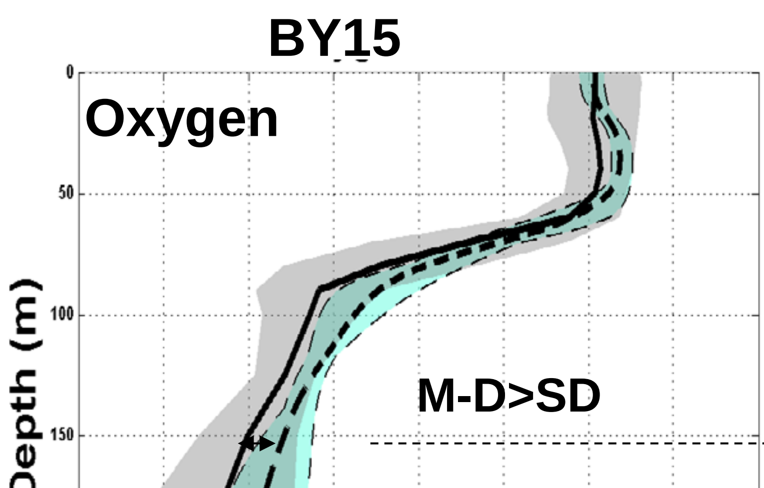
Assessment of model performances

Eilola et al. (2011)

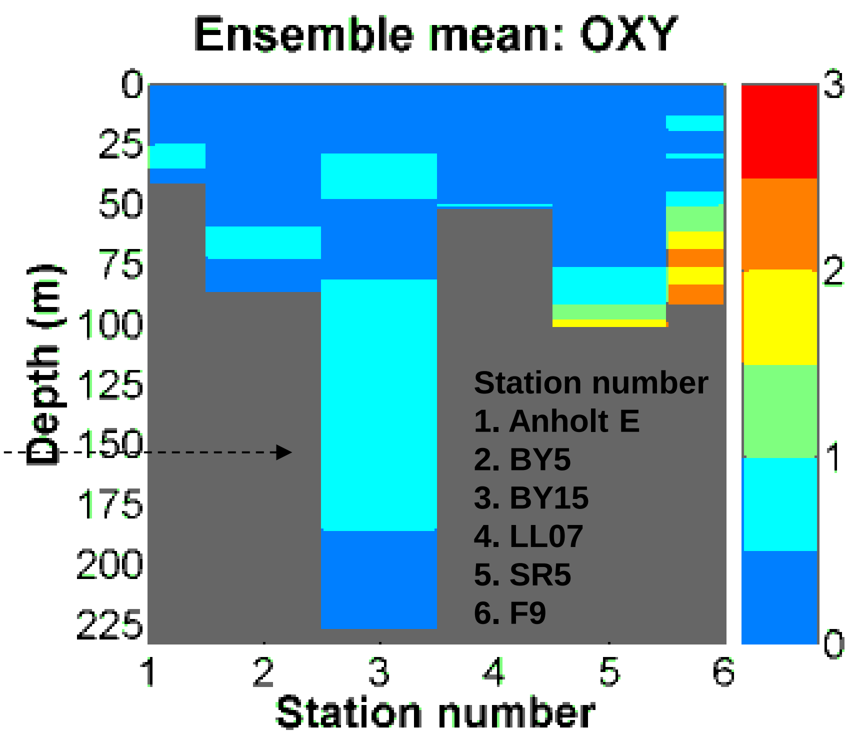


Cost function of Ensemble mean values

$0 \leq C < 1$ (good)
$1 \leq C < 2$ (reasonable)
$2 \leq C$ (poor)



$$C = \left|\frac{M - D}{SD}\right|$$



State of the art models

- **Temperature**
- **Salinity**
- **Oxygen**
- **Phosphate**
- **Nitrate**
- **Ammonium**

Mean of all variables and all stations

$$C = \left| \frac{M - D}{SD} \right|$$

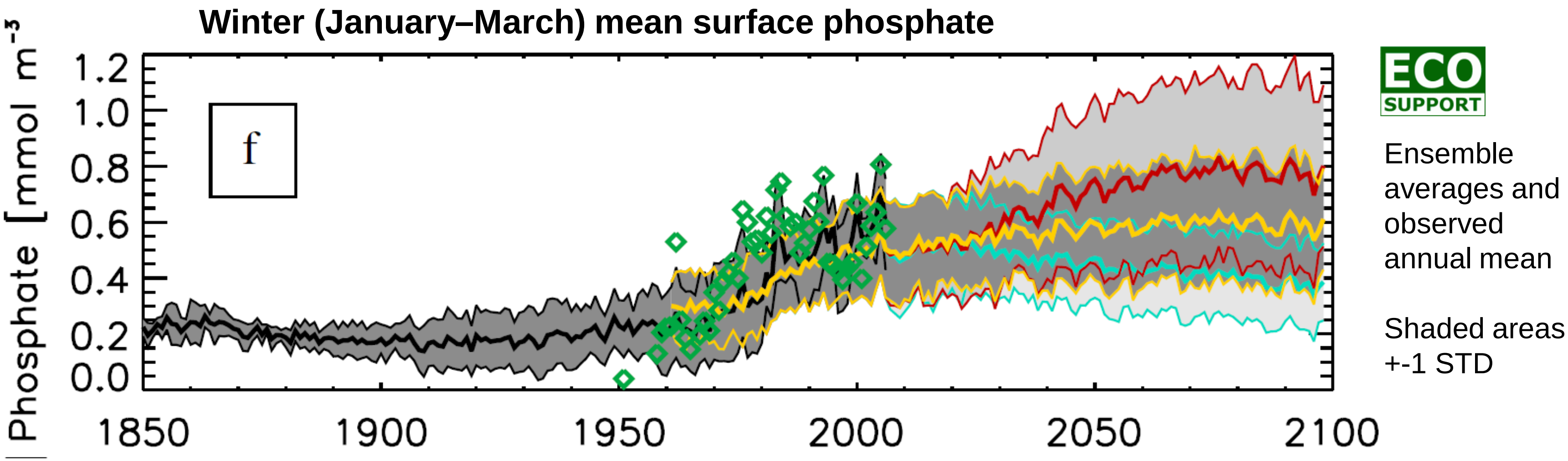
$$CSD_i = \left| \frac{SD_i - SD}{SD} \right|$$

Mean cost function **Standard deviation cost function**

- GOOD
- REASONABLE
- POOR

	All stations	Without Gulf of Bothnia	All stations	Without Gulf of Bothnia
Ensemble mean	0.69	0.34	0.36	0.21

Meier et al. (2012b) Comparing reconstructed past variations and future projections of the Baltic Sea ecosystem—first results from multi-model ensemble simulations



Uncertainty:

- **Historical spread caused by differences in <u>model responses</u> to changing nutrient loads and physical forcing**
- **Future spread in addition caused by different climate and socio economic <u>scenarios</u> (_not discussed in this presentation_)**

Historical Baltic Sea, ground truth ?

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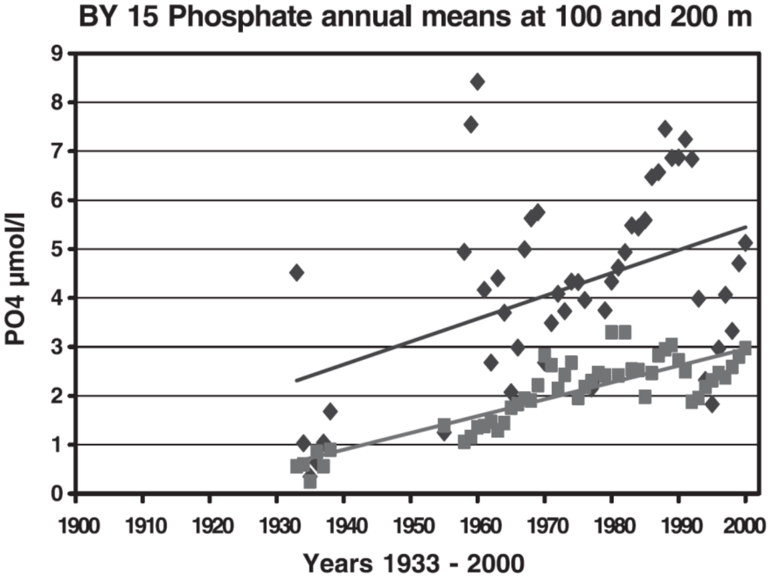
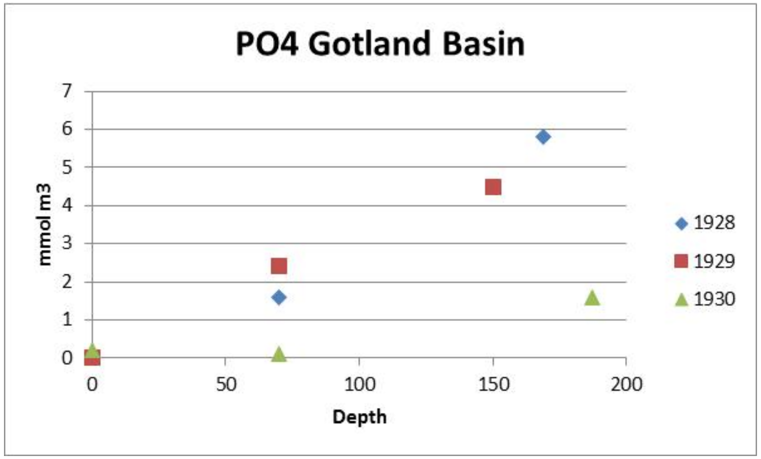
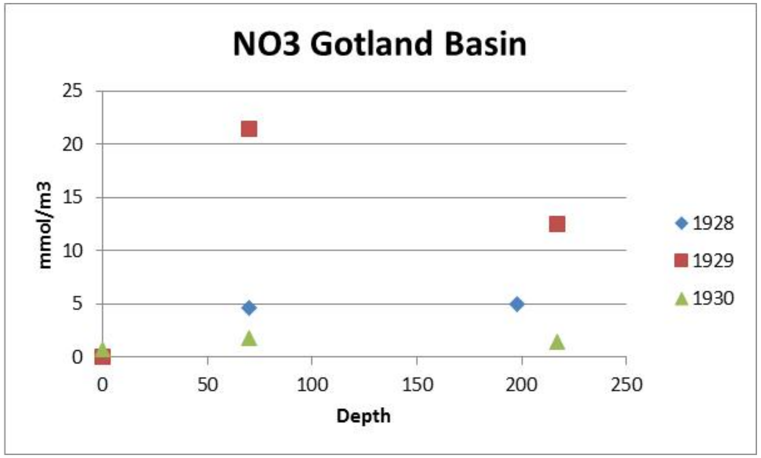
Fonselius and Valderama (2003)



More data available in data bases ?





Model validation:

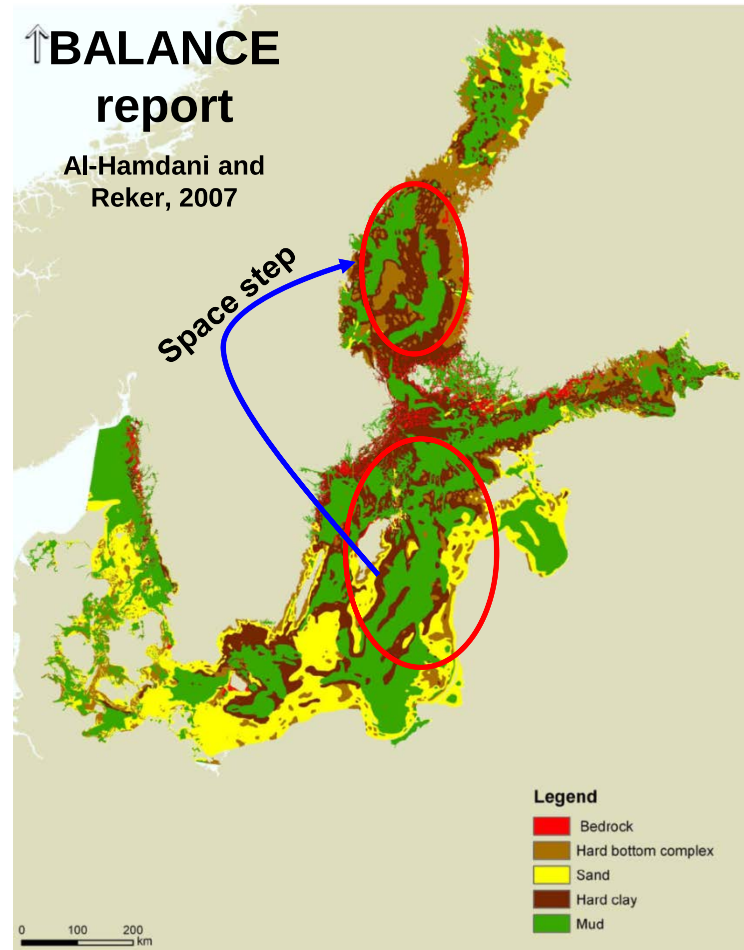
- **Available data?**
- **Uncertainty?**

Needed:

- **Common processed validation data with uncertainty included**

Burial (main P sink)

- Spatial and temporal changes of burial are not well resolved or understood in the models.



Annually accumulated sediment layer (mm/year)

	AAL 0-2cm	Age* Years	Ratio to BP	AAL ~10 cm	Ratio to BP
Bothnian Bay	3.5	6	1.3	1.9	2.4
Bothnian Sea	6.2	3	2.4	3.7	4.6
Gulf of Finland	5.6	4	2.2	2.4	3.0
Baltic Proper	2.6	8	1.0	0.8	1.0

** Age at 2cm depth.*

Time

Space

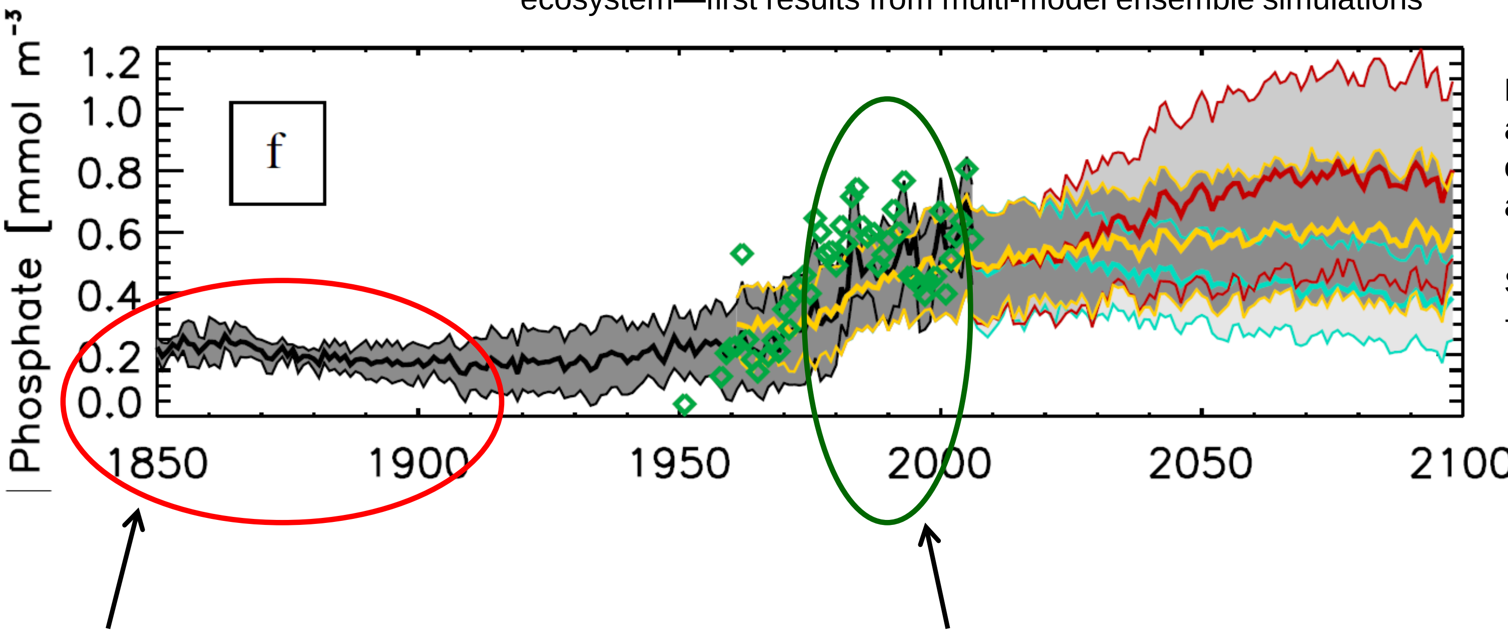
AAL data from Mattila et al. (2006)

- Factor 3-5 diff in time and space of median AAL

Historical Baltic Sea, modeling

SMHI

Meier et al. (2012b) Comparing reconstructed past variations and future projections of the Baltic Sea ecosystem—first results from multi-model ensemble simulations



Ensemble averages and observed annual mean

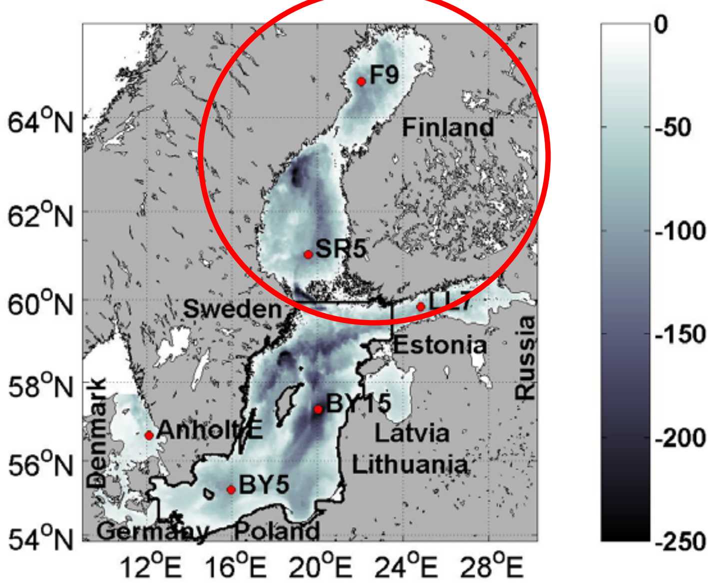
Shaded areas +-1 STD

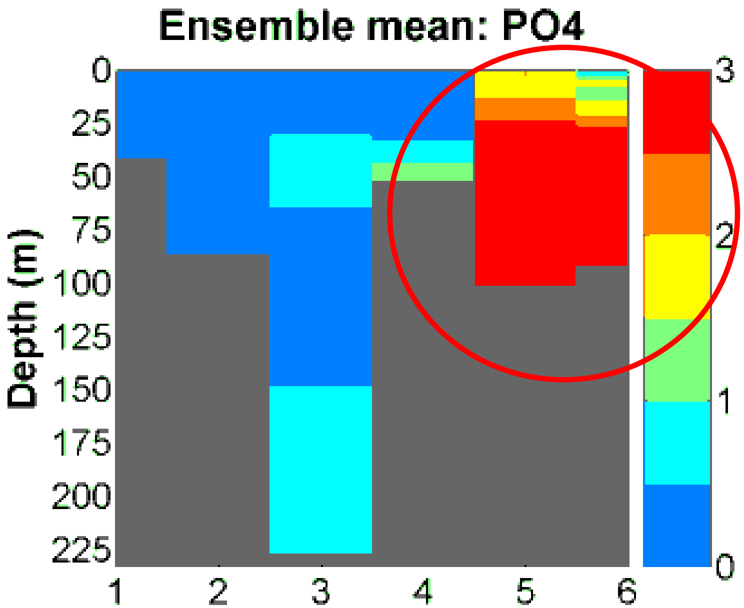
- Historical P very low.
- Comparable to Bothnian Bay dynamics ?
- Main model development in P-rich period.

SMHI

Eilola et al. (2011)

- **State of the art models show less good results in the northern Baltic Sea**





Station number
1. Anholt E
2. BY5
3. BY15
4. LL07
5. SR5
6. F9

The Baltic Sea Nutrient Cycling

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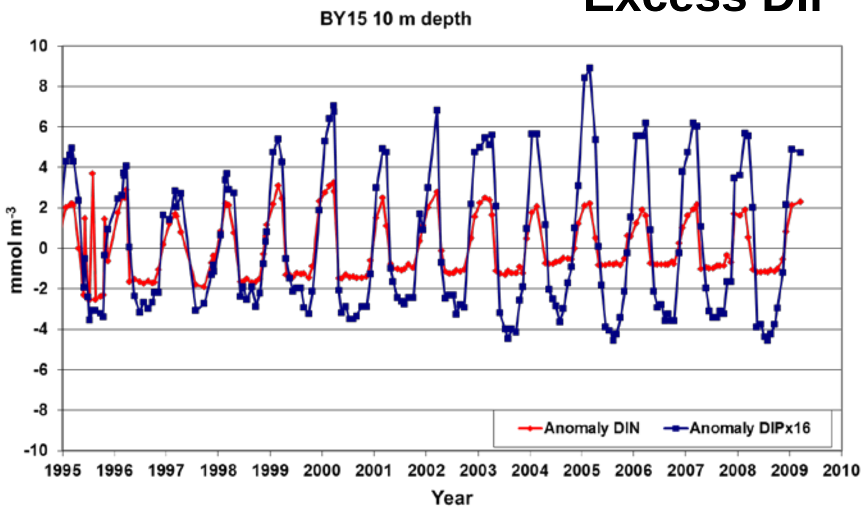
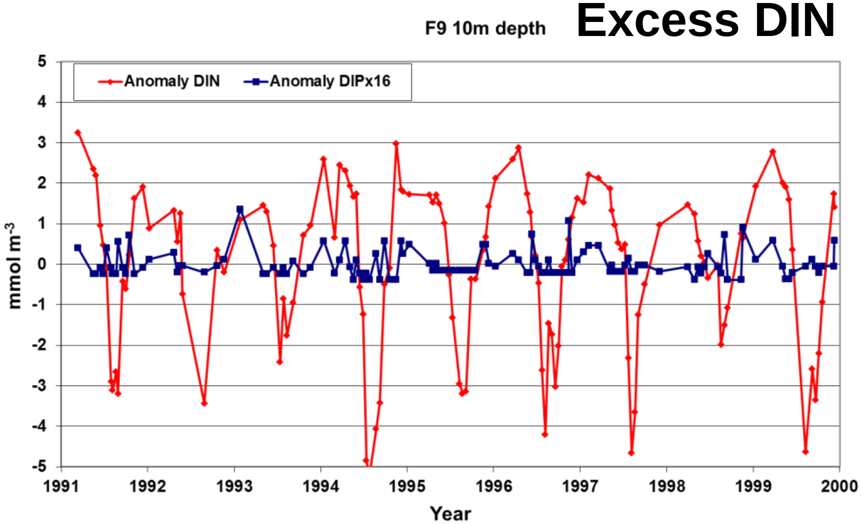
Excess DIP



Eastern Gotland Basin

- Anomaly relative to annual mean of DIN and DIPx16
- Challenge: Understand missing DIN.

Excess DIN



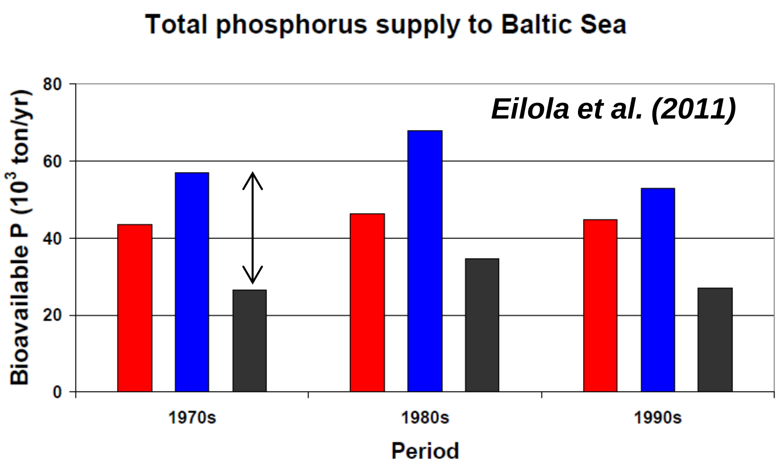
Bothnian Bay

- Anomaly relative to annual mean of DIN and DIPx16
- Challenge: Understand missing DIP.

Summary

SMHI

- **What are the actual supplies contributing to the Baltic Sea internal nutrient cycling in different climates? Bio availability and coastal retention?**
- **What is the inventory of different pools of nutrients actually contributing to the Baltic Sea nutrient cycling on centennial time scales?**
- **What causes differences of nutrient cycling in the northern and southern Baltic Sea?**
- **What causes differences in burial rates on centennial time scales?**
- **What is the oxygen and temperature dependence of nutrient recycling?**
- **What is the role of the open boundary in different times?**

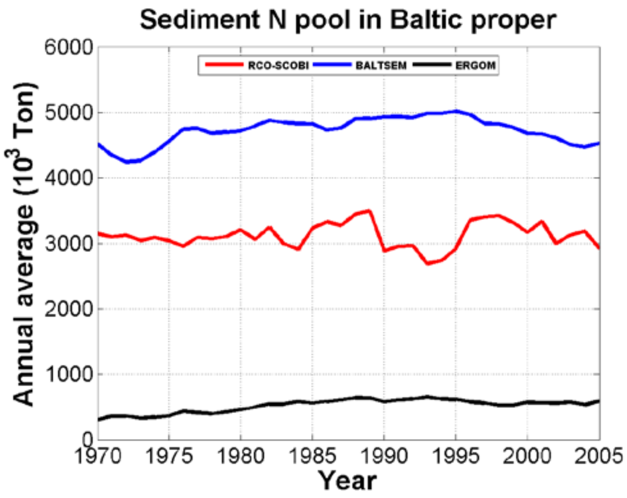


- **The P-loads differ by about 100%, from the smallest to the highest P-loads in the ECOSUPPORT state of the art ensemble. 70% of OrgN loads are neglected "not bioavailable".**

Nutrient supplies

- **Challenge: Understand the actual supplies contributing to the Baltic Sea internal nutrient cycling.**
- **Understand the dynamics of the biological availability of nutrients under different environmental conditions.**

Eilola et al. (2011)



Nutrient inventory

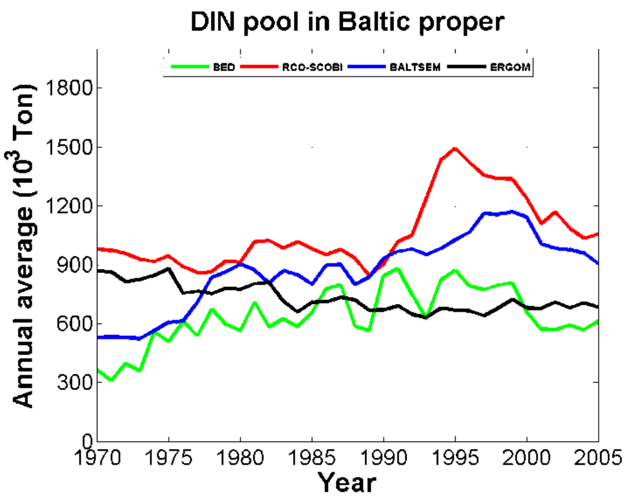
- **Challenge: Understand the inventory of different pools of nutrients actually contributing to the Baltic Sea nutrient cycling on centennial time scales.**

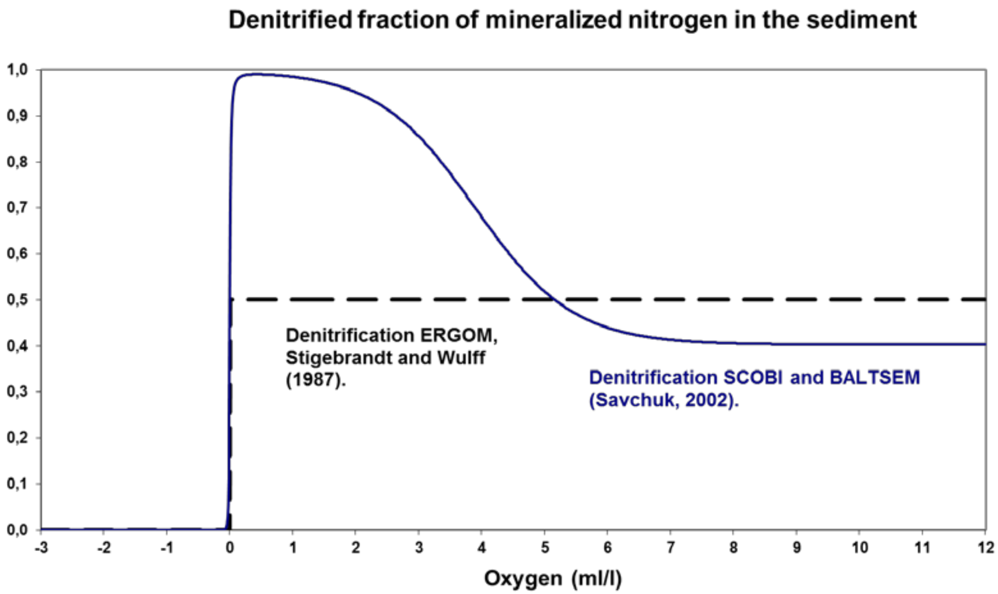
- ***The comparability of simulated pools to the amount of sediment nutrients in reality involved into biogeochemical cycles is still an open question.***

Denitrification (main N sink)

- **Bottom water oxygen dependent sediment denitrification and the denitrification in coastal river deltas differ among state of the art Baltic Sea models.**

- **Challenge: Understand dynamics of nitrogen removal.**



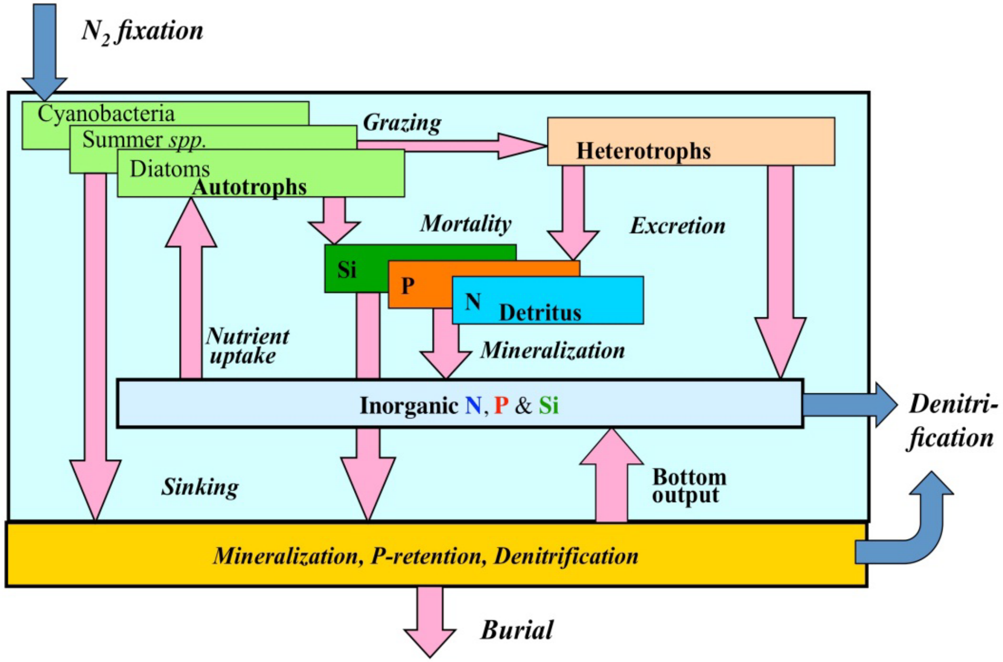


Nutrient recycling

- **Temperature and oxygen responses differ among state of the art Baltic Sea models.**

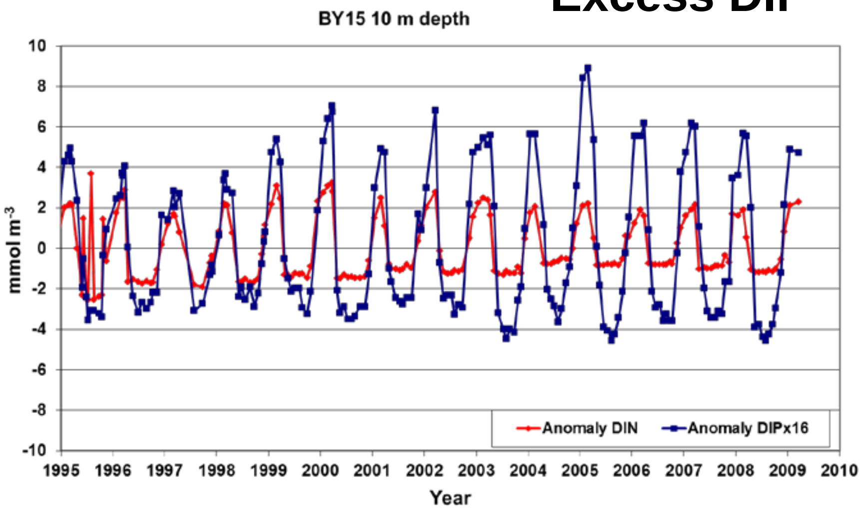
- **Challenge: Understand dynamics of nutrient recycling.**

- **Different temperature dependent mineralization rates**
- **Different temperature dependent responses of heterotrophs**
- **Different oxygen dependent phosphorus release dynamics**



Internal nitrogen cycling

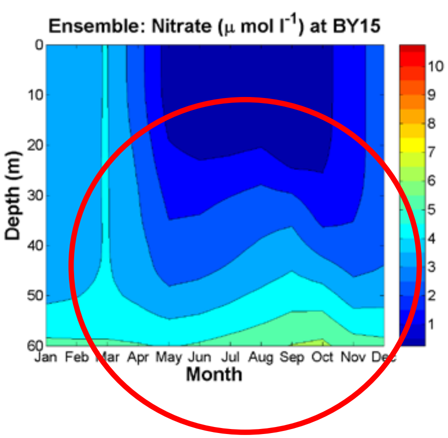
Excess DIP



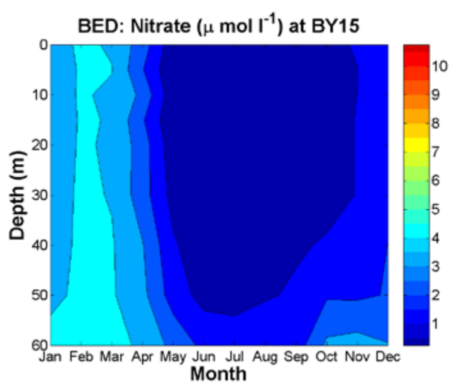
Eastern Gotland Basin

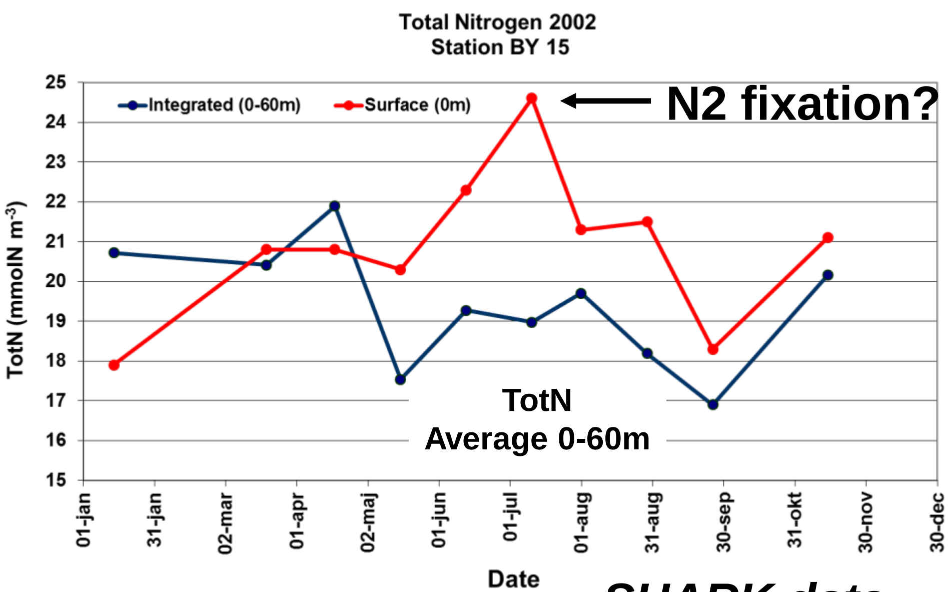
- **ECOSUPPORT models showed high NO3 below summer thermocline.**
- **Average TotN 0-60m show no large summer increase.**

ECOSUPPORT ensemble
Monthly mean 1970-2005



Observations





SHARK data

Thank you

Nutrient Budgets

SMHI

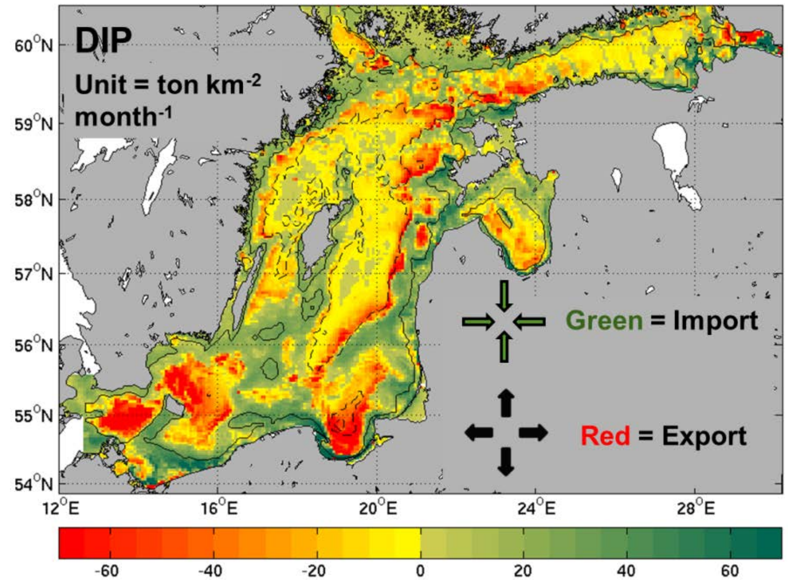
- ***Temporary net internal sources***

- **Reduce the nutrient supply to levels lower than the net nutrient export.**

Nutrient export		Nutrient supply	
23 N	<x	835 N	x<23 N
6 P	<y	39 P	y<6 P

- **Temporary, internal cycling continue largely unchanged.**
- **Internal sinks reduces the net nutrient export until it is below the nutrient supply.**

- **Challenge: Understand the nutrient inventory and time scales of change.**



Eilola et al (2012)

Nutrient Budgets

- ***Negative export***

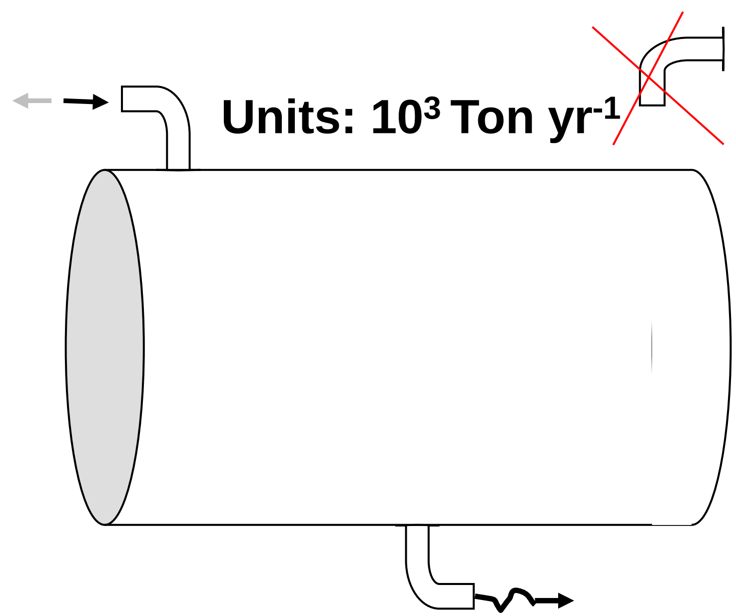
- **No supply.**
- **At some point the net export will become negative.**

- **The net import will finally be balanced by the internal nutrient removal.**

- **Challenge: Understand the role of open boundary conditions in pre-industrial times and in a future with climate driven sea level changes.**

import

~~**Nutrient export**~~	**Nutrient supply**
-? N	**→ 0 N**
-? P	**→ 0 P**



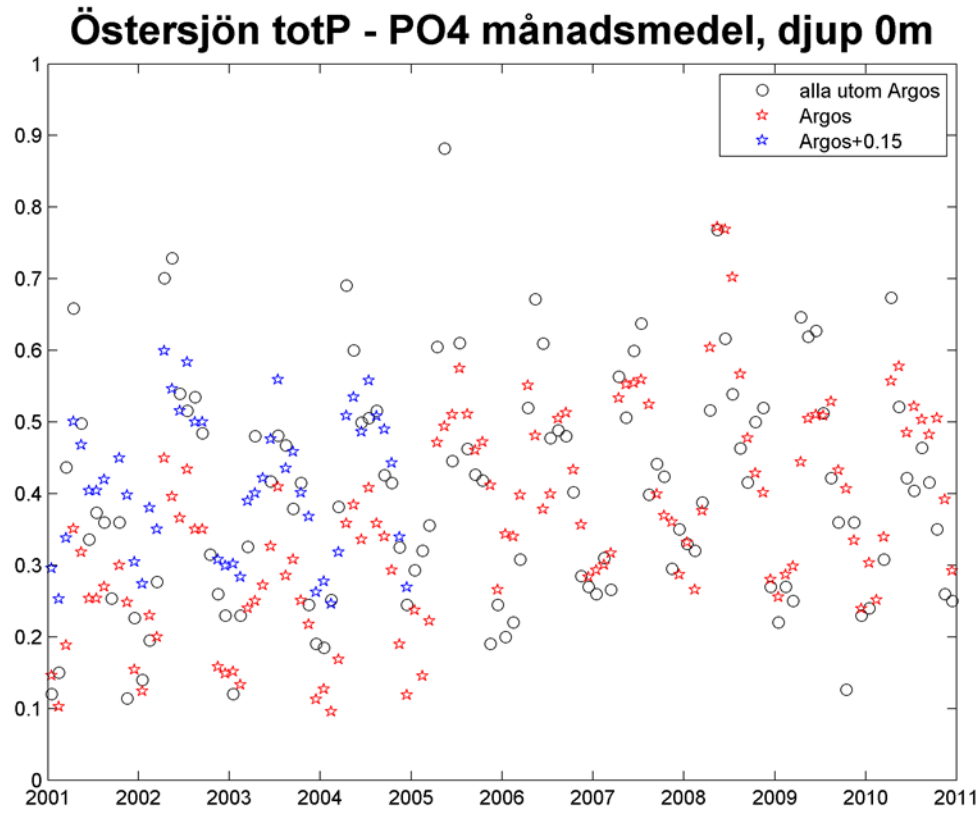
Internal nutrient removal

Historical Baltic Sea, ground truth

SMHI

Example: Method shift 1.1.2005

- **New TotP laboratory method introduced at SMHI**
- **Method change cause an increase of TotP, on average 0.15 µM.**
- **Method change is well documented including parallell measurements.**



Problem:

- **Old and new TotP data in the database are not directly comparable.**

Needed:

- **Common processed comparable data sets.**

Nutrient Budgets

SMHI

	Nutrient export	Nutrient supply
*Stigebrandt et al. (2013)**	7 P (1980) 9 P (2005)	60 P (1980) 35 P (2005)

- **P budgets 1980 and 2005**

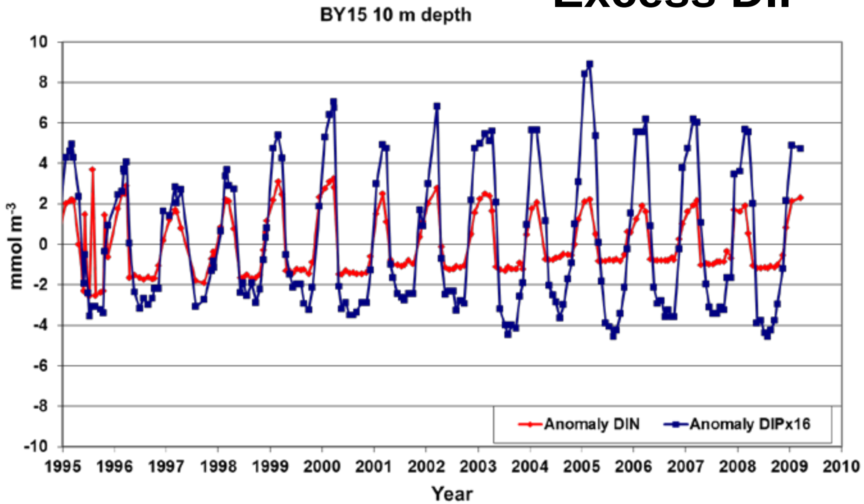
Sink efficiency

- **P 1980 = 88%**
- **P 2005 = 74%**

*A new phosphorus paradigm for the Baltic proper. AMBIO 2013

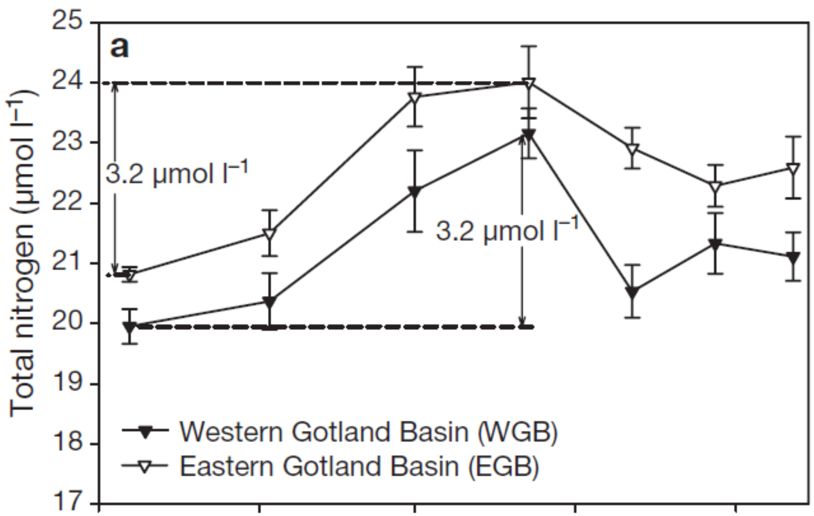
Internal nitrogen cycling

Excess DIP



Eastern Gotland Basin

- **Anomaly relative to annual mean of DIN and DIPx16**
- **Challenge: Understand missing DIN.**



Rolff et al. (2011)

Summer time nitrogen increase in surface layers

- **Nitrogen fixation**