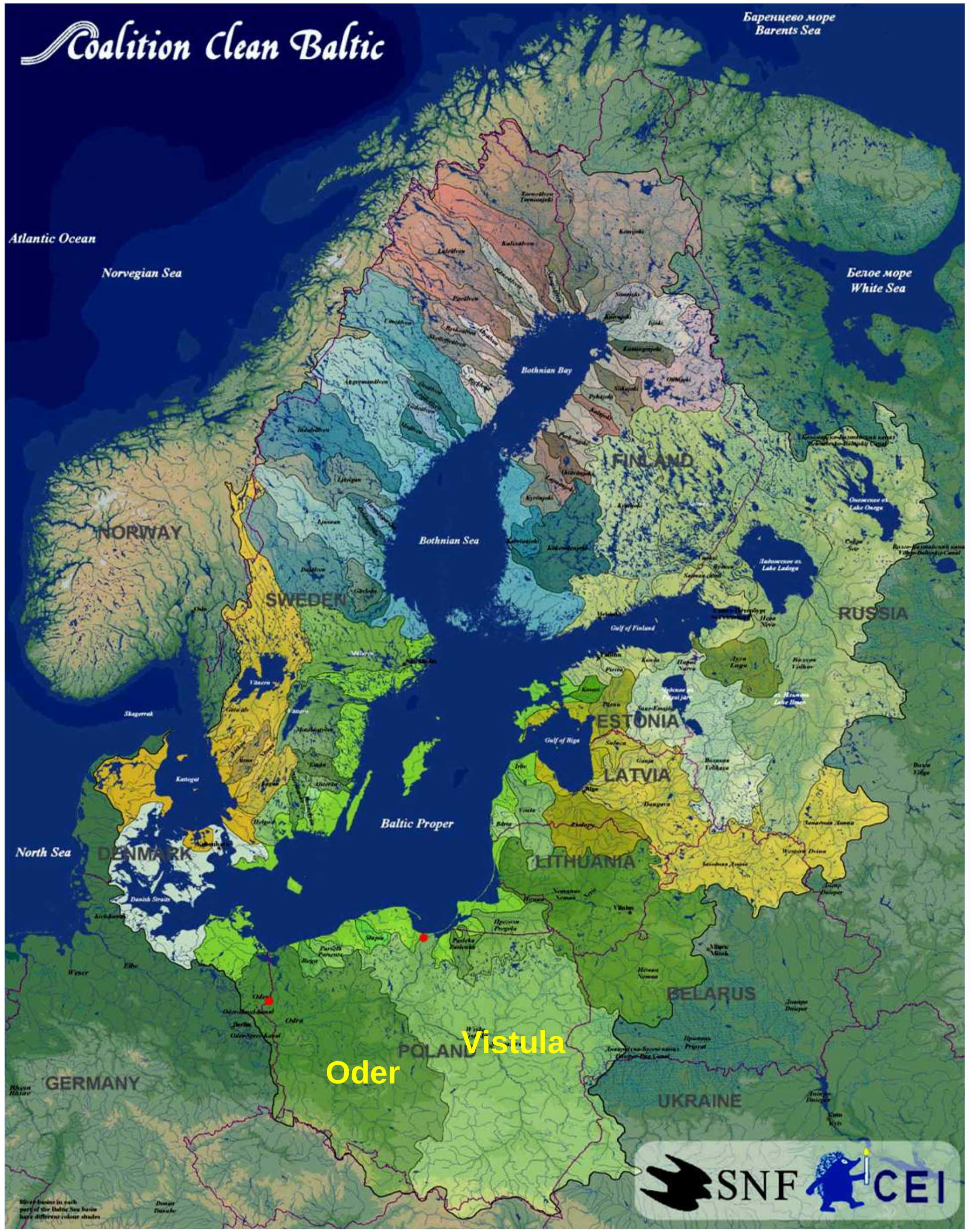
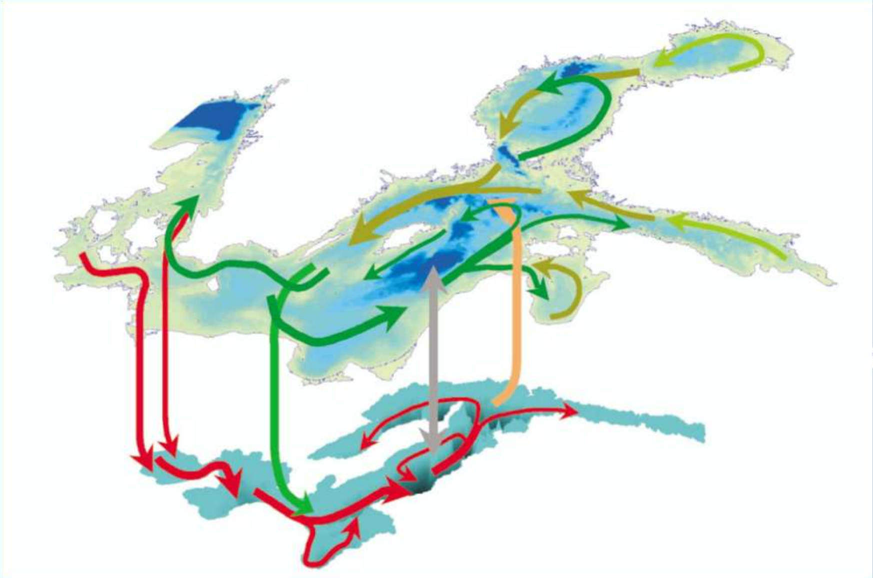
Eutrophication in the Baltic Sea – causes, consequences and mitigation measures

Marianna Pastuszak

National Marine Fisheries Research Institute
Department of Fisheries Oceanography and Marine Ecology
Gdynia, Poland

Baltic catchment; schematic illustration of water circulation in the Baltic Sea





Annual riverine outflow ca. 500 km^3

TN load – 638 000 tons (in 2006)

TP load – 28 370 tons (in 2006)

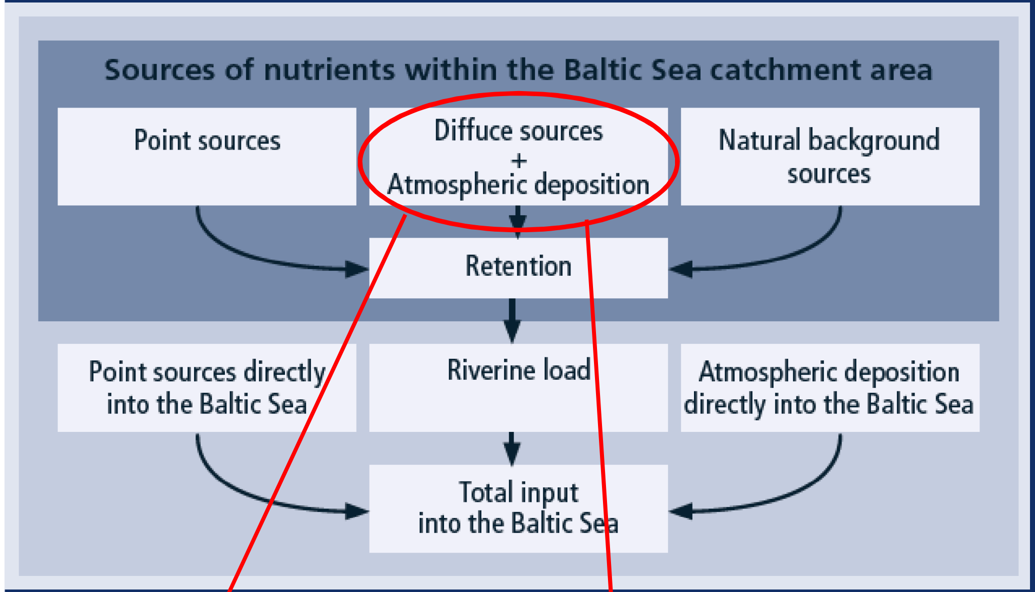
99.7% of Polish territory ⇒ Baltic catchment

Poland - second largest water supplier 63 km^3/yr

Vistula 34 km^3/yr Oder 16.7 km^3/yr

Elken and Matthäus, 2006; Pastuszak, 2012; HELCOM, 2011

N, P sources in the Baltic Sea catchment; source apportionment of nitrogen and phosphorus losses into inland surface waters in Poland in 2000 ; percentage contribution of Baltic countries to waterborn loads of TN and TP in 2006



Sources of nutrients within the Baltic Sea catchment area

Point sources

Diffuse sources + Atmospheric deposition

Natural background sources

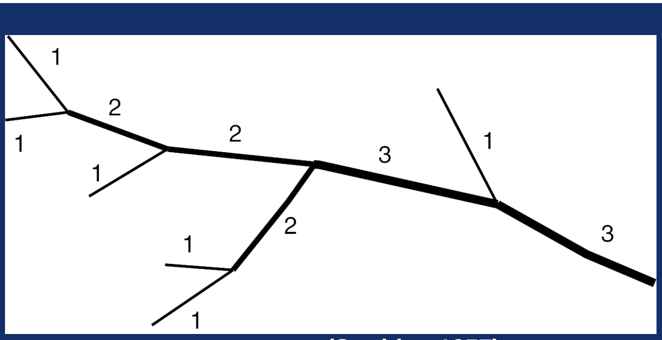
Retention

Point sources directly into the Baltic Sea

Riverine load

Atmospheric deposition directly into the Baltic Sea

Total input into the Baltic Sea



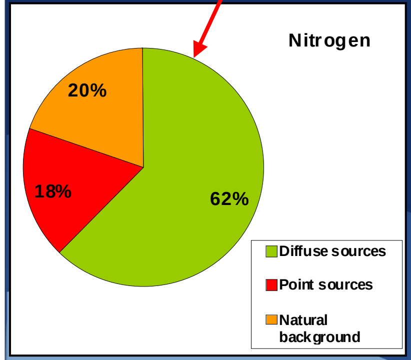
(Strahler, 1957)

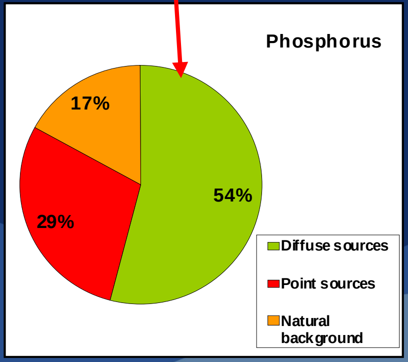
37-76 % N retention in river systems

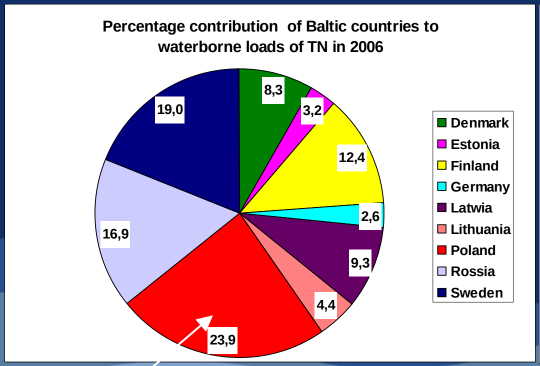
1/2 of N pool– removed in rivers of 1-4 order which constitute 90% of the entire length of all the rivers in the catchment ;

1/2 of N pool– removed in rivers of 5 and higher order which constitute 10% of the entire length of all the rivers in the catchment

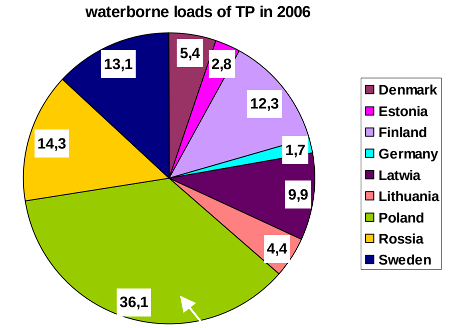
(Seitzinger et al., 2002)







Percentage contribution of Baltic countries to waterborne loads of TN in 2006



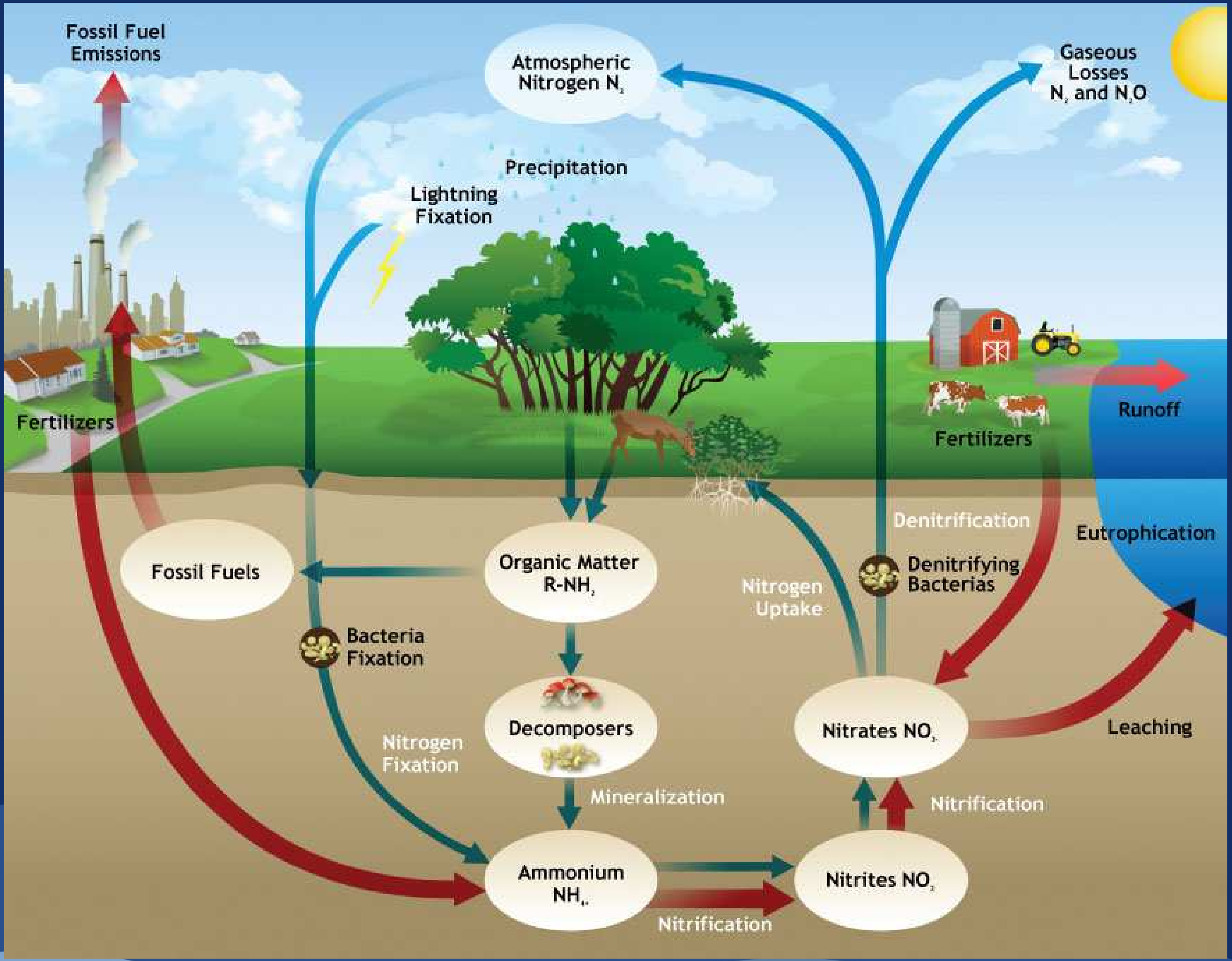
Percentage contribution of Baltic countries to waterborne loads of TP in 2006

26% in 2000

37% in 2000

HELCOM, 2004, 2011

Nitrogen (N) cycle in soil



http://landscapeforlife.org/give_back/3c.php

Fotyma et al., 2012; Pastuszak et al., 2012a, b

N easily moves along the soil profile ⇒ substantial leaching

➢N surplus

➢Geomorphological features

- Soil type

- Type of bedrock

- Land slope

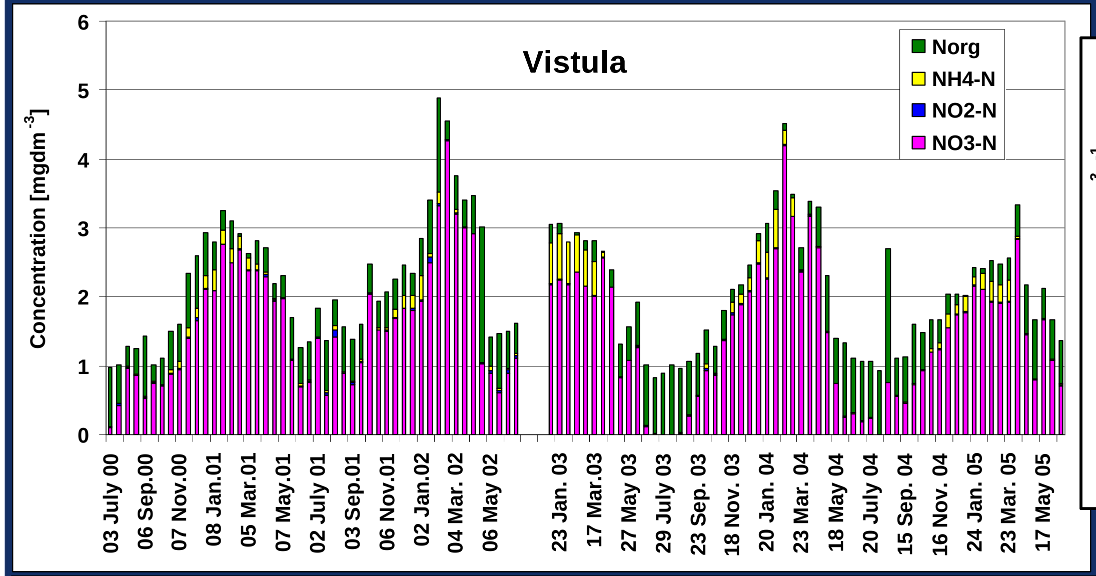
➢Hydrological-meteorological conditions

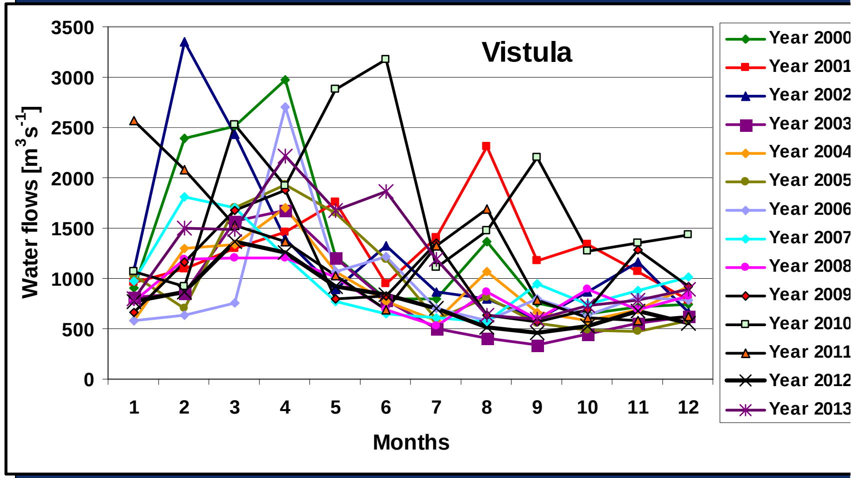
➢Poland - 84% of area land slope < 3º

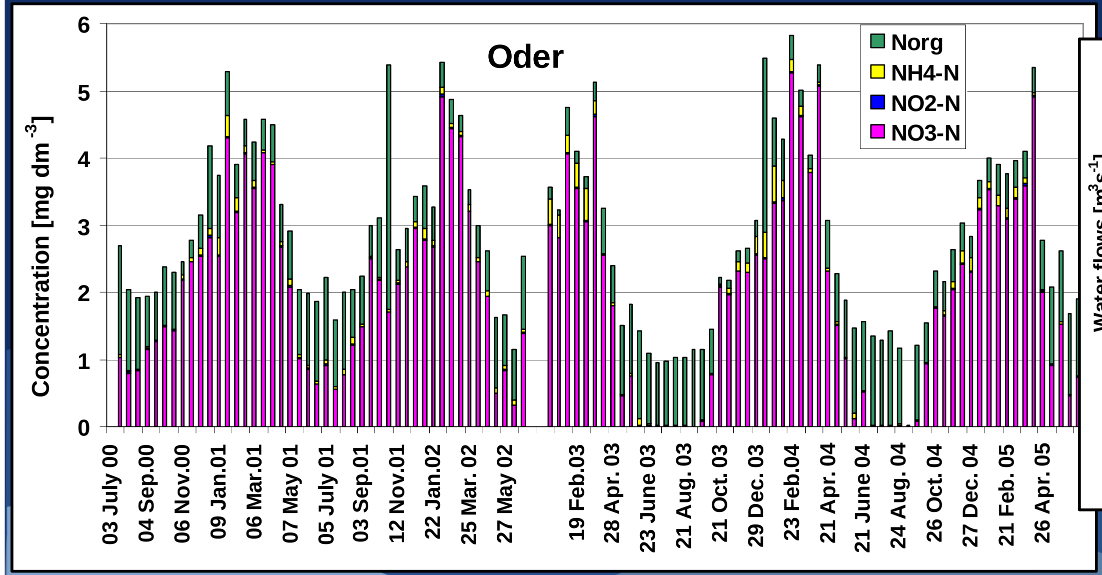
➢High contribution of groundwater in N emission

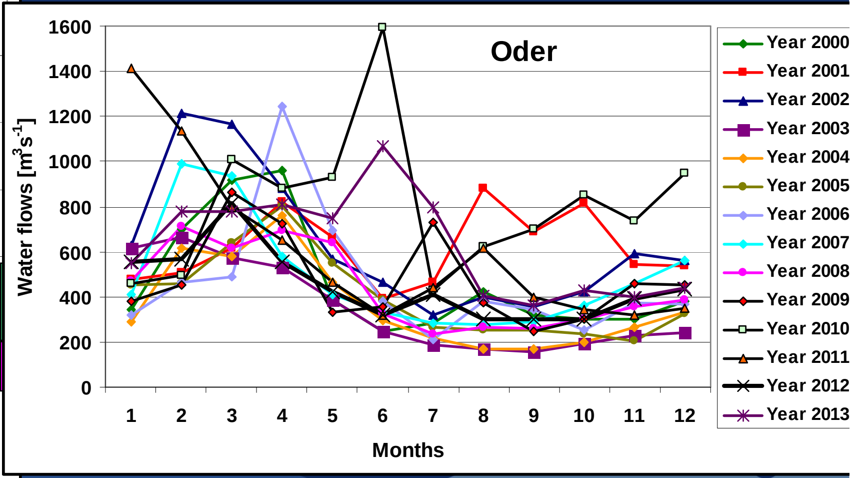
Predomination of slow flow systems, with long transit time, favors high N retention

Nitrogen species concentrations in the Vistula and Oder Rivers (own data – EU grants); water flows – data from IMWM









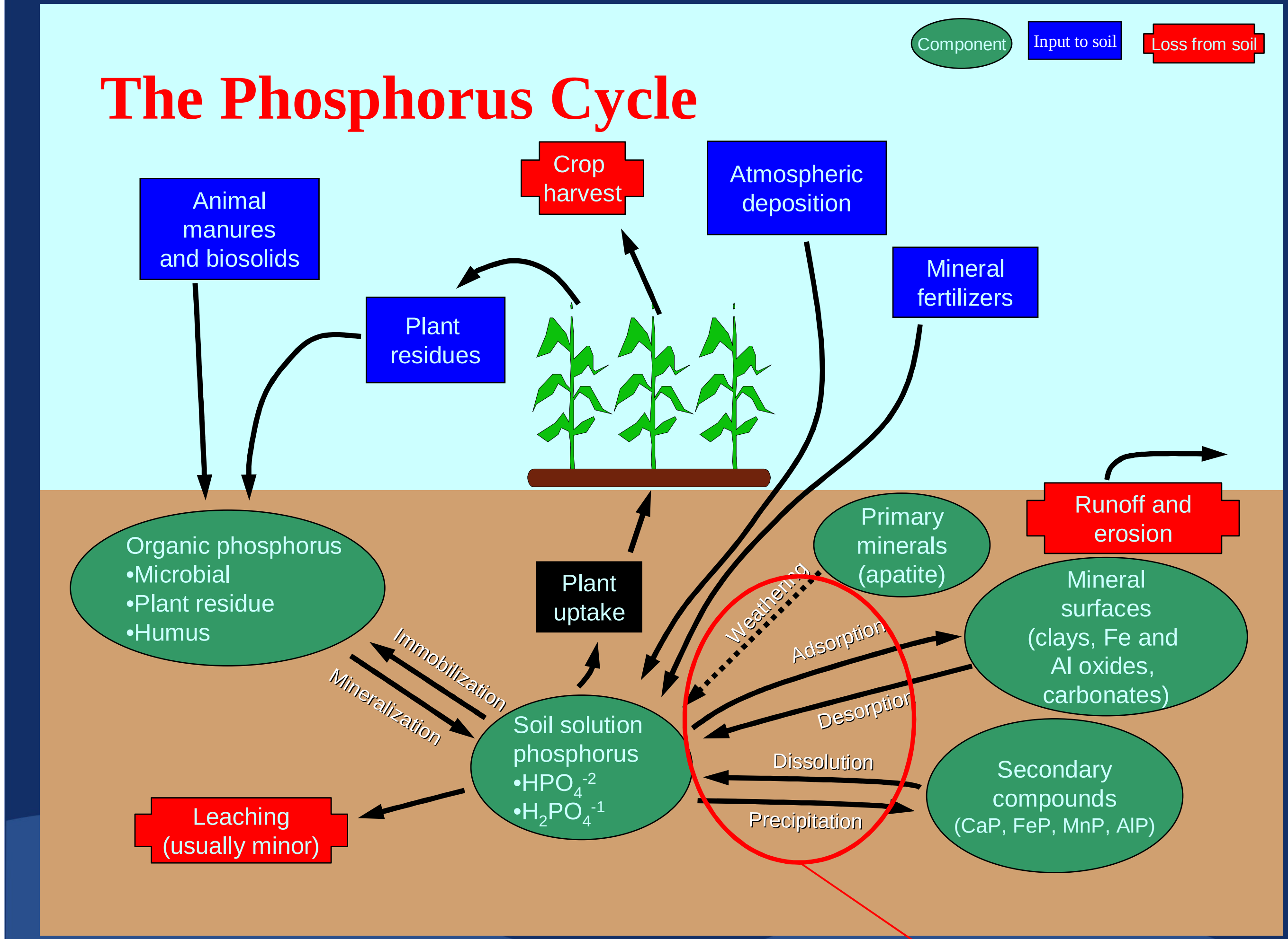
- ➢Predomination of nitrates
- ➢Well developed seasonal pattern
- ➢Higher TN concentrations in the Oder River (on average by 0.9 mg/dm^3)

Pastuszak and Witek, 2012

IMWM, 1999-2013

www.mir.gdynia.pl

Phosphorus (P) cycle in soil



Igras and Fotyma., 2012; Pastuszak et al., 2012 a, b

http://msucares.com/crops/soils/images/phosphorus.gif

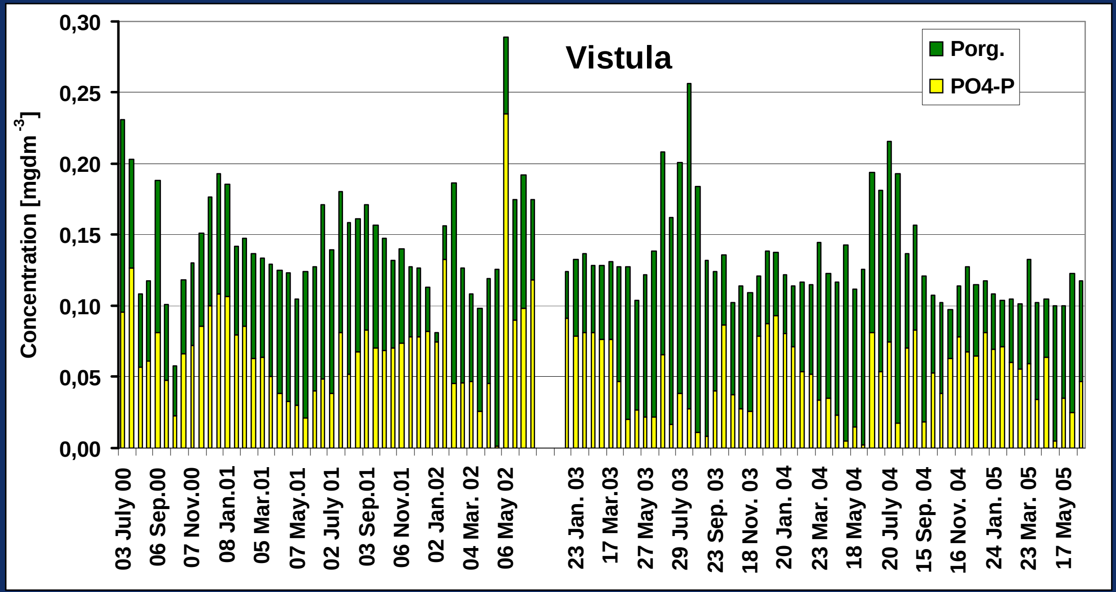
greatly affected by soil pH

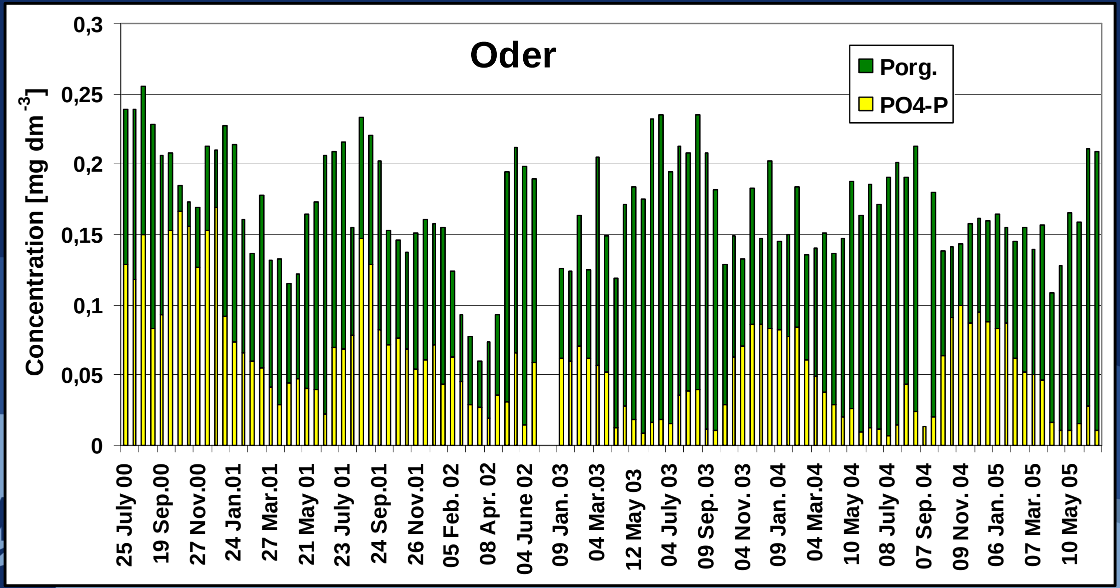
P easily sorbs on mineral surfaces ⇒ minor leaching ⇒ major contribution of erosion in P transport

- **P surplus**
- **Geomorphological features**
- **Soil type**
- **Type of bedrock**
- **Land slope**
- **Hydrological-meteorological conditions**

Poland - 60% of agricultural area – light soils; 21% of agricultural area and 8% of forested areas – threatened with erosion; 50% of agricultural area - acidified

Phosphorus species concentrations in the Vistula and Oder River (own data – EU grants)

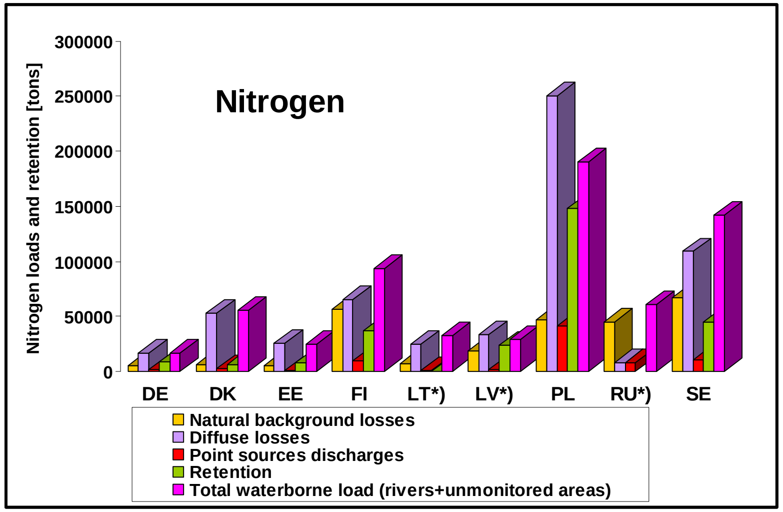


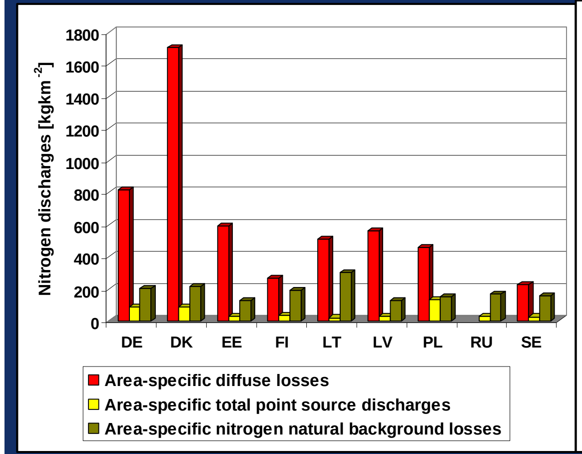


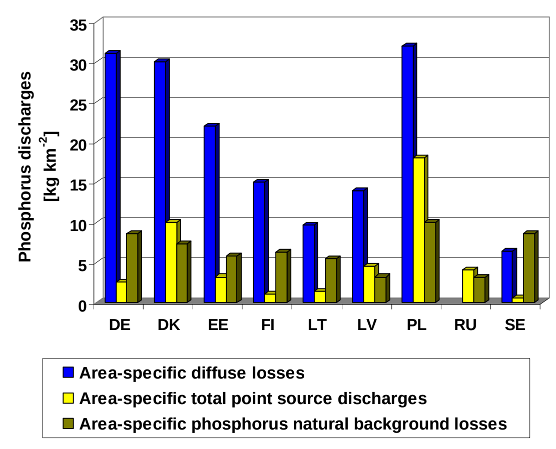
- ➢**High contribution of $P_{org.}$**
- ➢**Not overlapping patterns of concentrations**
- ➢**Higher TP concentr. in the Oder River**

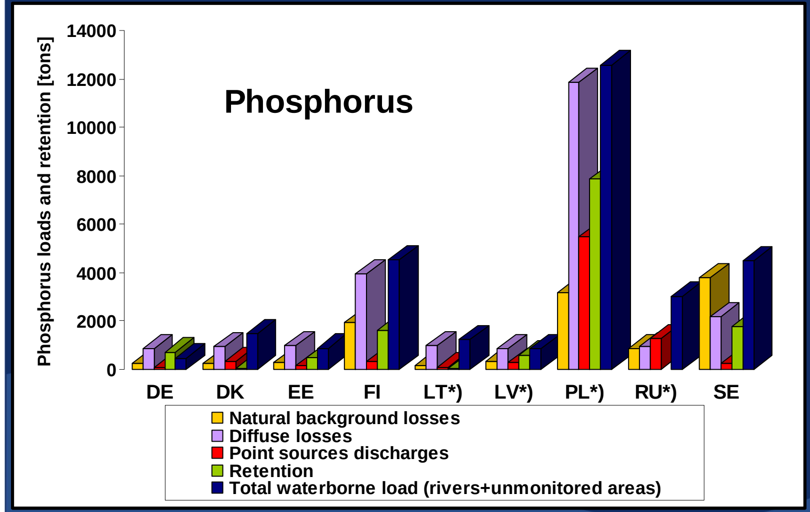
Pastuszak and Witek, 2012

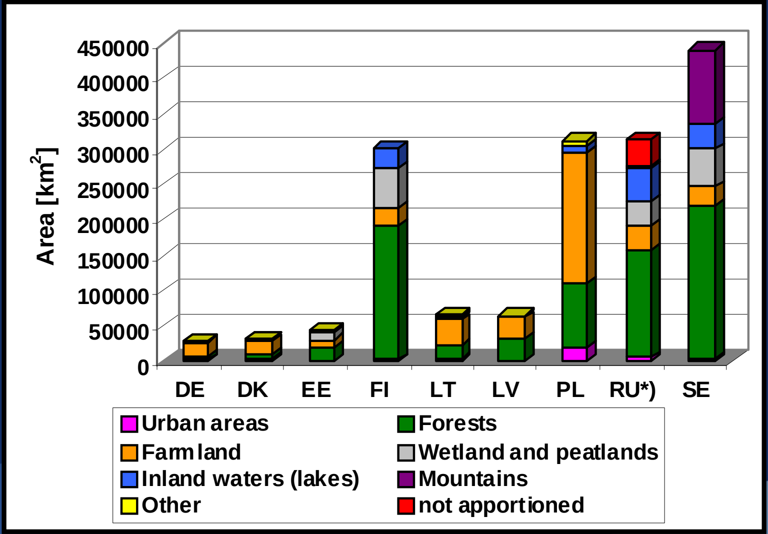
Contribution of Baltic countries to riverine export of nitrogen and phosphorus to the Baltic Sea in 2000; land cover/use in the Baltic countries











N emission from agricultural land –

7-10 times higher than from forested land

Pastuszak, 2012; Pastuszak and Witek, 2012
Rekolainen et al., 1995; Hatfield and Follett, 2008

www.mir.gdynia.pl

Observed changes – connection with eutrophication in the Baltic Sea

Global scale – climate change

manifesting in:

⇓

- Huge decline in frequency and strength of saline water inflows ⇒ strengthening oxygen deficits in bottom waters

- Anomalies in outflows of riverine waters

- Decline in S and increase in T of waters in the Baltic Sea ⇒ affecting e.g. biomass and species composition of zooplankton

Local scale – N, P, Si

⇓

- In 1950-1988 – 17-fold and 8-fold increases in consumption of mineral nitrogen and phosphorus fertilizers in the Baltic Sea

- XX century - 4-fold increase in TN loads and i 8-fold increase in TP loads discharged by rivers into the Baltic Sea

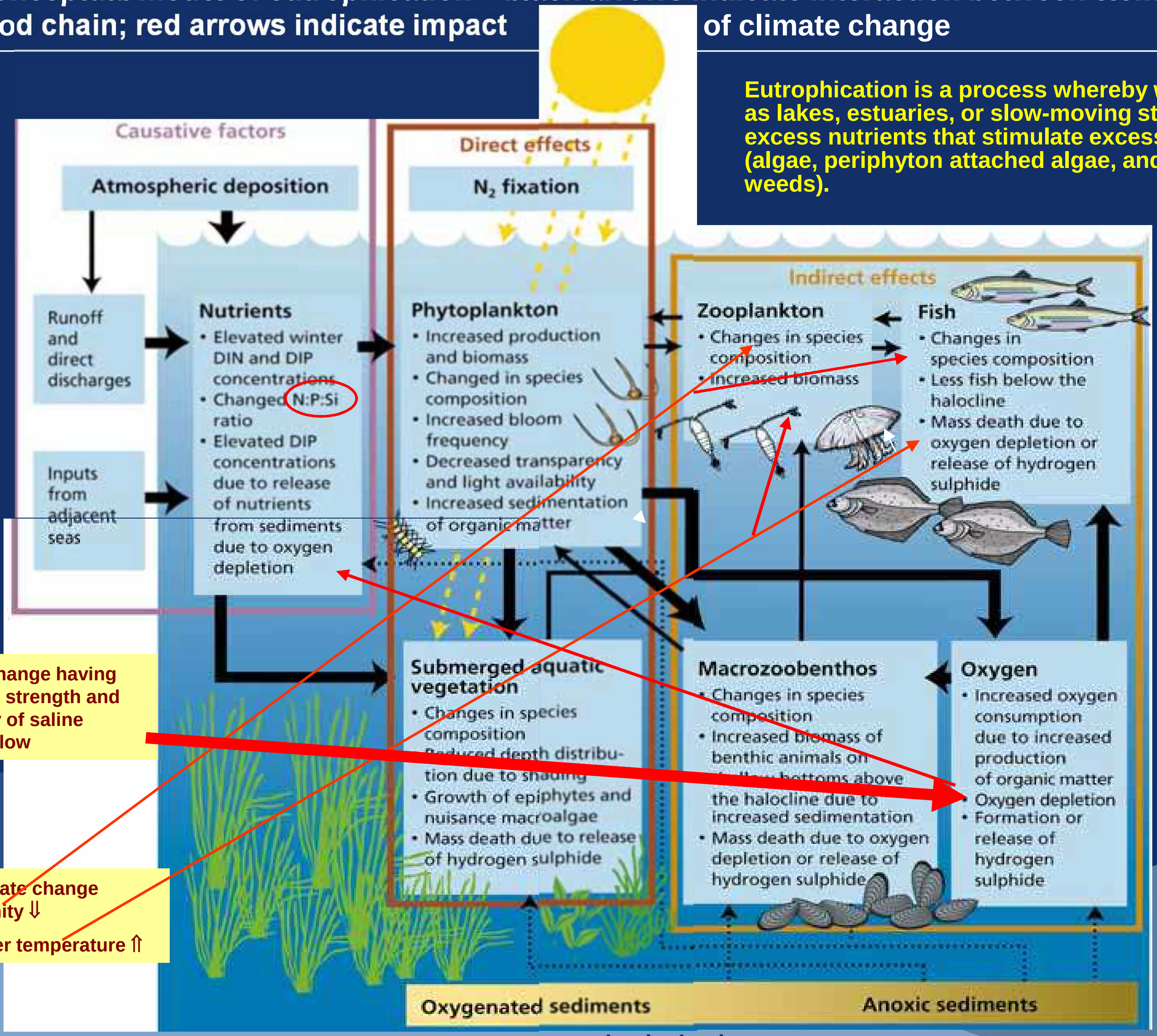
- XX century - 3- fold decrease in DSi loads discharged into the Baltic Sea ⇒ 3-fold decrease in DSi concentrations in the Baltic waters. Cause - river eutrophication and damming

Numerous international studies prove that **only ca. 50% of TN and only 30% of TP** introduced into natural environment in the form of natural and mineral fertilizers is effectively utilized by plants, the rest becomes dispersed in natural environment and leads to various negative ecological consequences and/or threat to health.

Kowalkowski et al., 2012; Pastuszak et al., 2012; Sharpley, 1995; Howarth, 2008; Conley et al., 2008; Nausch et al., 1999

Conceptual model of eutrophication – black arrows indicate interaction between elements of food chain; red arrows indicate impact of climate change

Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth (algae, periphyton attached algae, and nuisance plants weeds).



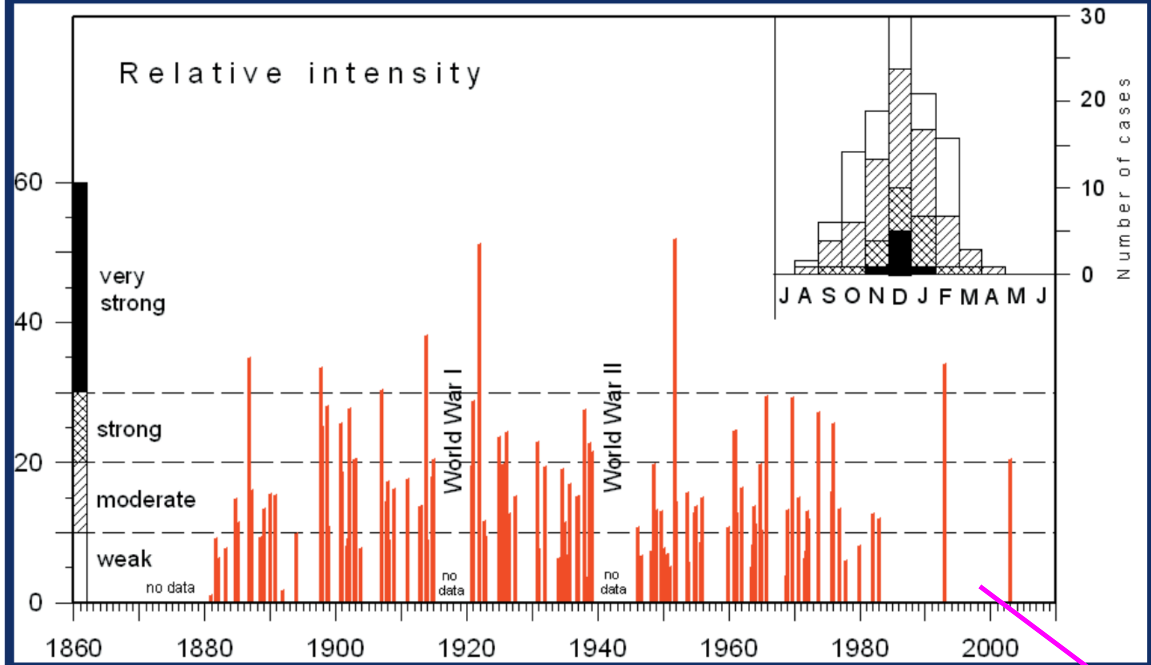
Climate change having impact on strength and frequency of saline waters inflow

Climate change
salinity ⇓

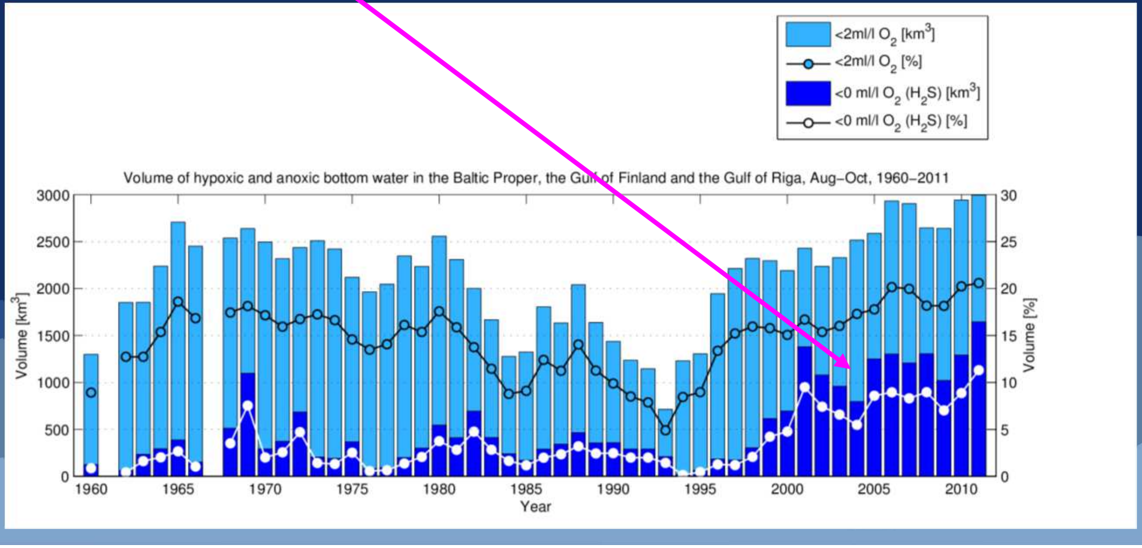
Water temperature ⇑

HELCOM, 2006 – supplemented with new knowledge

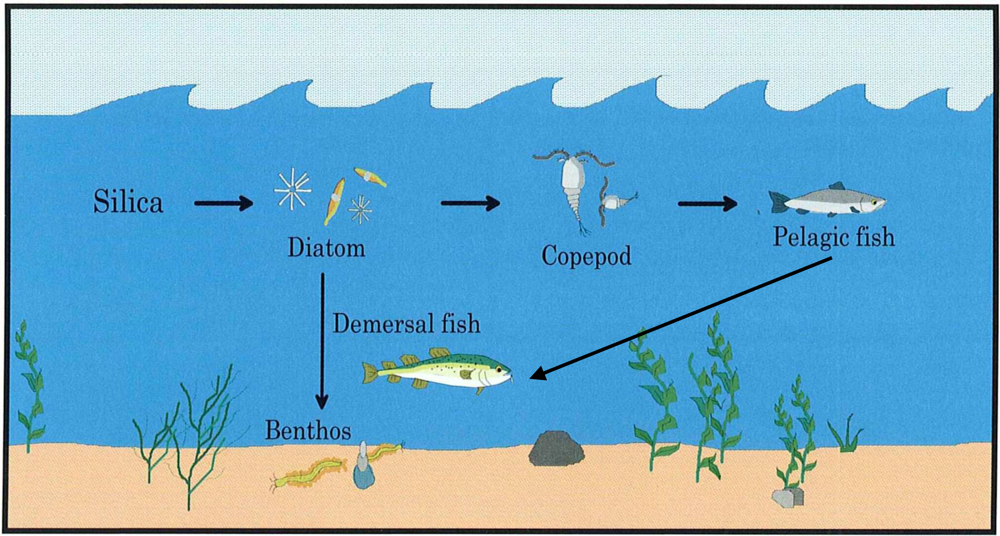
Saline water inflows to the Baltic Sea in 1880-2005; Volume of hypoxic and anoxic bottom water in the Baltic Proper, the Gulf of Finland and the Gulf of Riga in Aug.-Oct. 1960-2011

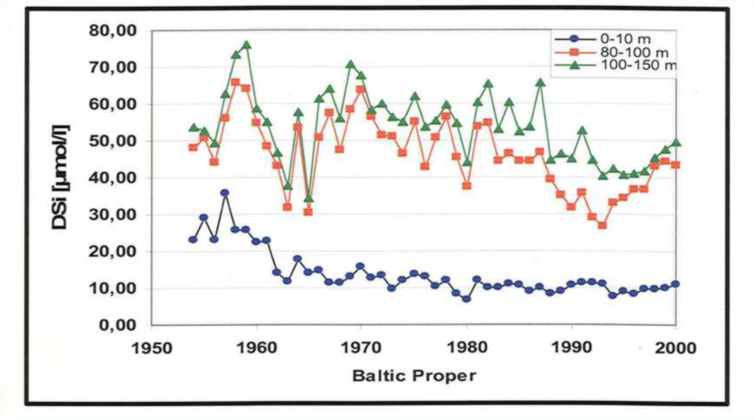


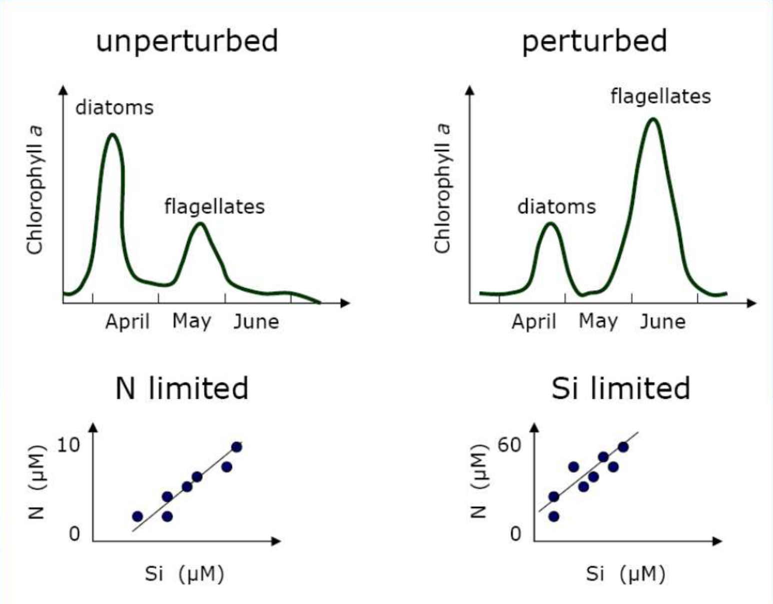
Matthäus and Franck, 1992; Fischer and Matthäus, 1996; HELCOM, 2007; Hansson et al., 2011



Four-level food chain in the Baltic Sea; role of silicon in ecosystem functioning







Pastuszak, 2012b; Billen et al., 1991

Changes in Polish economy – impact on N, P emission into Polish rivers and the Baltic Sea

Transition period (1989-2014) –

- Economic crisis (agricultural sector, industry)

- Restructuring, privatization of State owned farms

- Tremendous improvement in infrastructure in agricultural sector

⇓

Drop in N, P surplus

- Introduction of market economy in Poland ⇒ adjustment processes in agricultural production

- Closure of obsolete factories and modernization of the remaining ones, and introduction of clean technologies

- Absorption of EU funds and much greater national funds for environment protection

⇓

Construction of ca. 2000 WWTPs

⇓

Poland meets most of its environmental targets and has decoupled a number of environmental pressures from economic growth

Implementation of EU Directives after accession of Poland to EU:

-Nitrate Directive

-Water Framework Directive

-Pollution Prevention and Control Directive

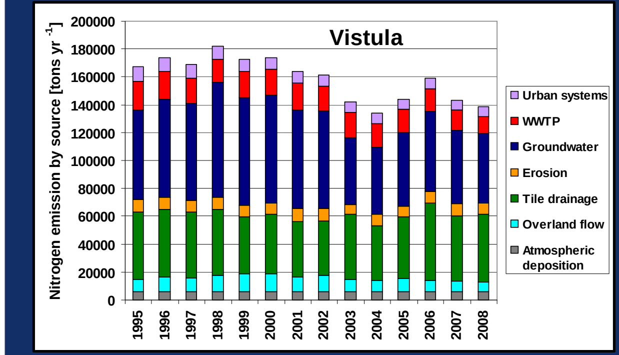
-European Marine Strategy Directive

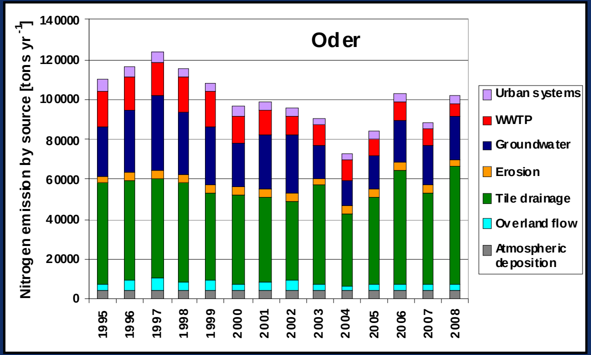
-Urban Waste Water Directive

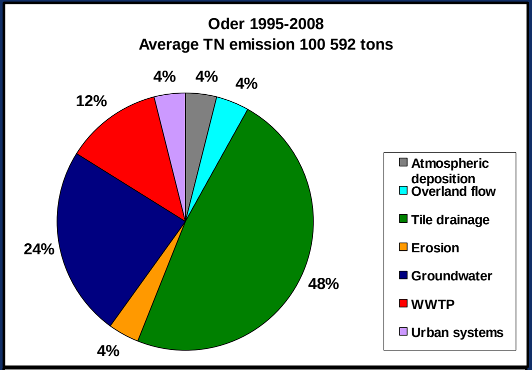
Realization of HELCOM agreements e.g. Baltic Sea Action Plan (BSAP), Country Allocated Reduction Targets (CART)

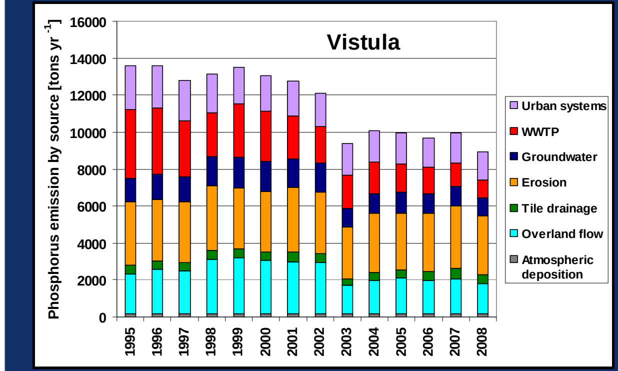
Kowalkowski et al., 2012; Pastuszak et al., 2012a,b; Pastuszak et al., 2014; Jadczyszyn and Rutkowska, 2012; HELCOM, 2011, 2013a.b

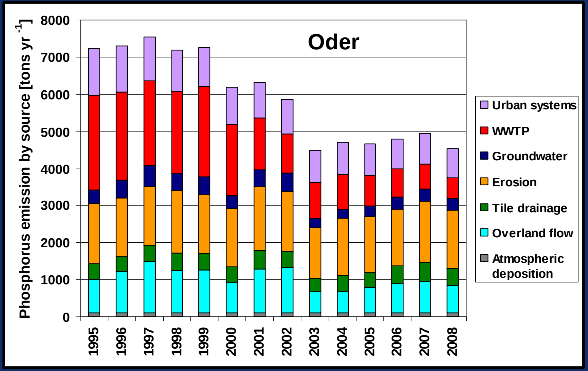
Annual source apportioned emission of N i P into the Vistula and Oder basins; average percentage contribution (1995-2008) of various pathways of N, P emission into the Vistula and Oder basins (model MONERIS)

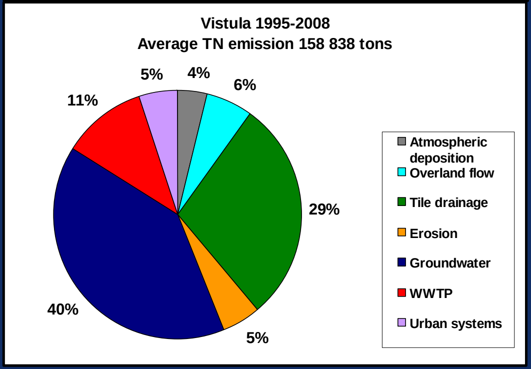

Vistula

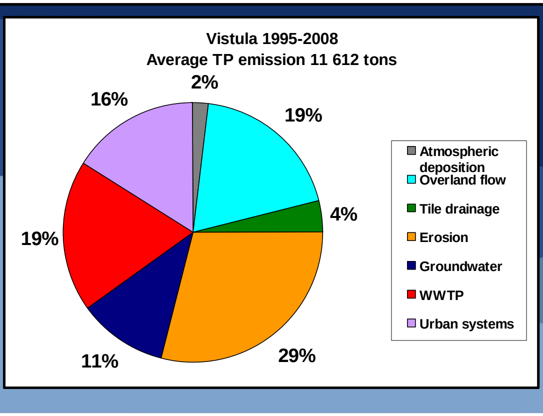

Oder

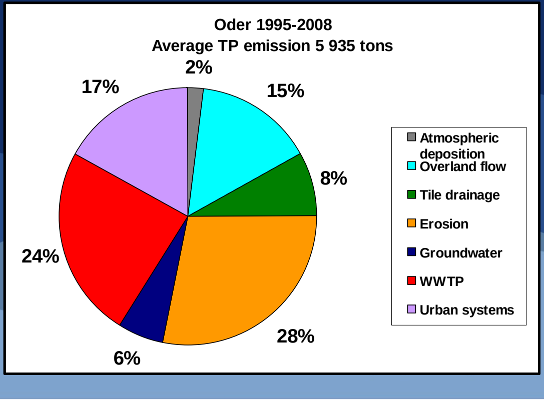

Oder 1995-2008
Average TN emission 100 592 tons


Vistula


Oder


Vistula 1995-2008
Average TN emission 158 838 tons


Vistula 1995-2008
Average TP emission 11 612 tons


Oder 1995-2008
Average TP emission 5 935 tons

Emission N between 1995-2002 and 2003-2008

Vistula and Oder

16-17% ⇓

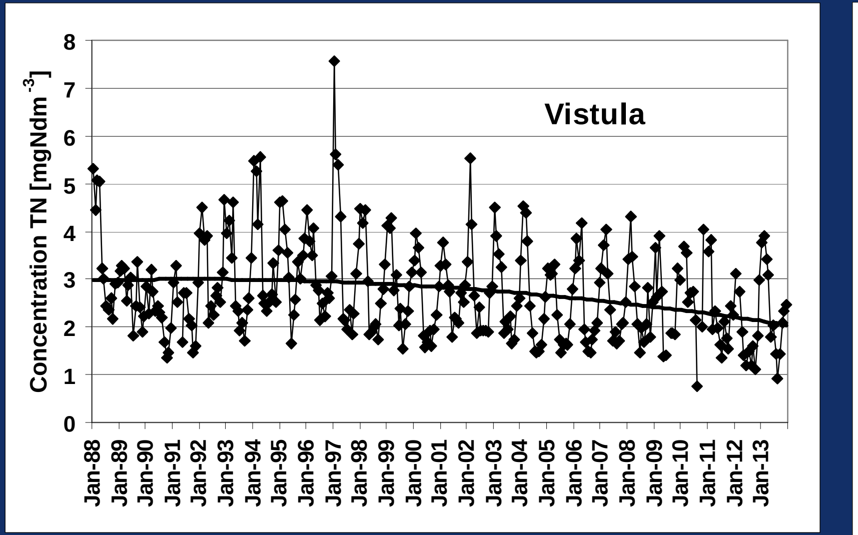
Emission P between 1995-2002 and 2003-2008 :

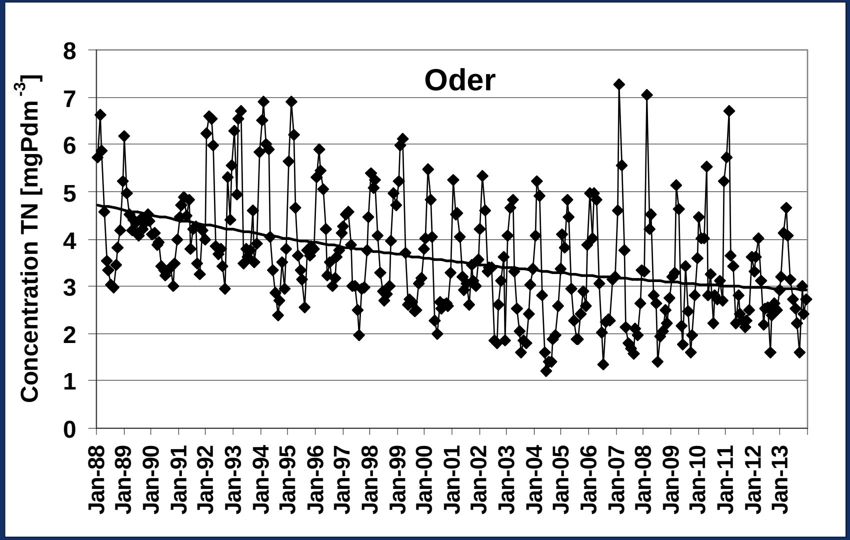
Vistula 23% ⇓

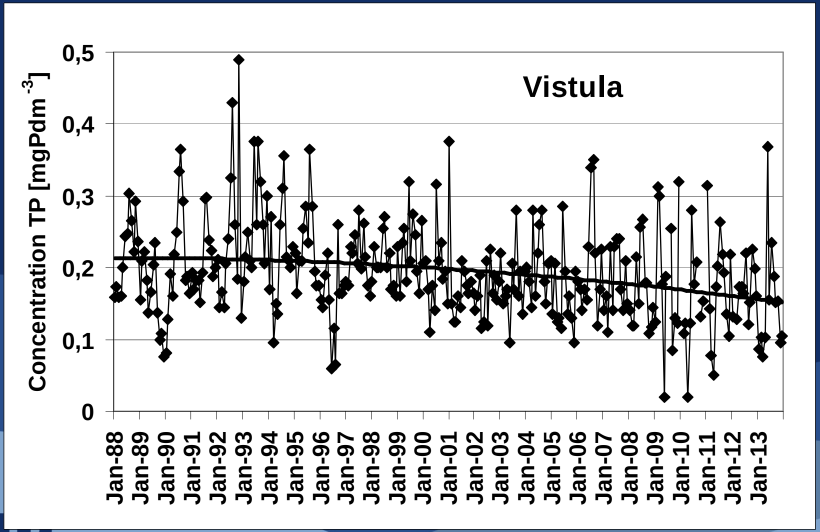
Oder 32% ⇓

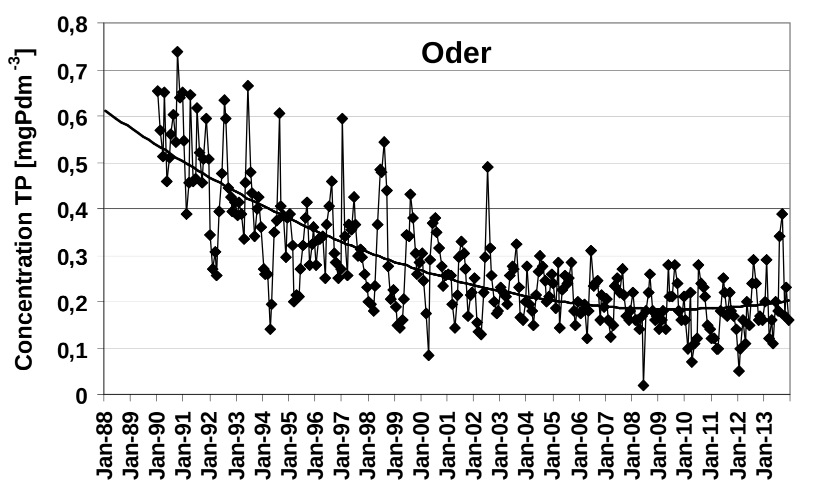
Kowalkowski et al., 2012; Pastuszak et al., 2012b

Concentrations of total nitrogen (TN) and total phosphorus (TP) in the Vistula and Oder waters (lowermost monitoring stations)



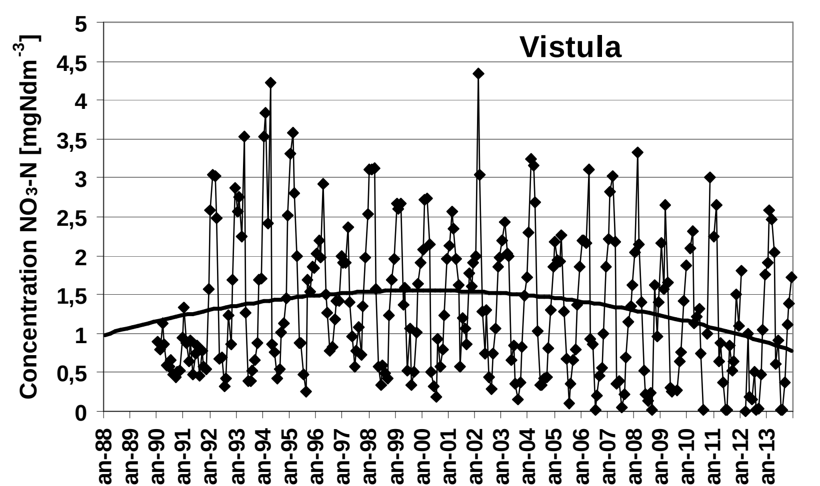


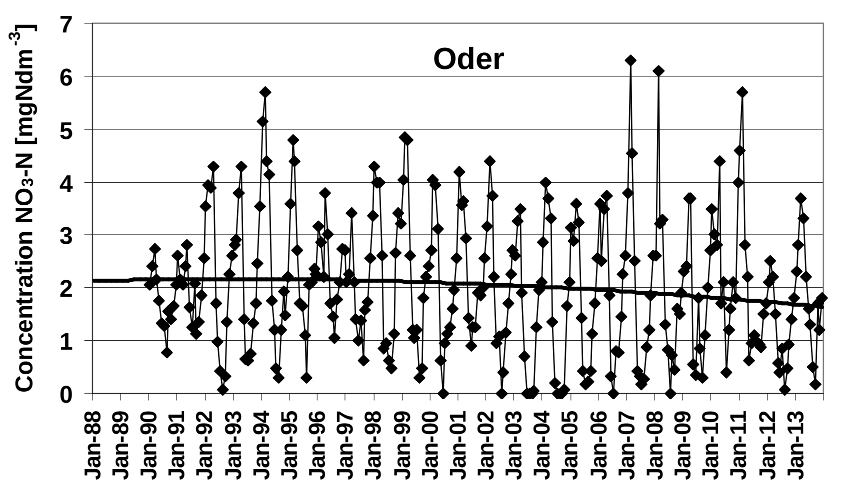


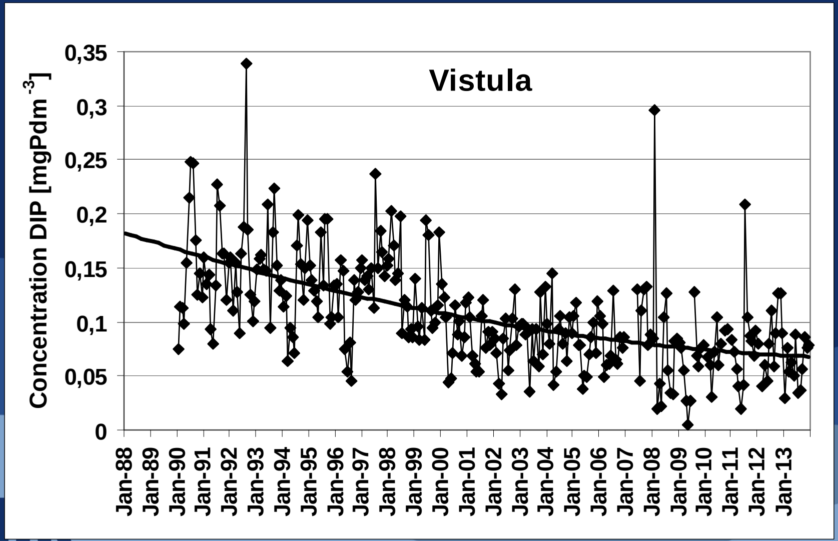


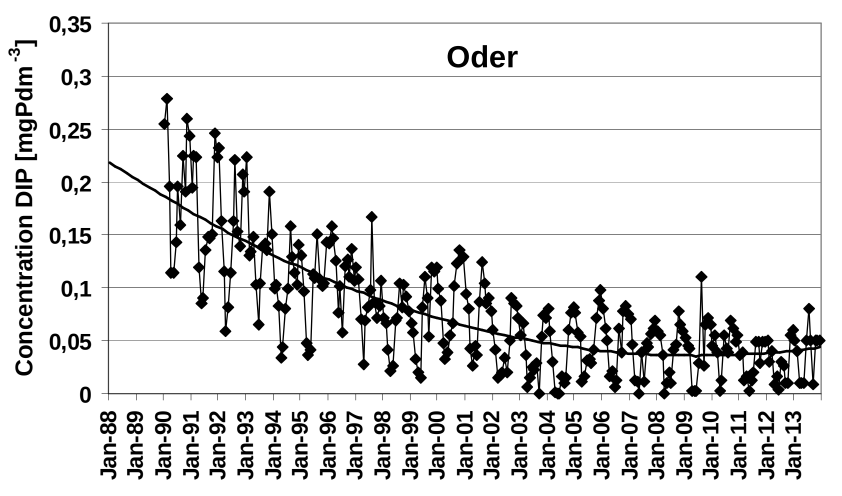
Pastuszak and Witek, 2012; Pastuszak, 2014

Concentrations of nitrates (NO_3-N) and phosphates (DIP) in the Vistula and Oder waters (lowermost monitoring stations)



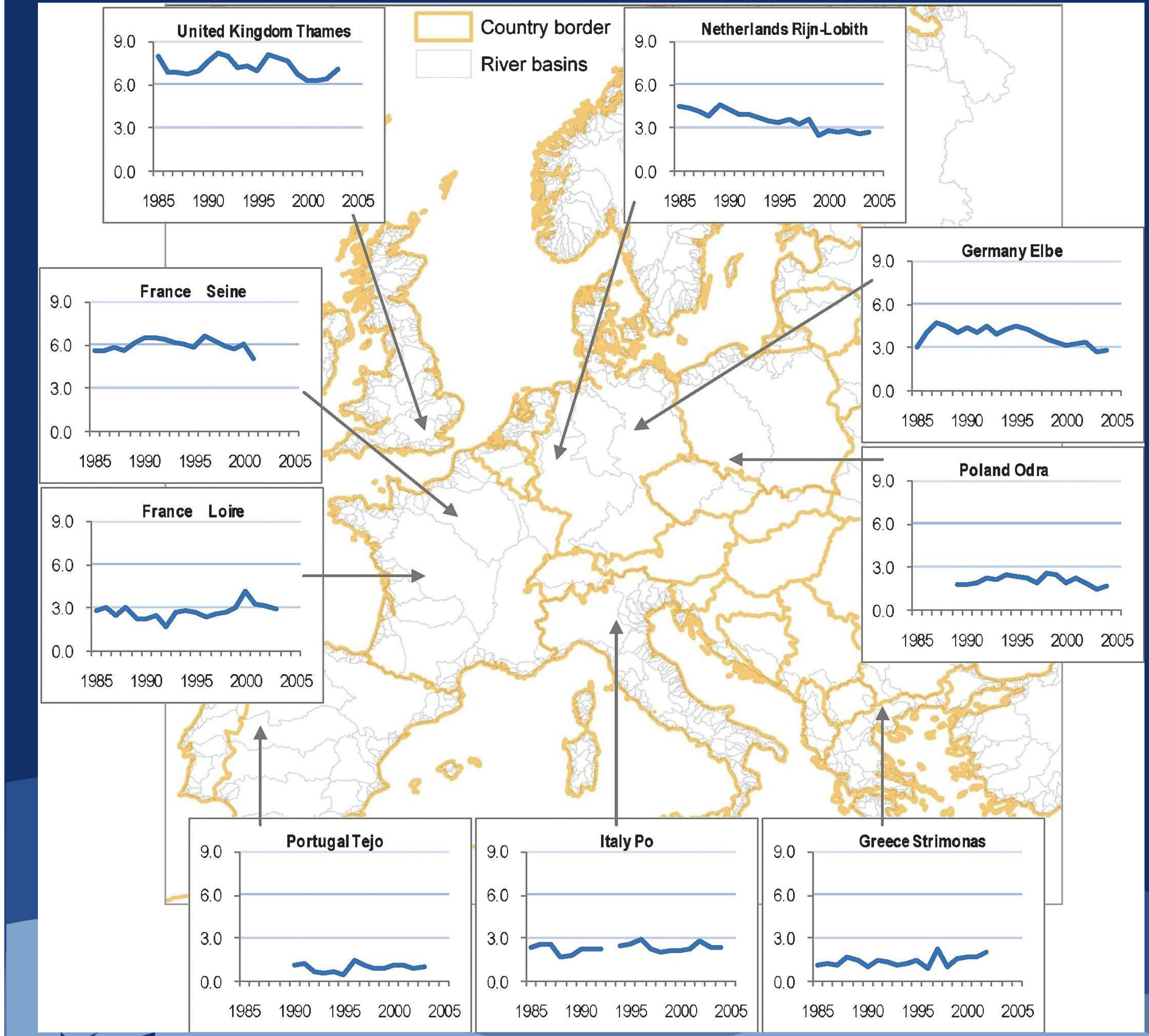






Pastuszak and Witek, 2012; Pastuszak, 2014

Nitrate concentrations in various European rivers at the lowermost monitoring stations

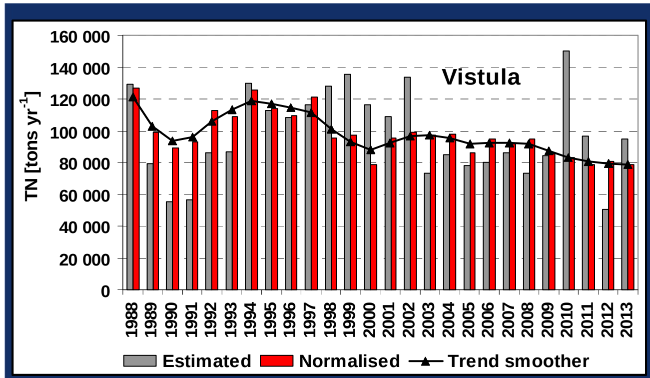


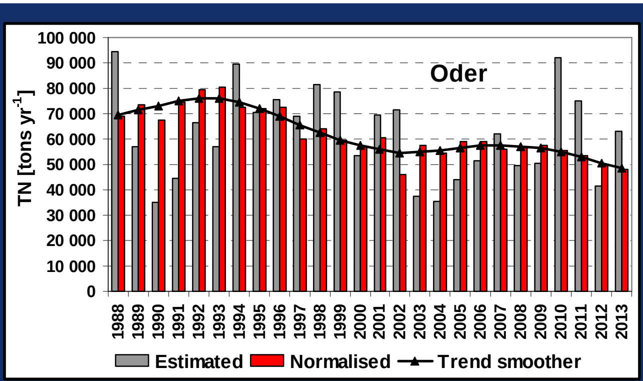
Nitrate concentrations in 2013

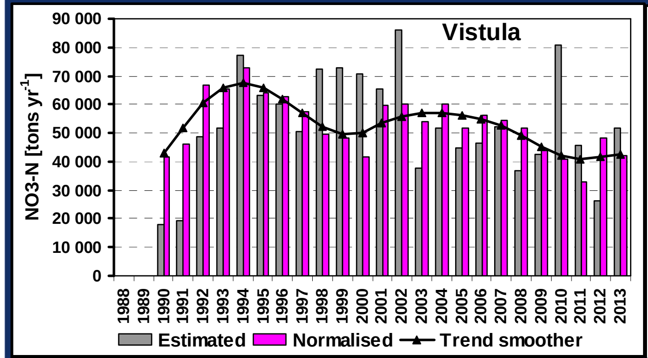
Oder – 1.7 mg/dm^3

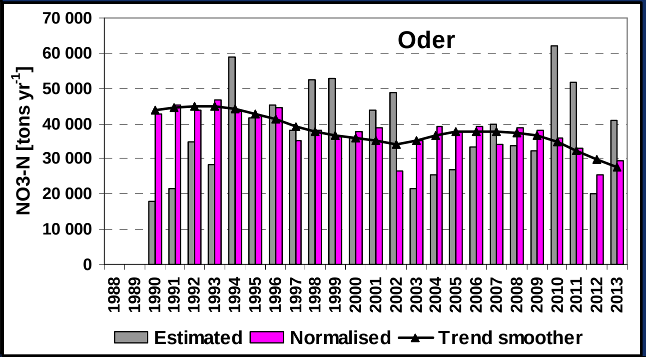
Vistula - 0.8 mg/dm^3

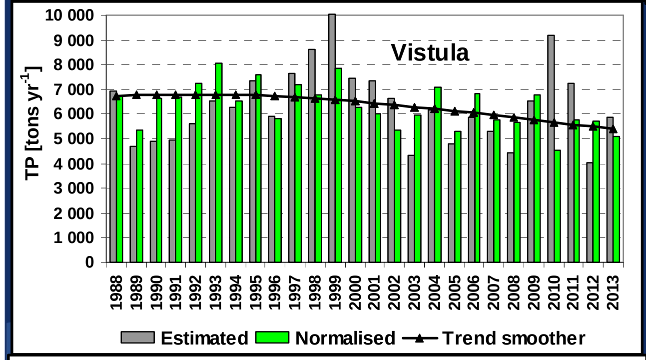
OECD, 2008

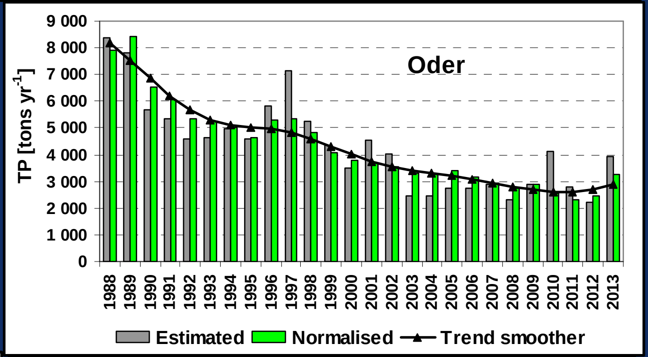


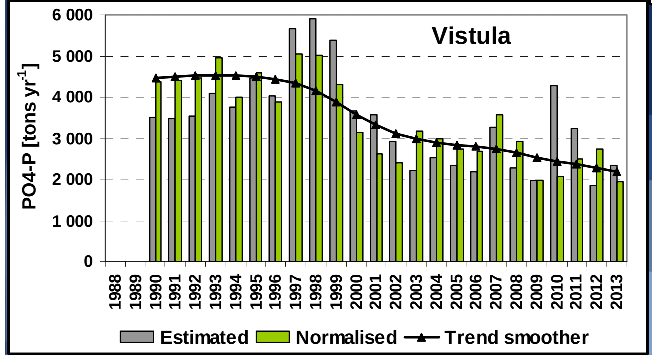


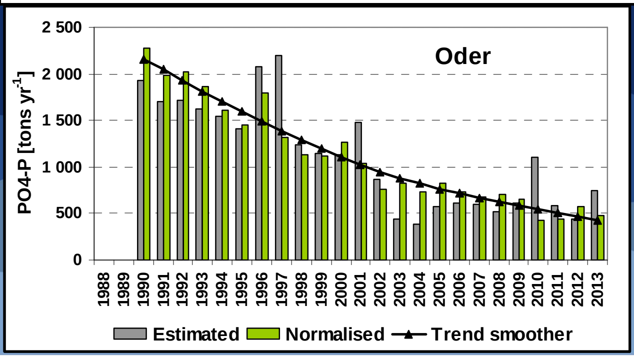












Normalization aims at removing the natural fluctuations in loads by variability in water discharge

Flow normalized loads

1988-2013

Vistula:

TN ~47 000 t (37%) ⇓

N-NO3 31 039 t (43%) ⇓

TP ~2 950 t (37%) ⇓

P-PO4 2 500 t (57%) ⇓

Oder:

TN 32 000 t (40%) ⇓

N-NO3 17 498 t (37%) ⇓

TP 5 100 t (61%) ⇓ referred to 2013

P-PO4 ca. 1 800 t (79%) ⇓

Pastuszak and Witek, 2012; Pastuszak et al., 2012; Pastuszak, 2014

Reduction of flow normalized TN and TP loads discharged by the Vistula, Oder and the Pomeranian rivers during the transition period (1988-2013); retention of TN, TP in the Oder estuary - taken into account

Specification	Reduction of TN load [tons]	Reduction of TP load [tons]
Vistula basin; transition period (1988-2013); flow normalized loads (Pastuszak et al., 2012; unpublished data)	47 000 (by 37%)	2 950 (by 37%)
Ode basin; transition period (1988-2013); flow normalized loads (Pastuszak et al., 2012; unpublished data)	32 000 (by 40%)	5 100 (by 61%) referred to year 2013
Pomeranian rivers (estimated for average normalized N, P loads in 2000-2013 r., at the assumption that average Pomeranian rivers loads constitute 10% of average Vistula+Oder TN load, and 9% of average TP Vistula+Oder TP load discharge in the same time period and at assumed average 40% reduction of TN load and 54% reduction of TP load (Pastuszak and Witek, 2012a)	2 850	216
Oder estuary – reduction estimated based on average Oder TN and TP loads for the years 2000-2013 at 45% retention of TN and 37% retention of TP in the estuary (Pastuszak et al., 2005)	25 000	1 150
Overall reduction of TN and TP loads discharged by Polish rivers as referred to max. loads observed on the turn of the 1980s and the 1990s	106 850	9 416

Load reduction is estimated by comparing the present loads with the highest ones on the turn of the 1980s and 1990s

N, P retention in the Oder estuary has never been taken into consideration by HELCOM

BSAP and CART - parameters taken into consideration in order to restore good ecological status of marine environment by 2021

- Nutrient concentrations close to natural,
- Transparent water,
- Natural blooms of marine algae,
- Natural distribution and occurrence of submerged plants and animals,
- Natural level of oxygen dissolved in water.

Reference HELCOM period – average loads from the period 1997-2003 but not the highest N, P emission to the Baltic Sea on the turn of the 1980s and 1990s

Country	BSAP 2007 (tons yr^{-1})	Ministers CART 2013 N (tons yr^{-1})	BSAP 2007 P (tons yr^{-1})	Ministers CART 2013 P (tons yr^{-1})
Denmark	17,210	2,890	16	38
Germany	5,620	7,670	240	170
Poland	62,400	43,610	8,760	7,480
Lithuania	11,750	8,970	880	1,470
Latvia	2,560	1,670	300	220
Estonia	900	1,800	220	320
Russia	6,970	10,380	2,500	3,790
Finland	1,200	3,030	150	356
Sweden	20,780	9,240	290	530
Sum	133,170	89,260	15,016	14,374

Polish contribution to nutrient load reduction (CART):

N	ca. 49%
P	ca 52%

Polish contribution to overall nutrient riverine loads:

	2000 ⇓	2006 ⇓
N	26%	23%
P	37%	36,1%

HELCOM, 2007, 2011, 2013 a, b

www.mir.gdynia.pl

Flow normalized loads of nitrogen and phosphorus - methodological requirements

Load = nutrient concentration x water outflow ⇒ **river catchment approach is essential**

Methodologies of TN, TP load normalization and trend line calculation, elaborated by: Grimvall, Hussian, Libiseller, Stålnacke, strongly require:

- River catchment approach; normalization must be based on average monthly nutrient concentration (nitrates, nitrites, ammonium, TN, phosphates, TP) and monthly water outflows ⇒ monthly values ⇒ aggregated to annual values ⇒ annual values undergo normalization;

- Long-term data are indispensable for normalization and calculation of trend lines;

- Any selection of sub-periods and calculation of trend lines for sub-periods is wrong and must be rejected

HELCOM EUROHARP methodology of TN, TP load normalization is based on annual nutrient concentrations and annual water flows

Vistula and Oder load normalization based on **Grimvall, Hussian, Libiseller, Stålnacke method, and on** ⇒ (i) monthly concentrations and monthly water outflows, (ii) annual concentrations and annual water outflows ⇒ did not generate a systematic error, but significant random differences in normalized loads calculated for these two separate data bases and for the period 1997-2003 (HELCOM reference period).

Differences in TN ⇒ from + 15 000 tons/yr to ca. – 46 000 tons/year (overall scatter range ca. 61 000 tons/yr – well above Polish allocation of TN load reduction).

Differences in TP ⇒ from ca. + 1 500 tons/yr to ca. -1 900 tons/yr (overall scatter range ca. 3 400 tons/yr – ca. 50% of Polish allocation of TP load reduction). This finding indicates that HELCOM approach is erroneous.

HELCOM, 2011; Stålnacke and Grimvall, 2001; Grimvall and Stålnacke, 1996, 2001; Libiseller and Grimvall, 2002; Grimvall et al., 2000; Grimvall et al., submitted for publication; Hussian et al., 2004; Pastuszak, 2014

TN normalized HELCOM 1997-2003 (PLC-5) – 187 693 t – average difference 16 649 t

TN – normalized for the period 1997-2003 (NMFRI data)

That includes Pomeranian rivers 4300 tons

Vistula Oder Pomeranian rivers + other (10% of V+O load)

97 800 t + 57 694 t + 15 550 t = 171 044 t – 43 610 t (CART) = 127 098 t

97 800 t + 57 694 t =155 494 t - 39 310 t (CART Vistula+Oder) = 116 184 t

72 034 t

44 150 t

Vistula 34 km^3
2.11 $mgNdm^{-3}$

Oder 16.7 km^3
2.64 $mgNdm^{-3}$

TP normalized HELCOM 1997-2003 (PLC-5) - 11 892 tons – average difference 244 t

TP– normalized for the period 1997-2003 (NMFRI data)

That includes Pomeranian rivers 670 tons

Wisła Odra Pomeranian rivers + other (9%)

6 497 t + 4 092 t + 953 t = 11 542 t – 7 480 t (CART) = 4 062 t

6 497 t + 4 092 t = 10 589 t - 6800 t (CART Vistula + Oder) = 3 789 t

2 349 t

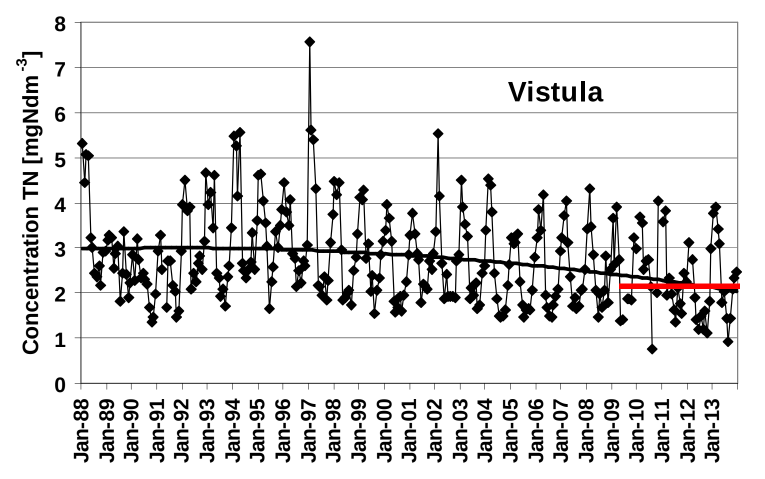
1 440 t

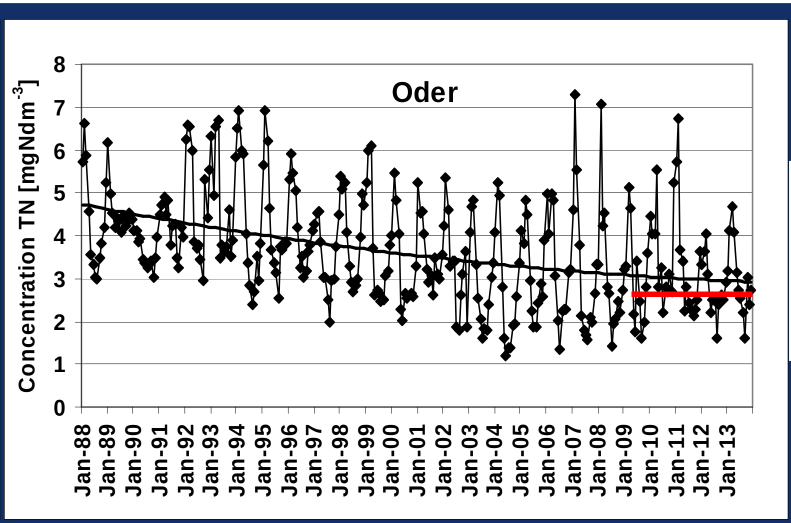
Present concentr. of DIP

Vistula 34 km^3
0.07 $mgPdm^{-3}$

16.7 km^3 Oder
0.08 $mgPdm^{-3}$

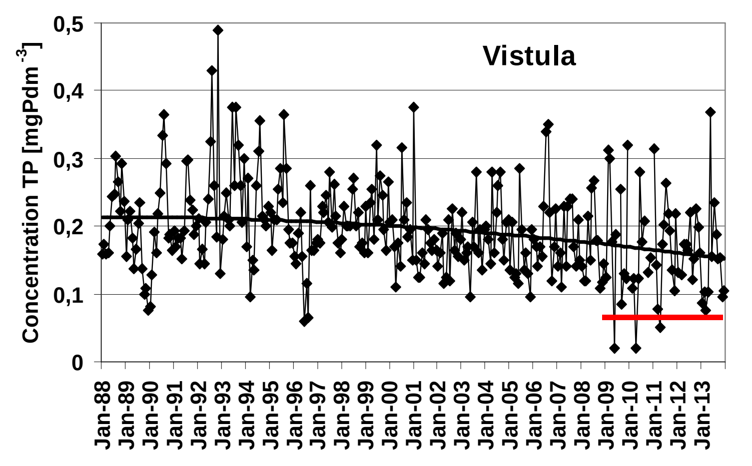
TN and TP concentrations in the Vistula and Oder at theoretical CART introduction

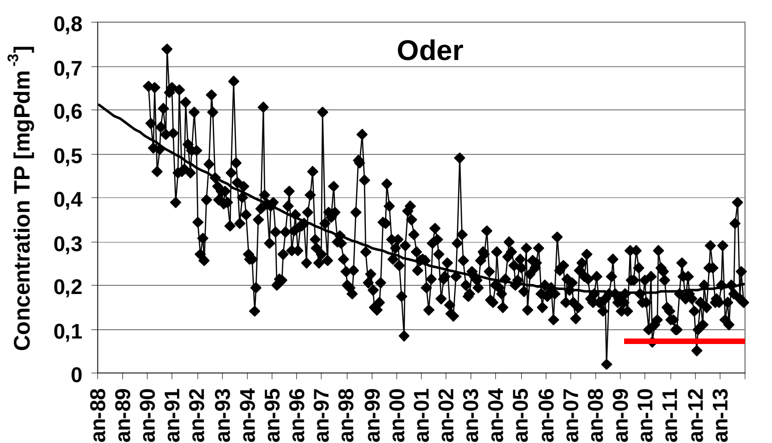




TN - Europe - 5-8 mg N dm^{-3}

TN - the USA – 3.75-4.79 mg N dm^{-3}





TP - the USA –

0.20-0.31 mg P dm^{-3}

Present concentrations of TN and TP in the Vistula and Oder Rivers not only meet, but are well below the WFD environmental targets set up for the river type 21

WFD and its standards are obligatory for every EU country and these standards, including environmental targets, as superior to HELCOM assumptions, must be respected by HELCOM

Garcia et al., 2012; Pastuszak et al., 2012a,b; Pastuszak, 2014

Conclusions:

1) Understanding of eutrophication problem in the Baltic Sea requires a holistic approach which takes into account all the driving forces (local and global) having impact on the ecosystem functioning (changes in N, P, Si loads and N:P:Si ratio, climate change with its consequences)

2) Over the period 1988-2013 flow normalized loads discharged by the Vistula declined by: TN ~ 47 000 t (37%), TP 2 950 t (37%); in Oder - TN by 32 000 t (40%), TP by 5 100 t (61%). With nutrient retention in the Oder estuary and contribution of other rivers - Poland reduced riverine loads of TN by ca. 107 000 t and TP - by ca. 9 000 t

3) Over the last decades, Polish contribution to overall riverine TN discharges ⇒ ca. 25%;

TP discharges ⇒ 36.5%

In the light of these facts – it is not clear why Poland is responsible for ca. 50% of overall HELCOM CART reduction of TN, TP loads reaching the Baltic Sea

4) Simple calculations of target TN, TP concentrations in the Vistula and Oder show that Polish allocation of N, P load reduction (CART) is irrational, particularly in the case of P. TP target concentrations on the level of 0.07 – 0.08 mg dm^{-3} are not achievable as they may be close to natural background. Such low TP concentrations are not found in the world large rivers, draining densely populated and agriculturally active catchments

Conclusions:

5) Present concentrations of TN and TP in the Vistula and Oder Rivers are well below the WFD environmental targets set up for the river type 21

WFD and its standards are obligatory for every EU country and these standards, including environmental targets, as superior to HELCOM assumptions, must be respected by HELCOM. Goods and services of one ecosystem cannot destroy goods and services of the other ecosystem

6) Irrational HELCOM CART load reduction may result from different methodology in load calculations. According to international standards (strengthened with common sense) flow normalization must be based on monthly nutrient concentrations and monthly water flows, but not on annual TN, TP concentrations and annual water flows

7) Preliminary load normalization, based on monthly and on annual data for the Vistula and Oder, shows an overall scatter range of ca. 61 000 tonsTN/yr, which is well above Polish allocation of N load reduction, and overall scatter range 3 400 tonsTP/yr, which constitutes ca. 50% of Polish allocation of P load reduction

8) All questions and errors require HELCOM explanation and most probably renegotiation of allocation of N and P load reduction (CART)

Thank you for your attention !