ON THE ROLE OF LAND DERIVED N AND P INPUT FOR EUTROPHICATION IN THE BALTIC SEA

Maren Voss, Leibniz Institute for Baltic Sea Research, Germany
Jacob Carstensen, National Environmental Research Institute, Denmark
Daniel Conley, Lund University, Sweden,
Joachim Dippner, Leibniz Institute for Baltic Sea Research, Rostock, Germany
Claudia Frey, Leibniz-Institute for Baltic Sea Research, Germany,
Susanna Hietanen, University of Helsinki, Finland
Tom Jilbert , Utrecht University, The Netherlands
Frederike Korth, Leibniz Institute for Baltic Sea Research, Germany
Caroline Slomp, Utrecht University, The Netherlands

Leibniz-Institut für Ostseeforschung Warnemünde iow

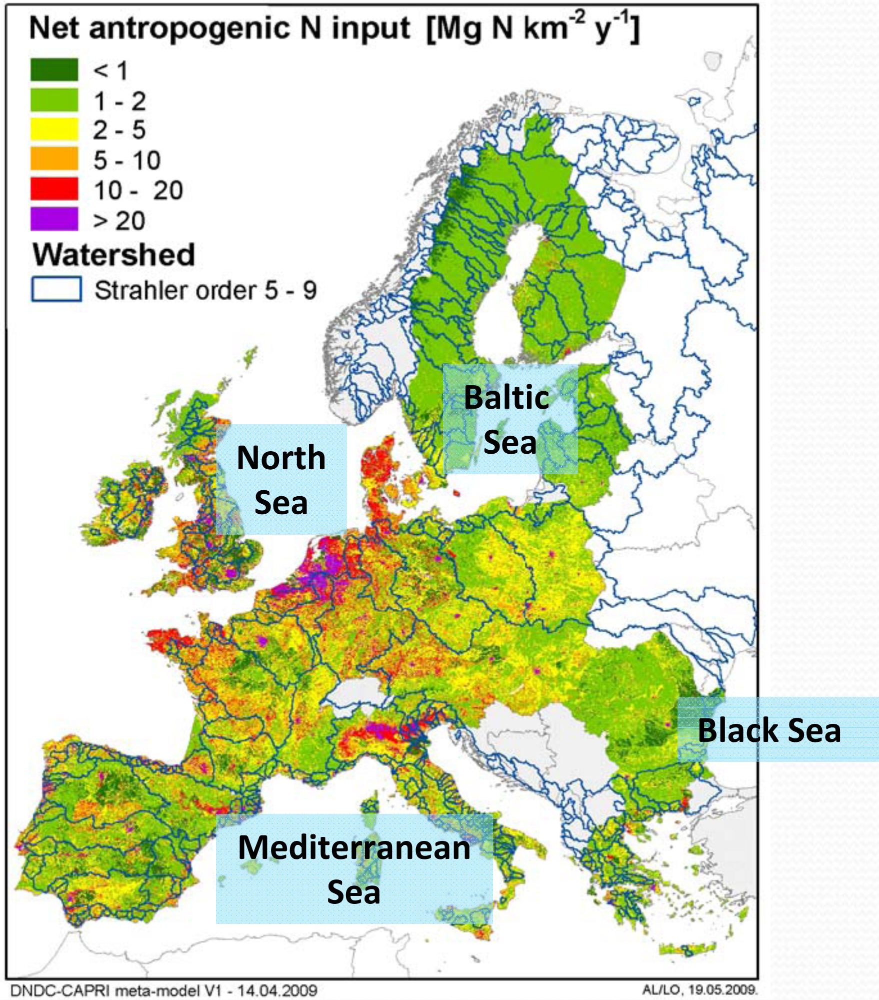
HYPER HYPoxia mitigation for Baltic Sea Ecosystem Restoration

BONUS Baltic Organisations Network for Funding Science EEIG

Seventh Framework Programme

Net anthropogenic nitrogen inputs, NANI

(export over background of 228 ± 100kg N km^{-2} y^{-1}, Howarth et al. 2006, Billen et al. in press)



Baltic Sea northern part
1-2 Mg N km^{-2} y^{-1}

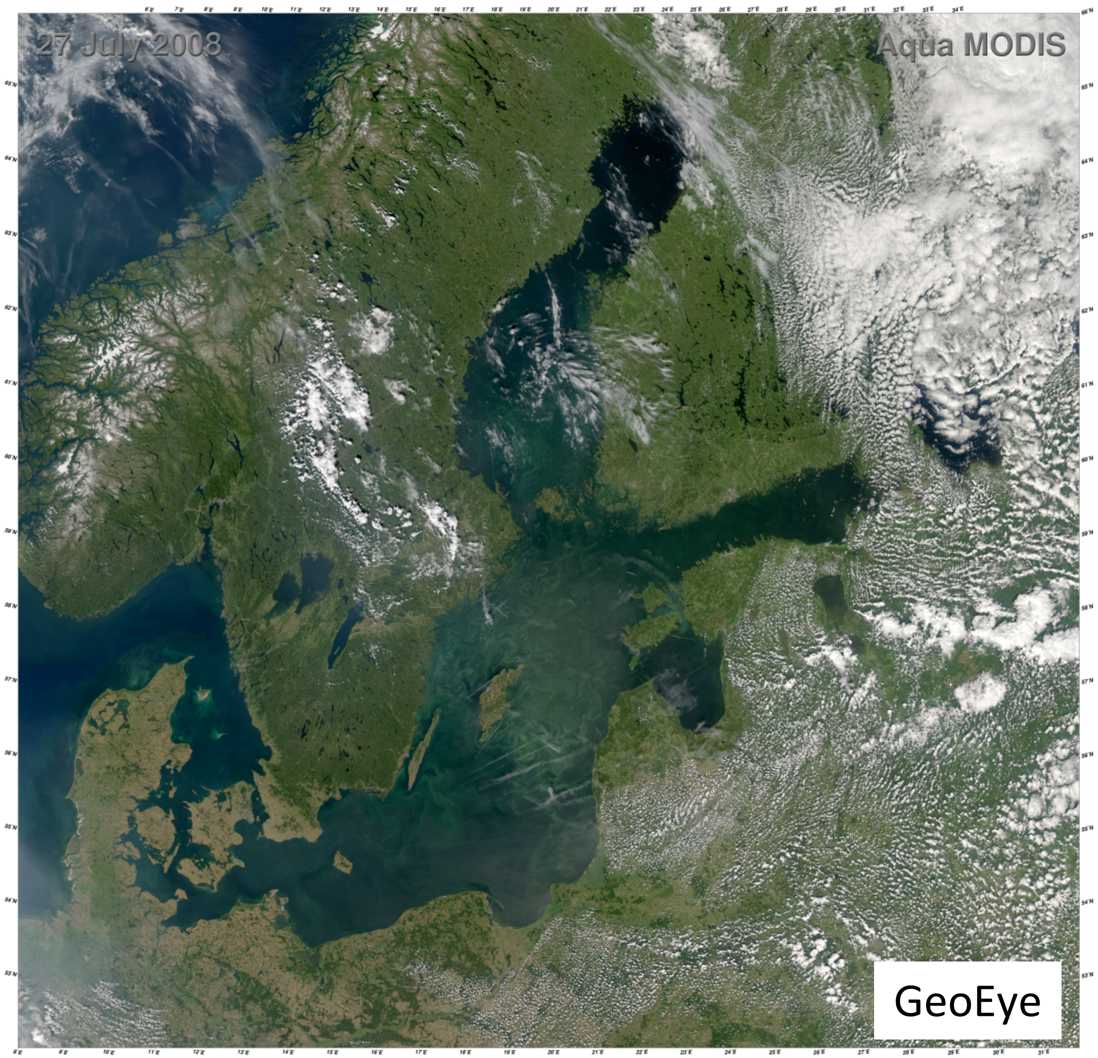
Baltic Sea southern part
2-20 Mg N km^{-2} y^{-1}

European Nitrogen Assessment
Billen et. al in press

Comparison of regional seas

	Baltic Sea	Black Sea	Mediterranean Sea	North Sea	Chesapeak Bay
Size (km^2)	412,560	436,400	970,000	750,000	11,000
Drainage area (km^2)	1,600,000 (4X)	2,400,000 (5.5X)	1,335,000 (1.4X) 2,800,000 (Nile)	526,000 (0.7X)	167,000 (15X)
Averg/Max depth (m)	30 / 480	1500 / 2200	1500 / 5200	95 / 700	14 / 63
Population in drainage in Million (M)	85 M	190 M	168 M (all people in riparian countries)	185 M	15 M
Nitrogen load estimate (kt y^{-1})	1,000	800	600 (only rivers)	800 (only rivers modelled)	155

The Baltic Sea: land cover



- The Baltic Sea receives the largest N-load from a comparatively small drainge area.
- The mean residence time of the water is 30-35 years because it is an enclosed sea.
- 50%-60% of all riverine nutrients come from the 5 largest rivers in the south and east.
- Four of them enter lagoons/bays before they flow into the coastal zone.
- in the central Baltic Sea, large blooms of nitrogen fixing cyanobacteria occur every summer.

N:P ratio of sources varies from 40 to 95

Baltic Nutrient Noad (thousand tons/year of N and P)

Basin and Area	Riverine Load, Natural + Anthropogenic	Coastal Point Sources	Atmospheric Load, Natural + Anthropogenic	Sum Total	N:P Ratio (molar)
Gulf of Bothnia* (115,500 km²)	N: 100 P: 5	N: 10 P: 1	N: 48 P: <1	N: 158 P: 6	58
Baltic proper (211,100 km²)	N: 363 P: 23	N: 27 P: 4	N: 185 P: 2	N: 575 P: 29	44
Gulf of Finland (29,600 km²)	N: 126 P: 6	N: 31 P: 4	N: 23 P: <1	N: 180 P: 10	40
Gulf of Riga (16,300 km²)	N: 113 P: 2	N: 5 P: 1	N: 11 P: <1	N: 129 P: 3	95
Baltic Sea total (373,200 km²)	N: 702 P: 37	N: 73 P: 9	N: 267 P: 3	N: 1042 P: 48	48

* Gulf of Bothnia = Bothnian Bay + Bothnian Sea. Modified after Elmgren and Larsson[49].

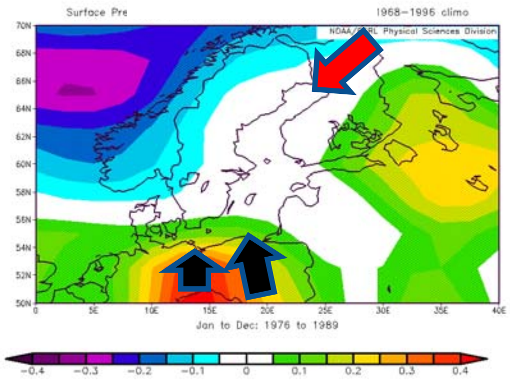
Sources: Riverine load[35], coastal point sources[45], atmospheric N load[53] multiplied by 1.25 to include organic N. Atmospheric P load calculated as 1% of N load.

- N:P ratios of all major sources are far above 16:1
- Nevertheless the Baltic Sea is known for its N-limitation in summer – leading to spectacular cyanobacteria blooms.
- Where and how change the nutrient ratios?

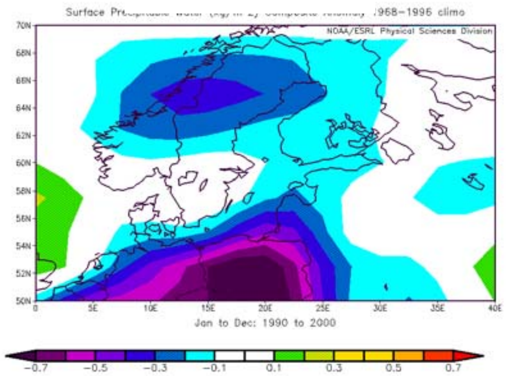
Elmgren 2001

Annual mean anomalies in the precipitation (kg m^{-2})

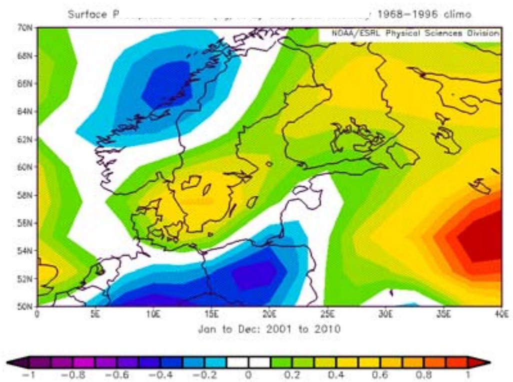
1976-1989



1990-2000



2001-2010



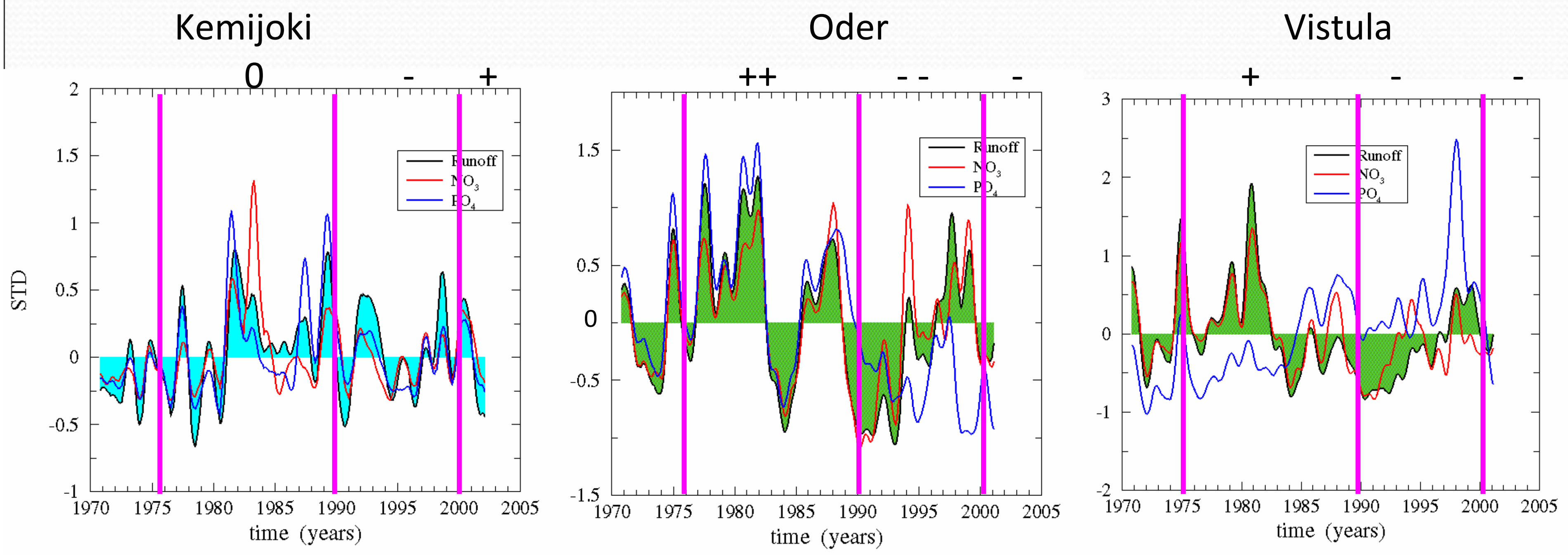
- Two regime shifts visible as changes in the precipitation anomaly:

Kemijoki:	**0**	**-**	**+**
Vistula:	+	-	-
Oder:	+ +	- -	-

- Changes in precipitation are different in the catchments of the river
- What are the effects on the loads?

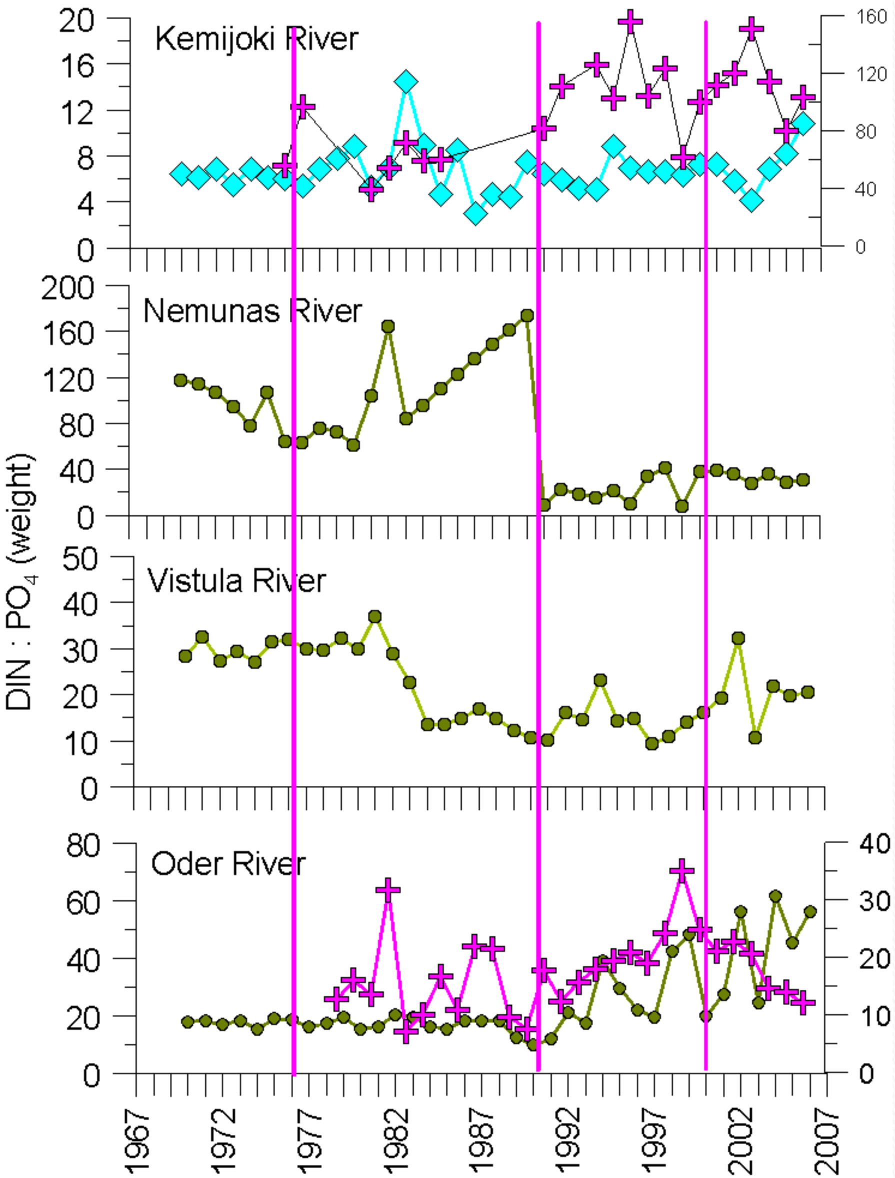
Data source: NCEP/NCAR reanalysis

Anomalies in runoff, loads of NO_3, and PO_4



- Strong responses in southern rivers
- Weak response in northern river
- Pristine Kemijoki shows a co-variation of runoff and nutrients
- Anthropogenically dominated Oder and Vistula respond differently esp. after the 2nd regime shift

River DIN:PO_4



Precipitation

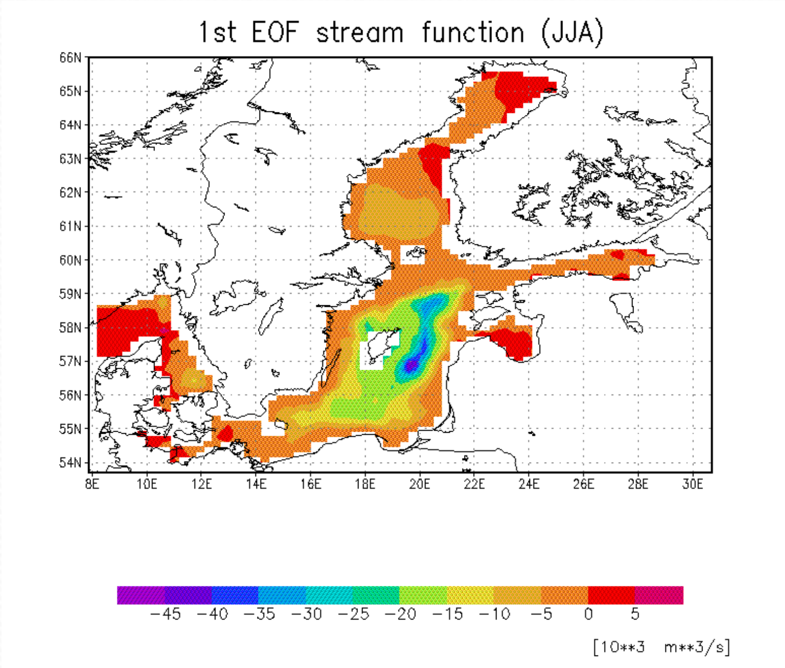
•Kemijoki:	0	-	+	
•Vistula:		+	-	-
•Oder:	+ +	- -	-	

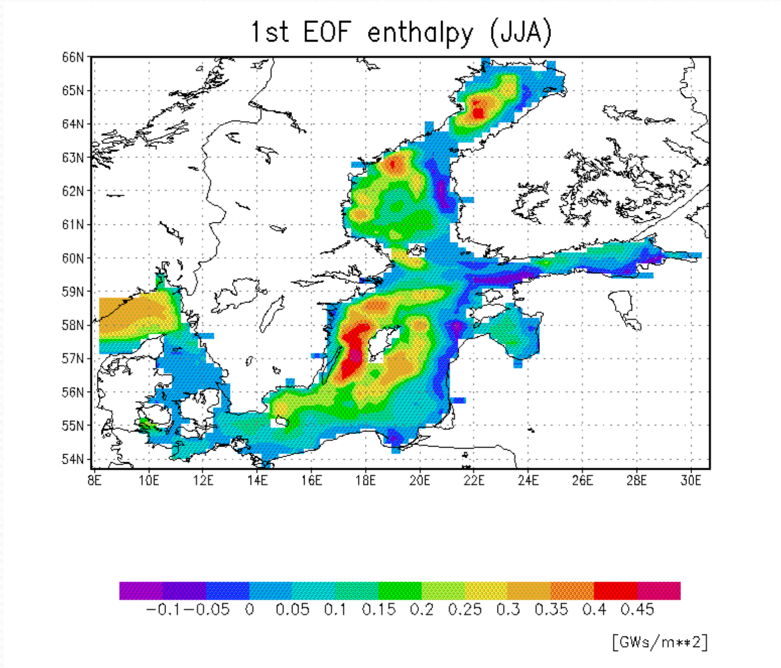
Molar ratios in rivers:

•Kemijoki:	19 -	17 -	18
•Nemunas:	274 -	100 -	78
•Vistula:	76 -	38 -	51
•Oder: 43 -	63 -	106	

+ Coastal values

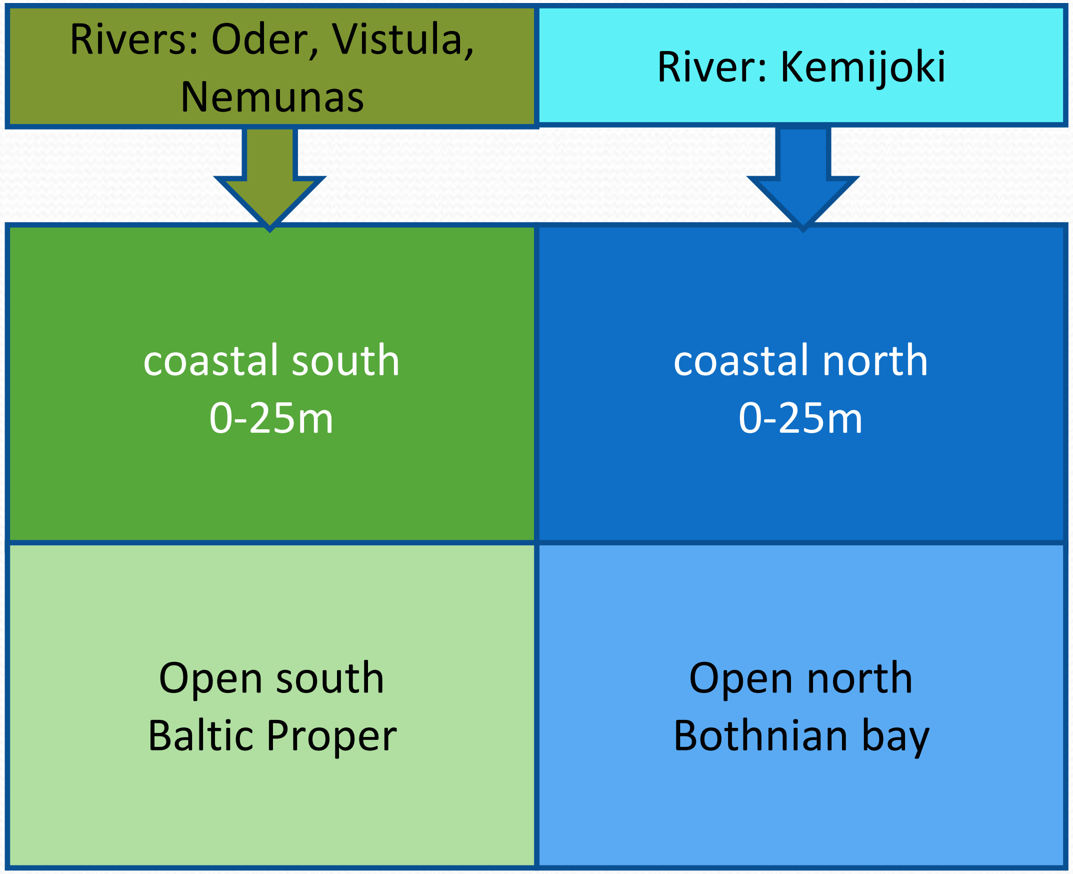
Closed stream functions in the central Baltic Sea





They ensure the transport of the river loads along the coastline at in a band of approximatly 20 km width

Systematics of data presentation



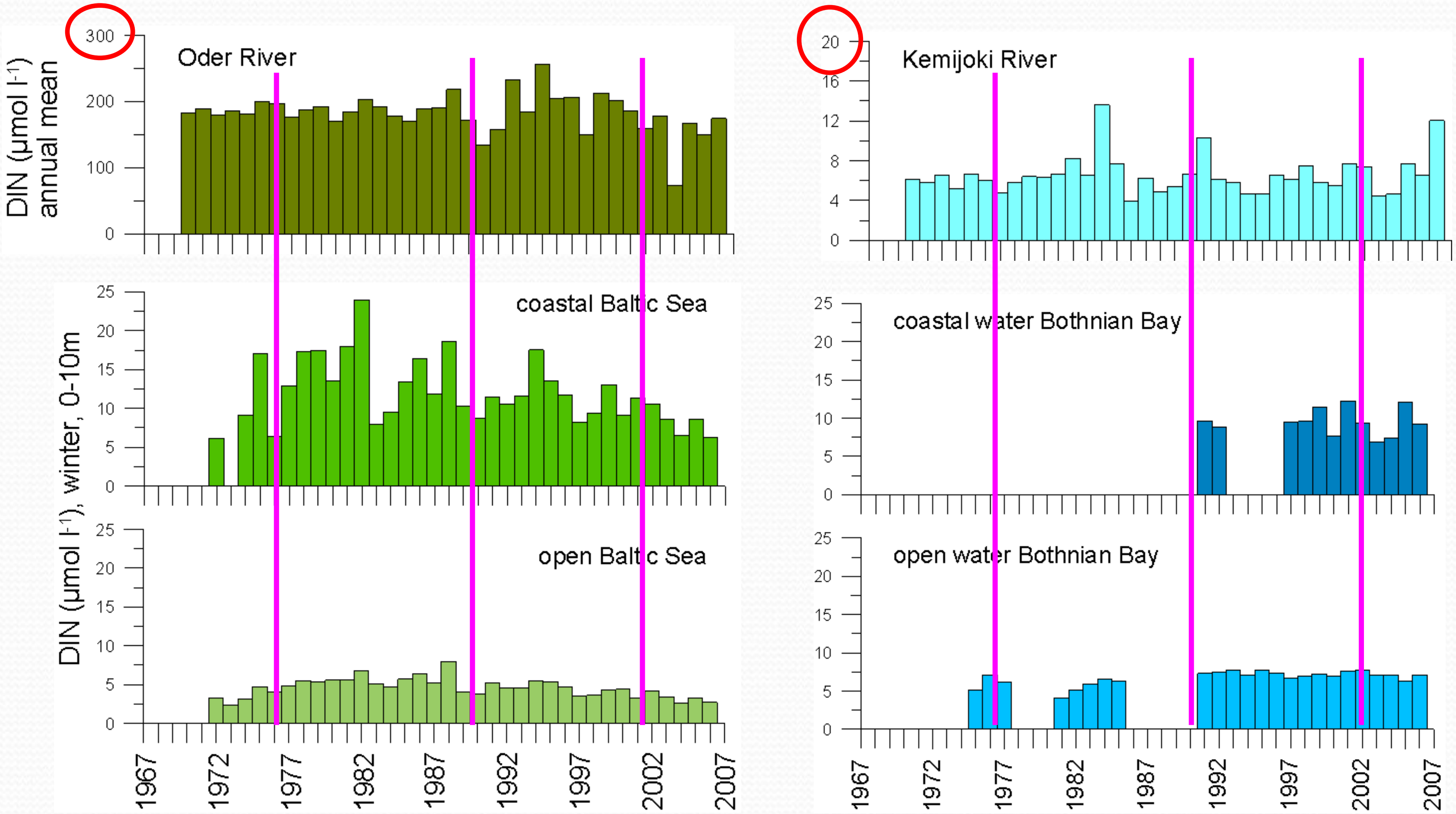
Moreover we will look at:

DIN and DIP concentrations
DIN:DIP ratios

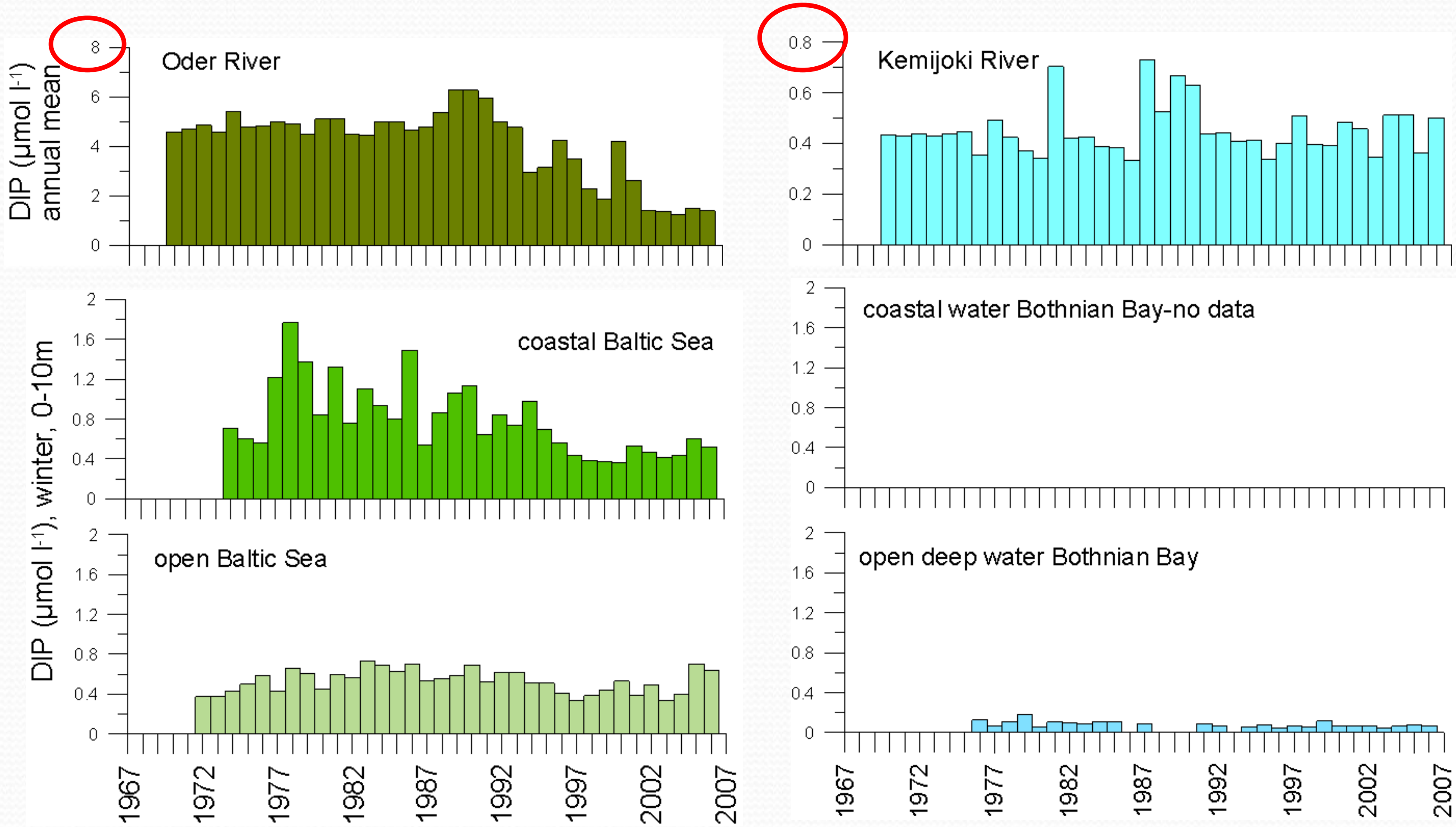
(total N and total P)
(N_{tot} :P_{tot} ratios)

2 regime shifts
1976-1989
1990-2001
2001-2010

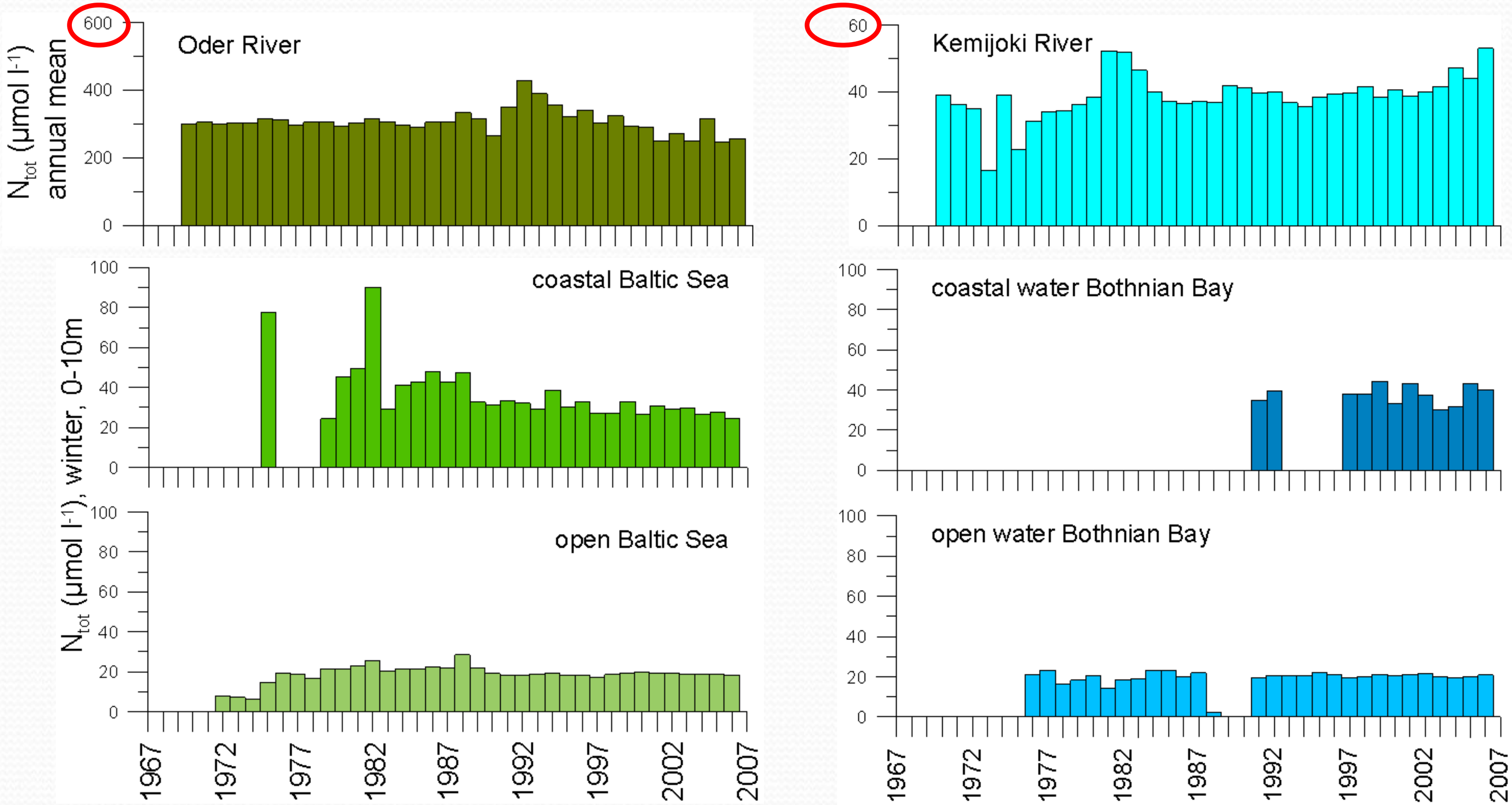
River DIN concentrations over time



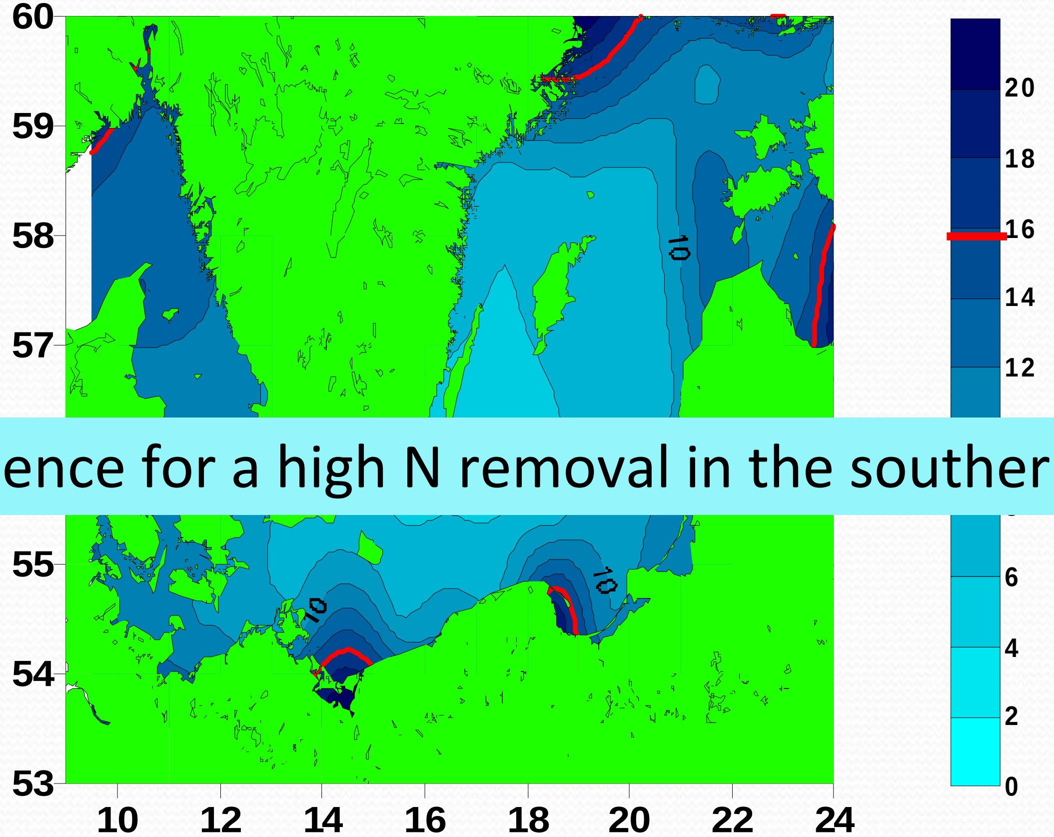
River DIP concentrations over time



River N_{tot} concentrations over time



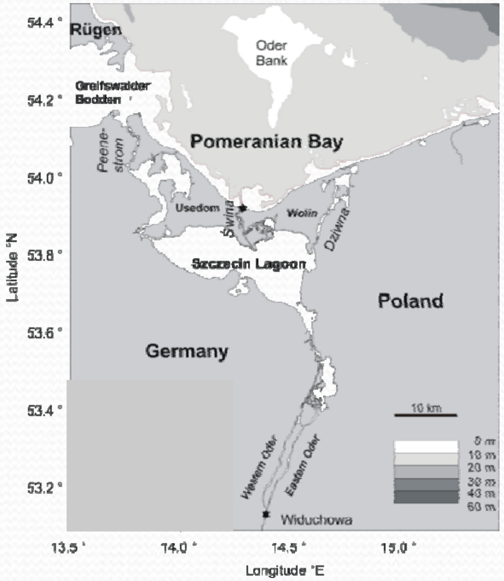
Surface N:P ratio (molar) in winter



Is there evidence for a high N removal in the southern Baltic Sea?

Decreasing N:P ratios towards the open Baltic Sea
Stream functions again visible

A budget for the Oder lagoon

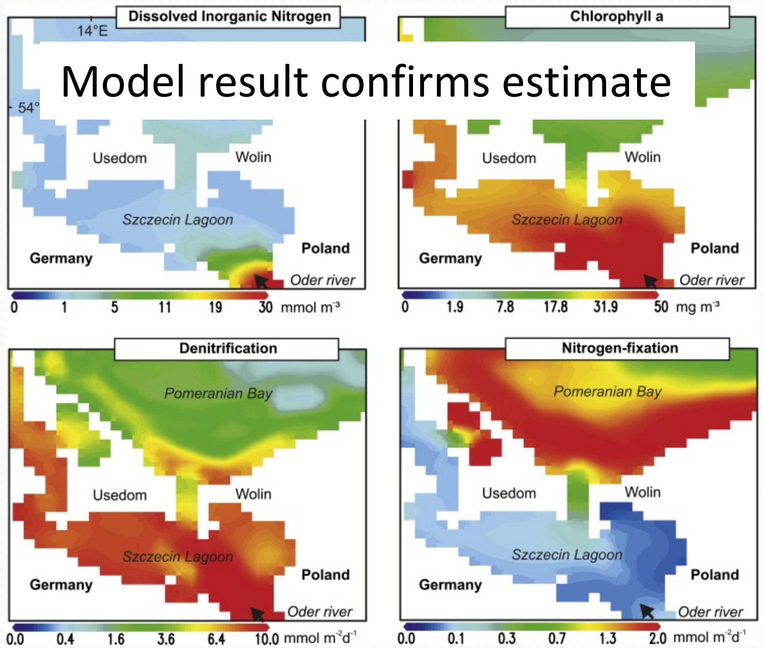


River load mean: 77 kt N_{tot} y^{-1}

Denitrification rates of 5-7 mmol m^{-2} d^{-1}

→ extrapolated removal app. 10% of load
But measurements suggest max. 76% N and 60% P (Voss et al. 2010)

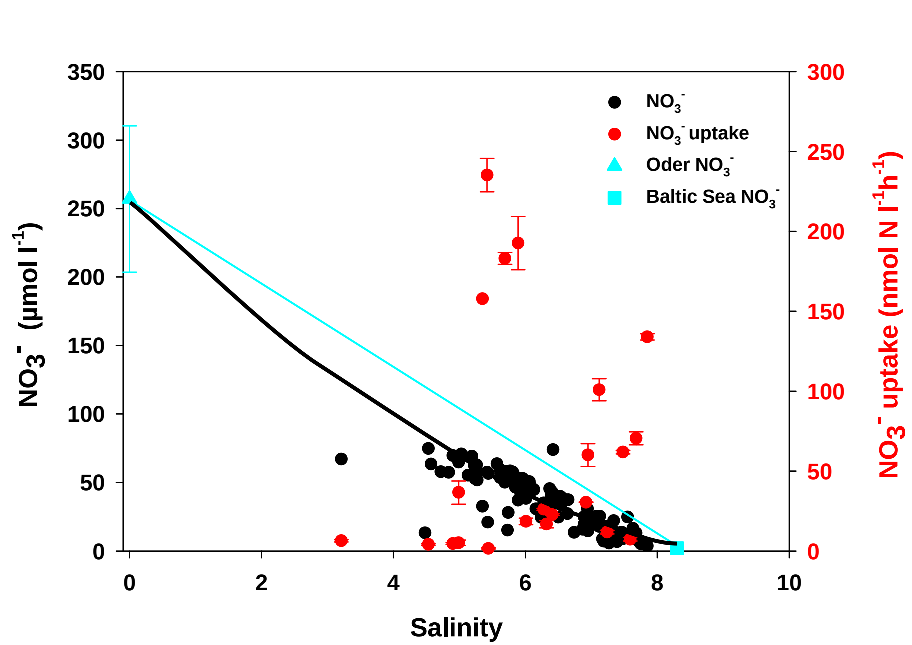
→ in any case has the export to coastal zone a high N:P ratio

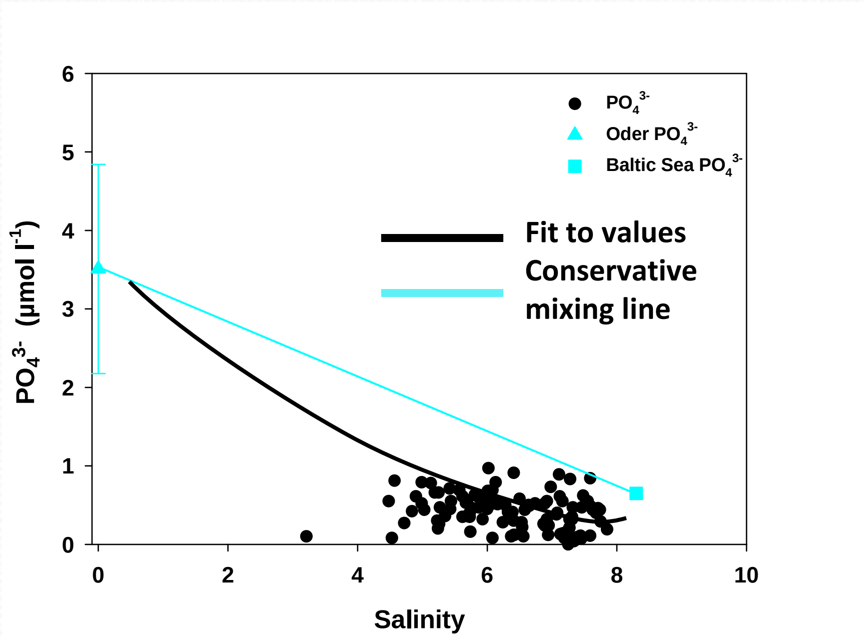


Remaining load (esp. N) is supposed to be sequestered and lost in the coastal zone.

Voss et al., 2011

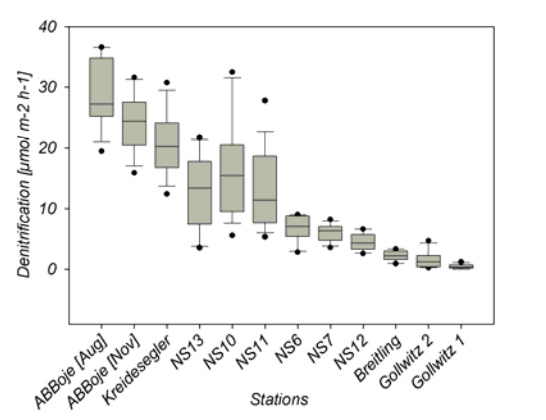
Evidence for NO_3 and PO_4 uptake in the coastal zone (Oder lagoon outflow)

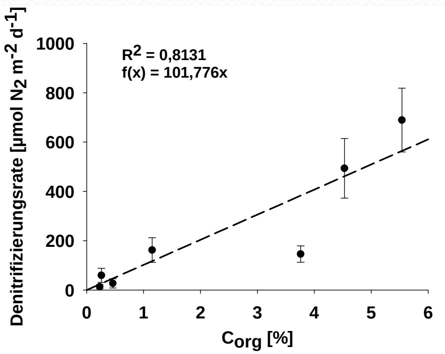


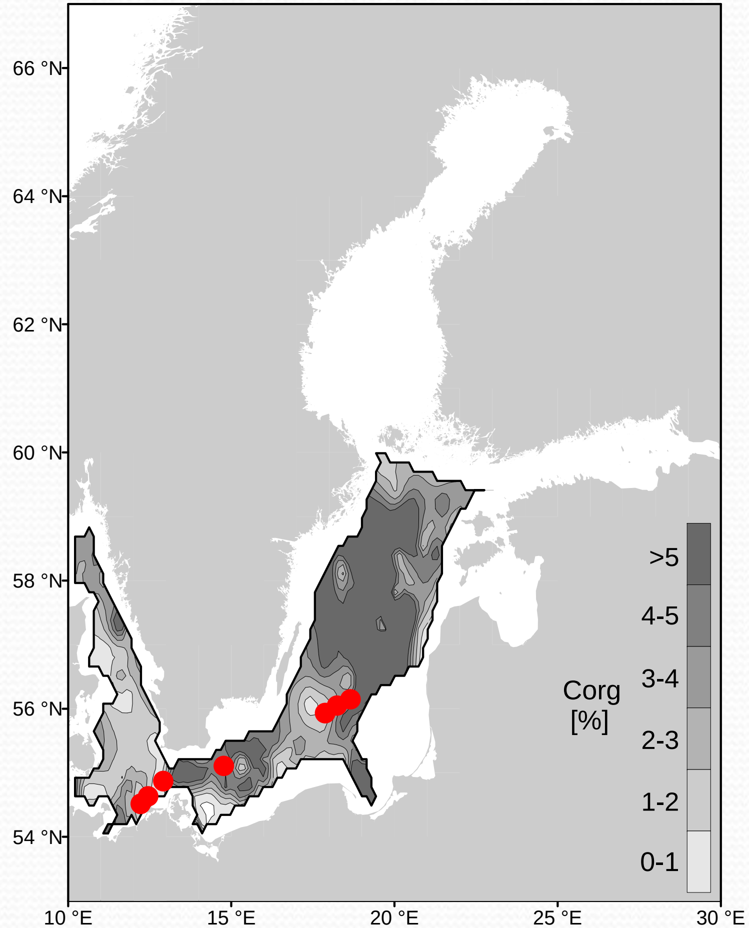


Preliminary data show high NO_3 and much lower PO_4 uptake in spring

Evidence for denitrification:
Losses in the coastal zone and open Baltic



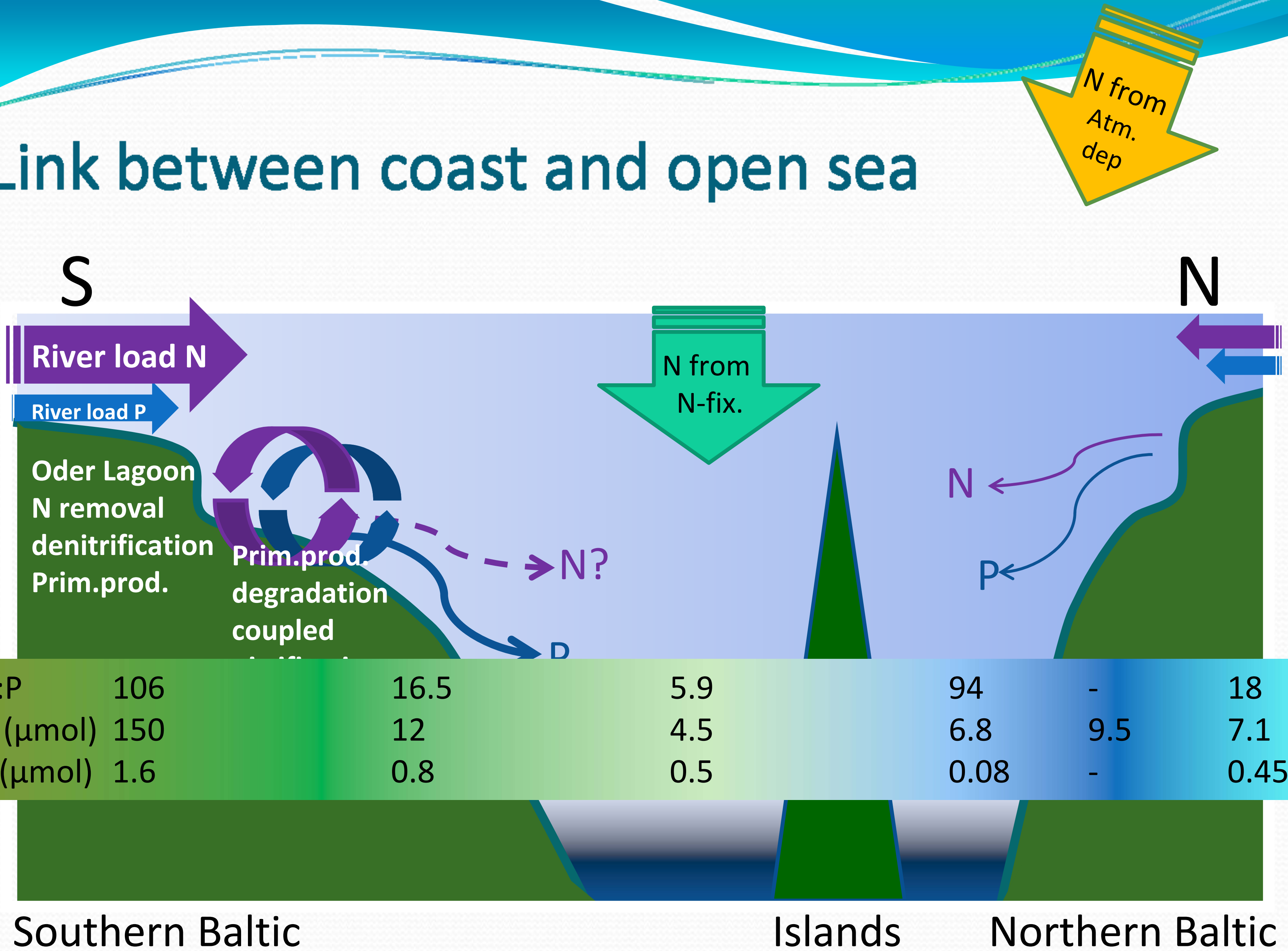




- Denitrification rates extrapolated by means of their positive relationship with organic carbon content in sediments.
- Anoxic ares not included
- The N removal by denitrification roughly matches the annual river loads.

Deutsch et al., Biogeosciences 2010

Link between coast and open sea



N:P	106	16.5	5.9	94	-	18
N (µmol)	150	12	4.5	6.8	9.5	7.1
P (µmol)	1.6	0.8	0.5	0.08	-	0.45

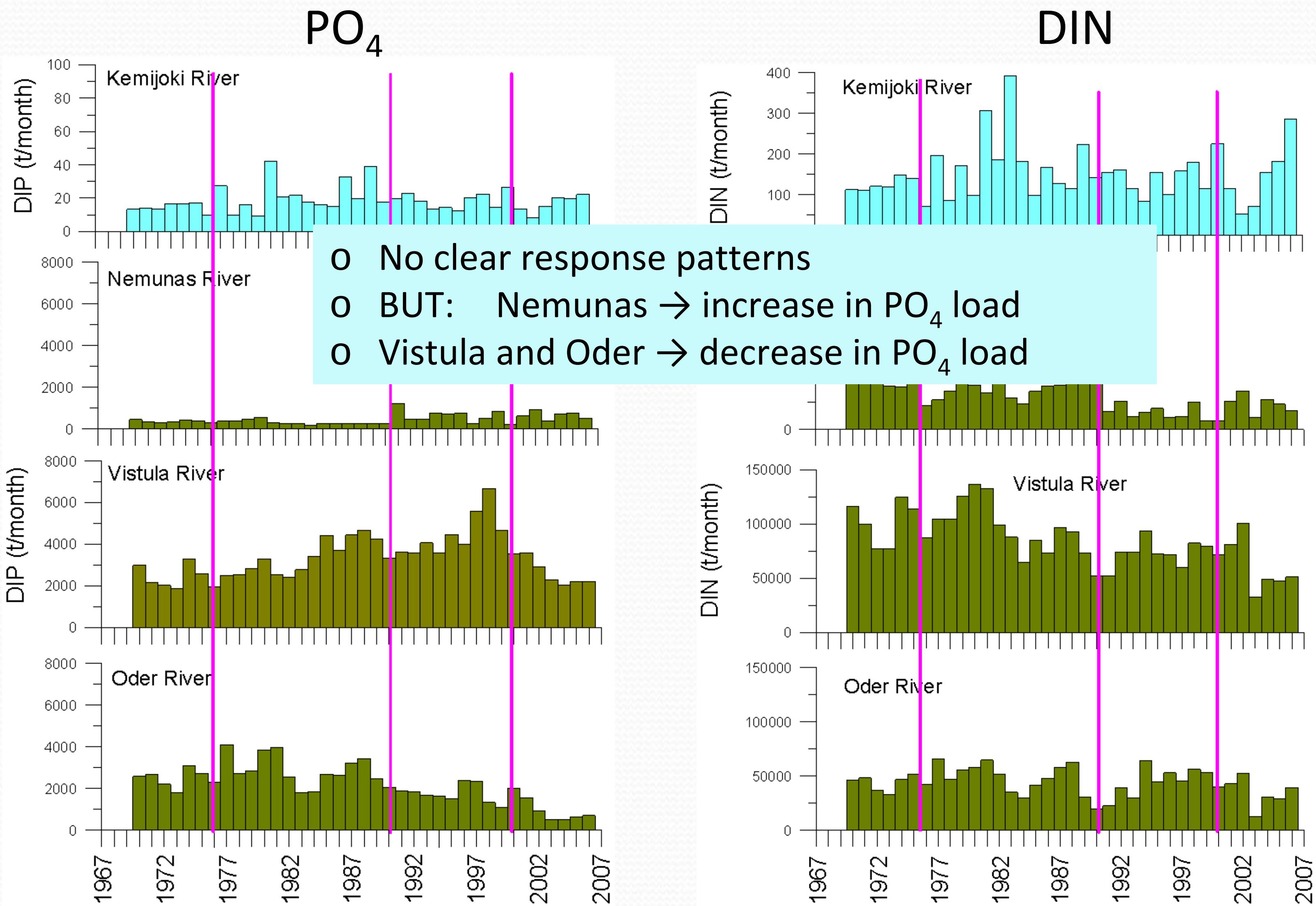
northern catchment

Southern catchment

Summary

- Global regime shifts affect the catchments and runoff of rivers.
- Nutrient loads change in response, but in different ways
- Northern and southern rivers „behave“ quite differently in terms of nutrient export.
- Most N from the southern major rivers seems to be removed in lagoons/bays and along the coast
- This N removal is bound to the availability of nitrate and thus oxygen in the coastal zone, but hypoxic zones are increasing in size and duration.

Response of flow to regime shifts?



- No clear response patterns
- BUT: Nemunas → increase in PO_4 load
- Vistula and Oder → decrease in PO_4 load