Inland waters and Baltic Sea eutrophication: Is there a link?

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Outline

- Baltic Sea - a unique brackish water ecosystem
- Characteristics of the drainage basin
- Historical and socio-economical perspective to the eutrophication
- Nutrient loading from the Finnish territory
- From manual to high frequency monitoring
- New measures are needed
- Conclusions

The Baltic Area in Brief

- The catchment of the Baltic Sea covers of $1.720*10^6$ km^2
- Ca. 90 million people in 14 countries
- From the temperate, densely populated and heavily industrialized south to rural subarctic north
- Landscape includes lowland coastal areas and mountains, different vegetation zones, and numerous rivers and lakes with considerable seasonal, inter-annual, and long-term variations
- Human impact has a long history in the area and at present it is strong particularly close to the sea
- Baltic Sea is among the most polluted sea areas on the earth

Baltic Sea –
a unique brackish water ecosystem

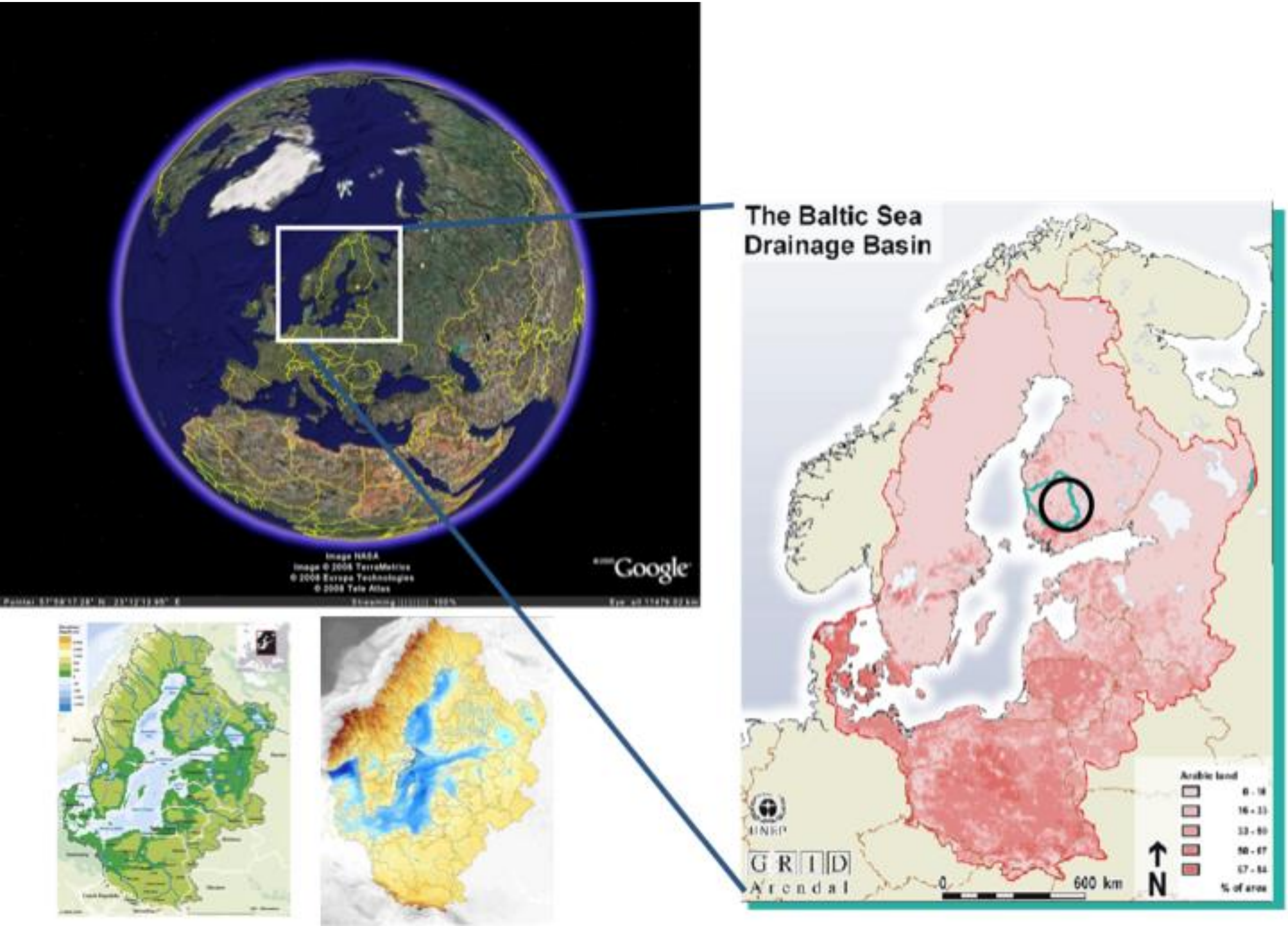
Image NASA
Image © 2008 TerraMetrics
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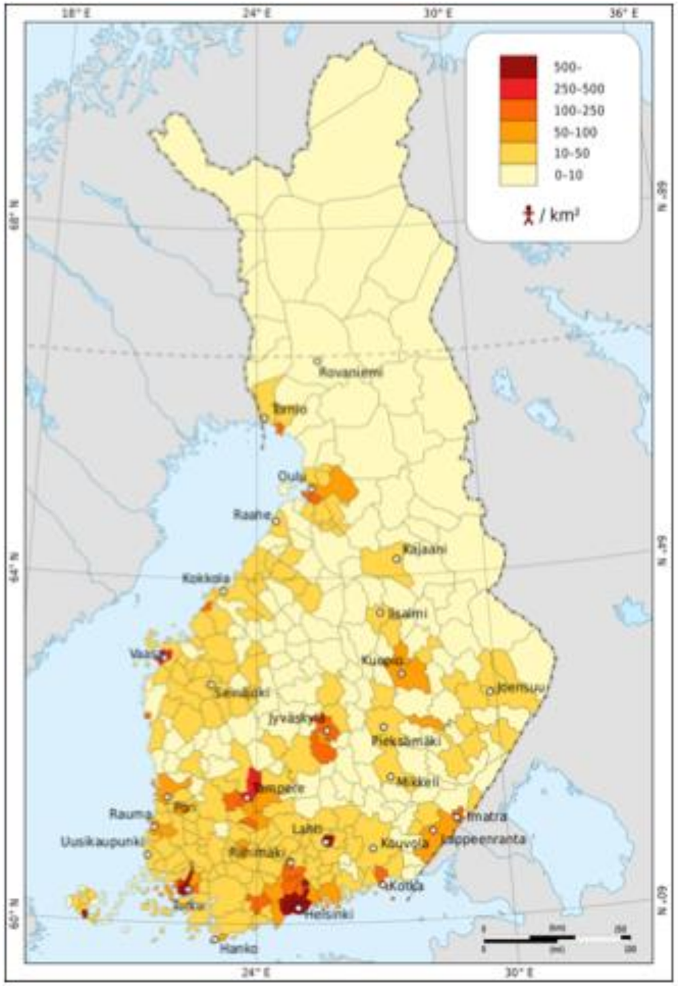
Google
The Baltic Sea
Drainage Basin
Arable land
% of area
UNEP
GRID
Arendal
0
600 km
N

Historical and socio-economical perspective to the eutrophication

Density of human population in Finland



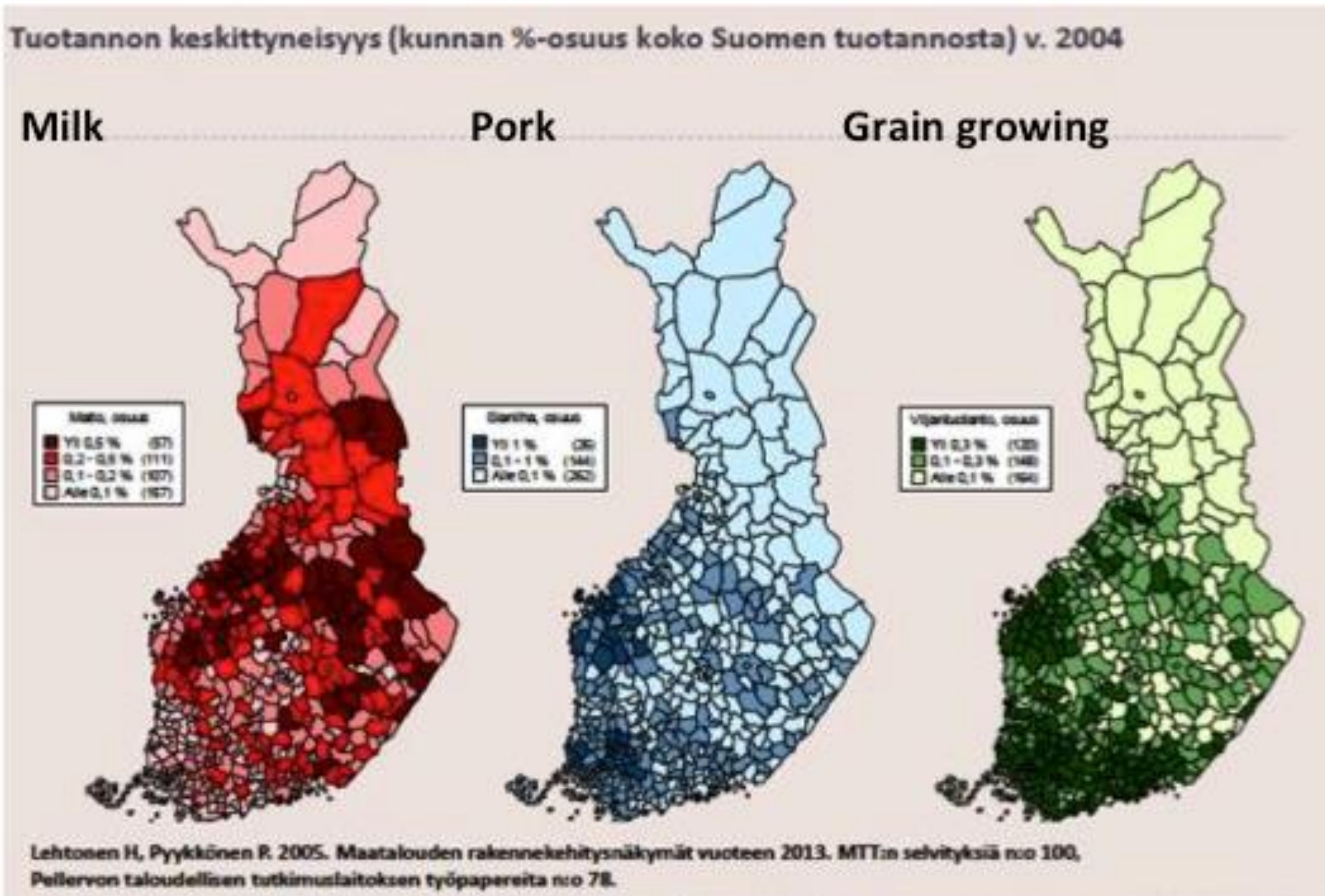
First paper and pulp mills started 200 years ago

Teollisuutta runsaasti; esim. Tervakoski Oy perustettiin jo v. 1818.

Joki valjastettiin energiantuotannolle 30 vuoden aikana.
Vuonna 1921 rakennettiin ensimmäinen voimalaitos Äetsään.

Äetsän voimalaitos. Kuva © Satakunnan Museo

”Areal Efficiency” of Agriculture

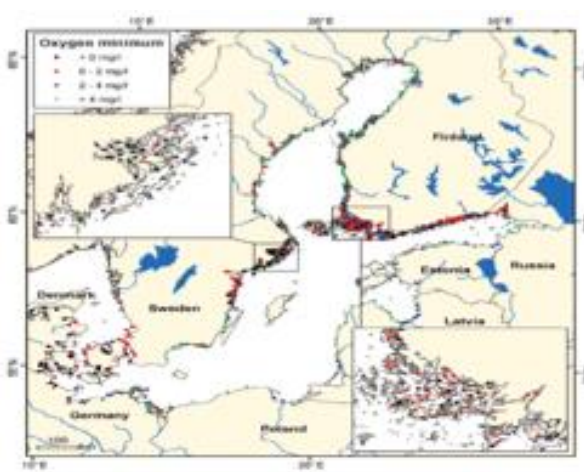


Eutrophication = Major Problem

10x increase of low-oxygen areas!

8(N)-25(P)% due to nutrient input!

Areas with low oxygen content (red) or no oxygen (black) in the Baltic Sea in 1906, 1955, 2012 (Carstensen et al. 2013). Estimated bottom oxygen concentrations <2 mg · L^{-1} are shown in red, and concentrations <0 mg · L^{-1} are shown in black.



Lowest recorded oxygen concentration at all Baltic coastal monitoring locations throughout 1955-2009 (Conley et al., 2011)

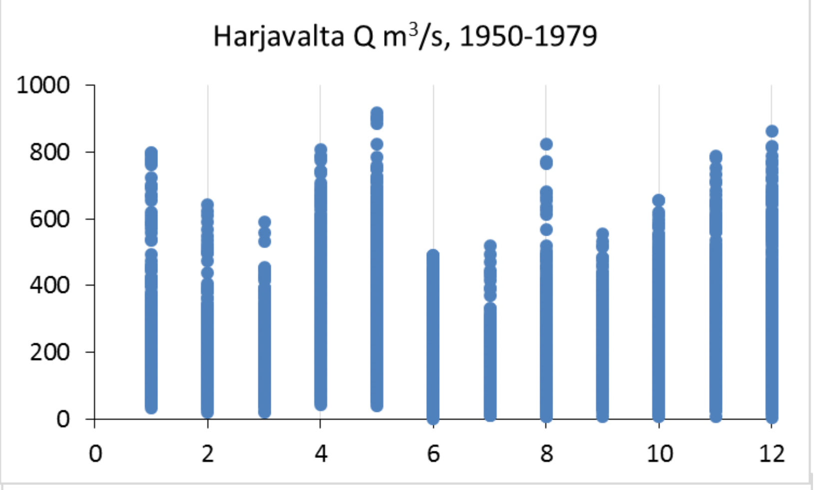
Oxygen concentrations

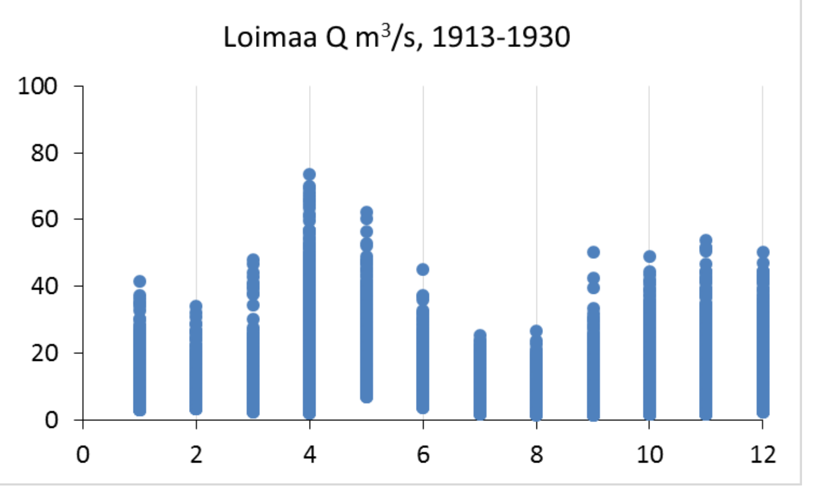
<0 mg L^{-1} - anoxic

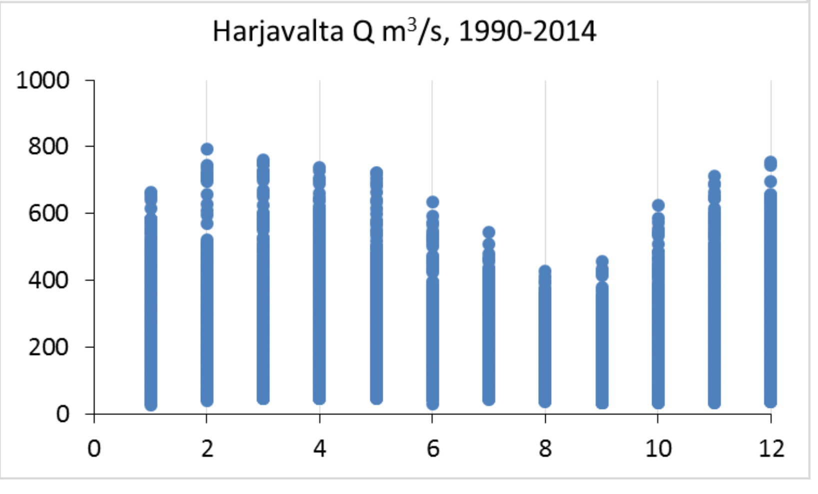
0-2 mg L^{-1} - considered hypoxic

2-4 mg L^{-1} - considered oxygen stressed

Discharge (Q): Seasonal variation





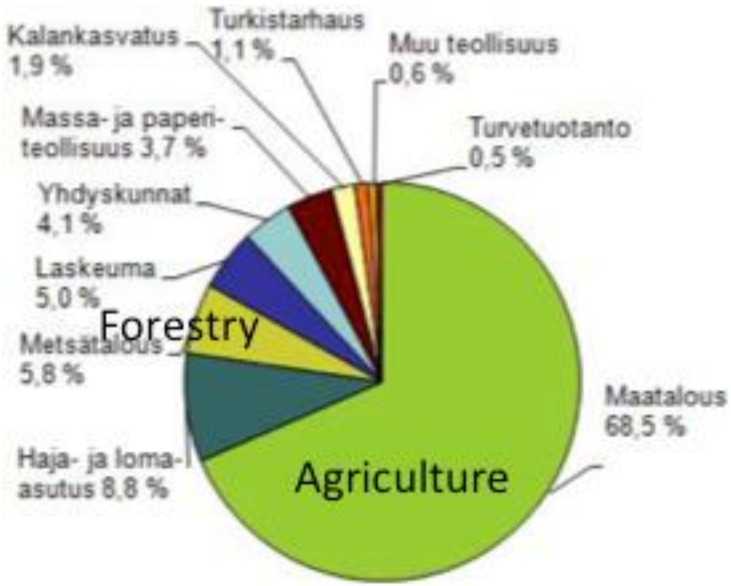


Seasonal pattern has changed

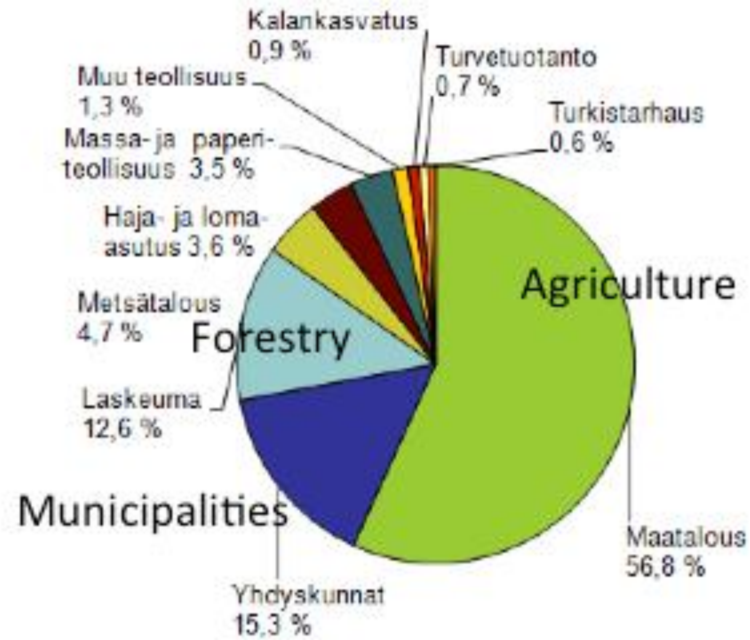
- Due to man-made water regulation?
- Due to climate change?

Nutrient loading from the Finnish territory

P and N Loading from Finland



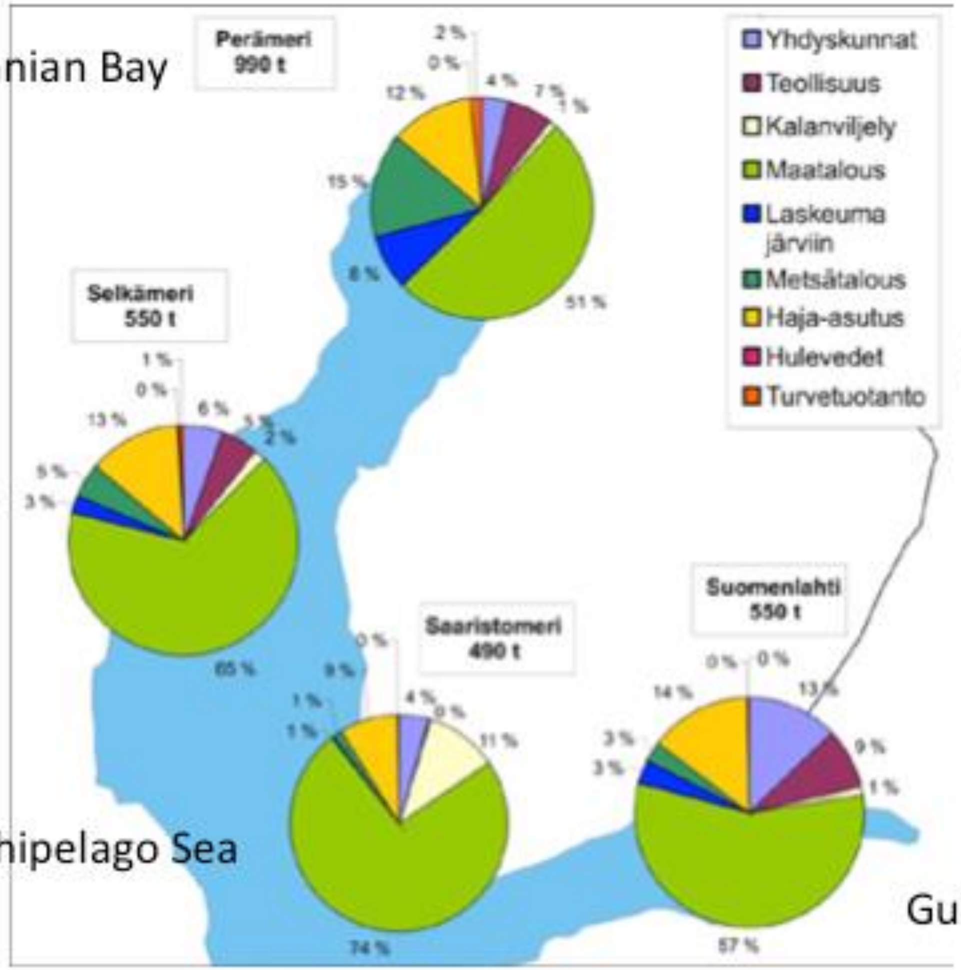
P loading in 2010 (SYKE).



N loading in 2010 (SYKE).

Human Based P Loading

Bothnian Bay



Municipalities
Industry
Fish farming
Agriculture
Deposition to lakes
Forestry
Scattered settlement
Storm waters
Peat production

Sea of Bothnia

Finnish Arghipelago Sea

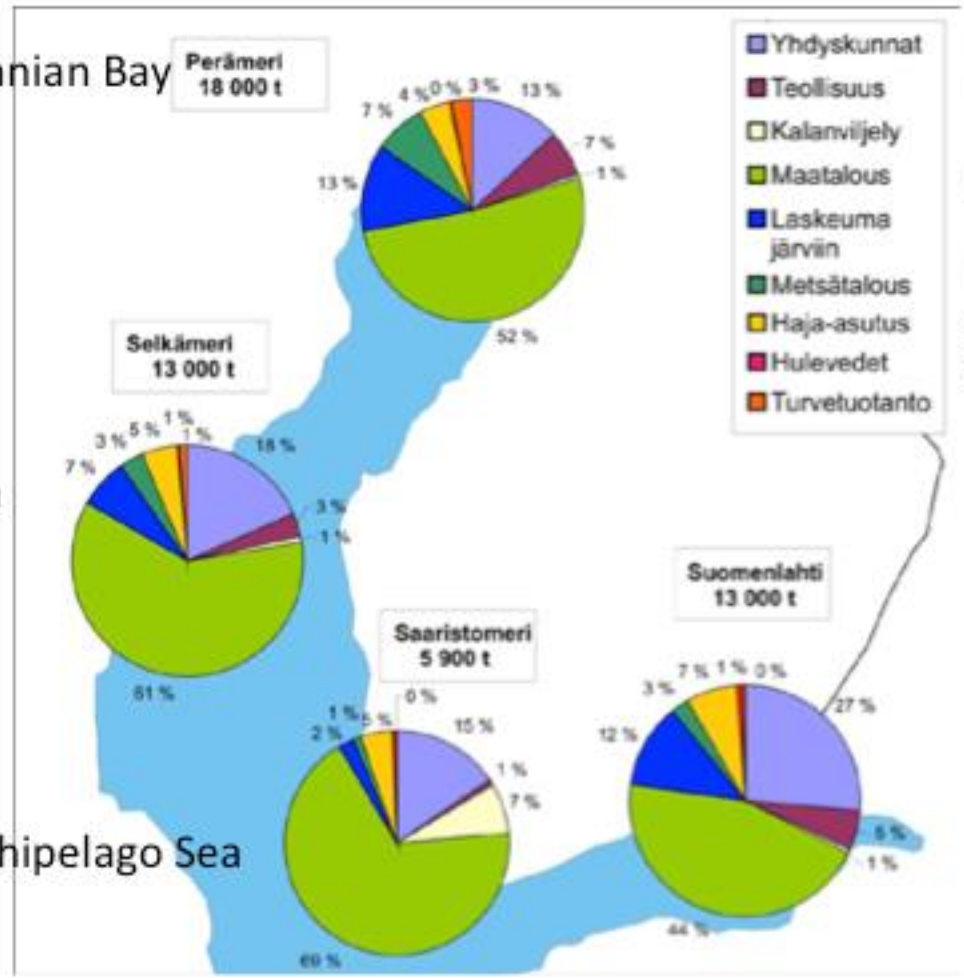
Gulf of Finland

Human Based N Loading

Bothnian Bay

Sea of Bothnia

Finnish Arghipelago Sea



Municipalities

Industry

Fish farming

Agriculture

Deposition to lakes

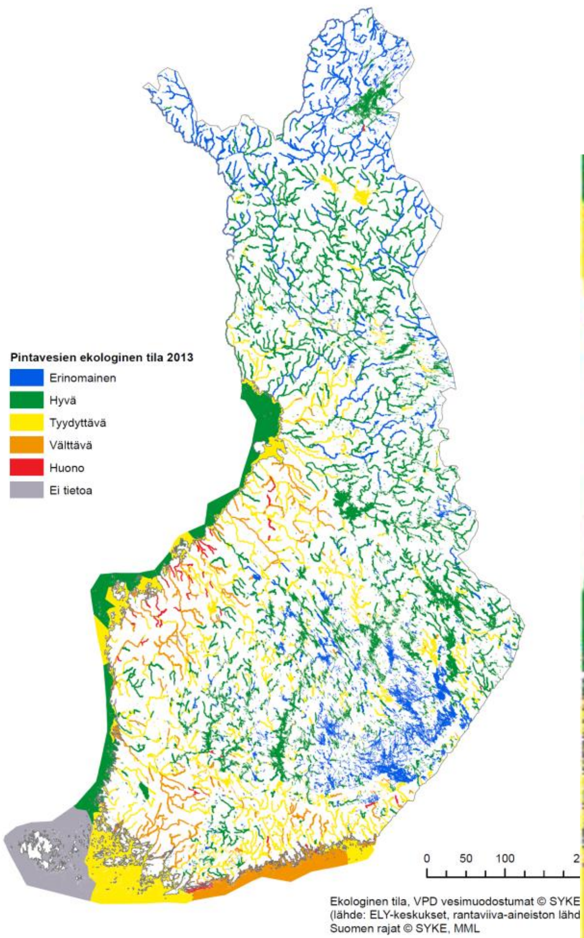
Forestry

Scattered settlement

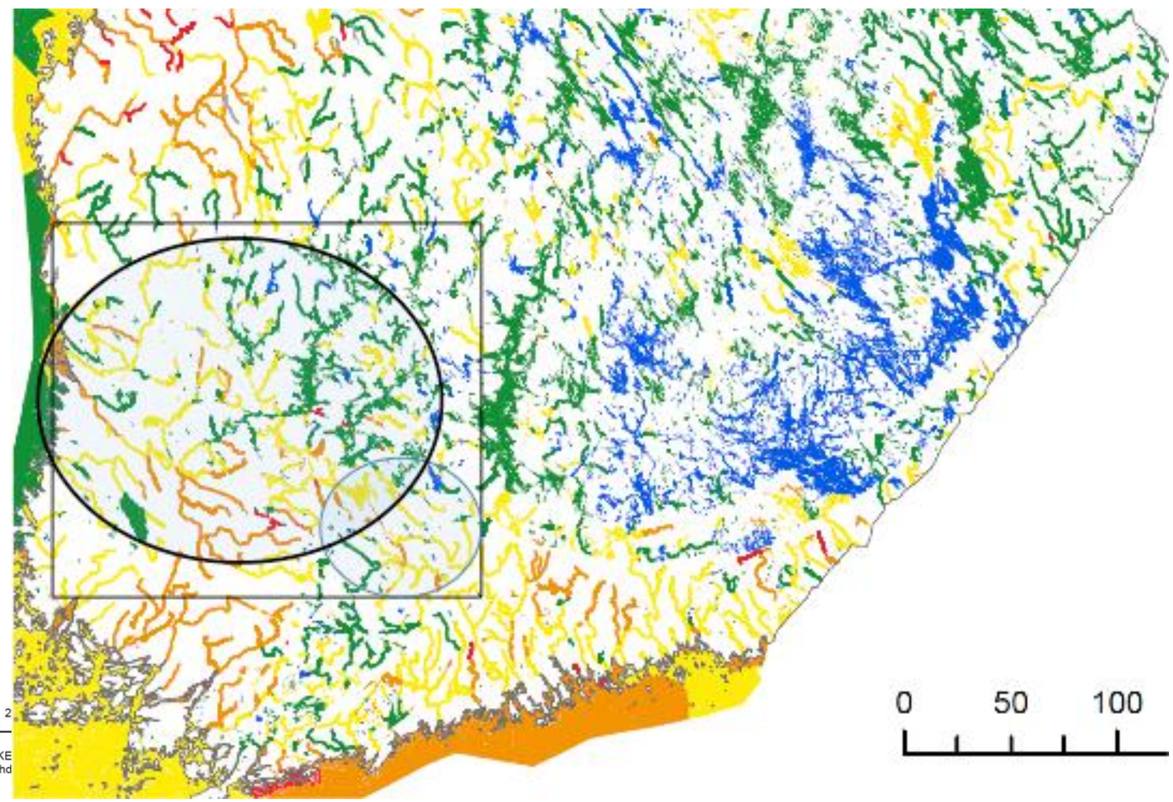
Storm waters

Peat production

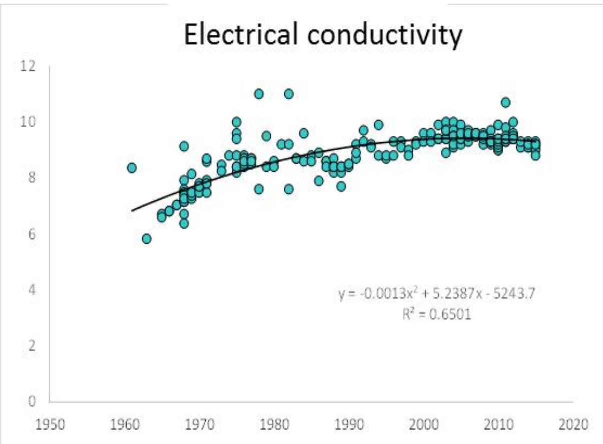
Ecological status of inland waters in 2013

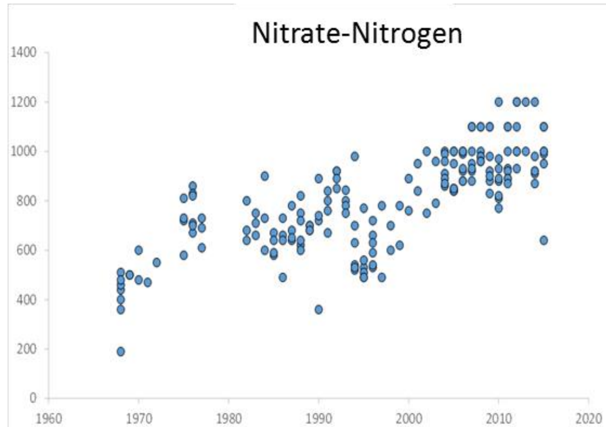


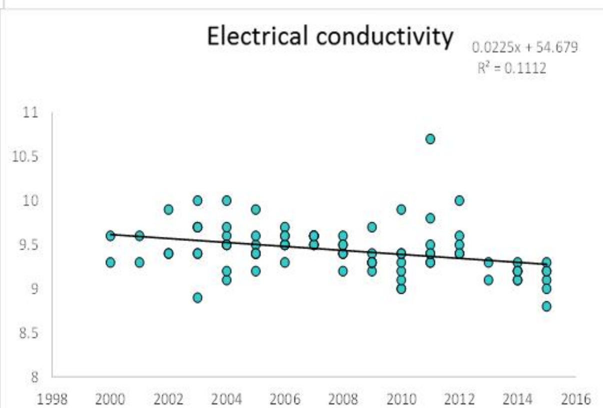
Kokemäenjoki drainage basin

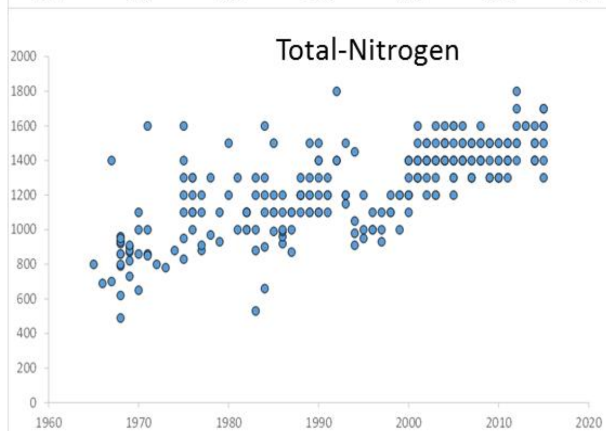


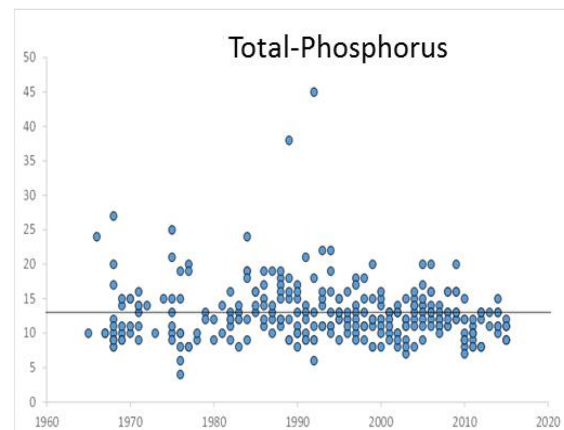
Long-term chemistry changes in lake Pääjärvi

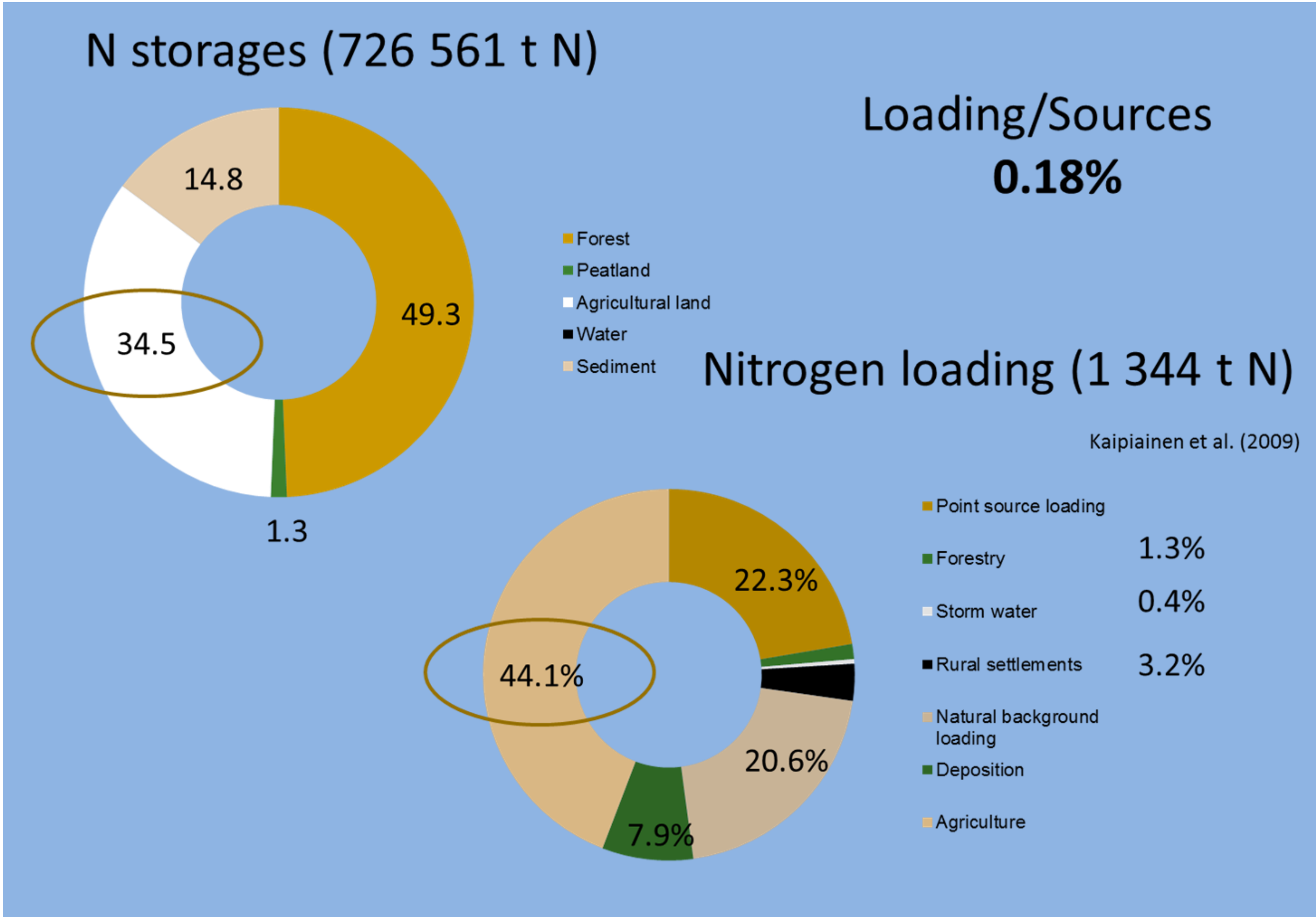




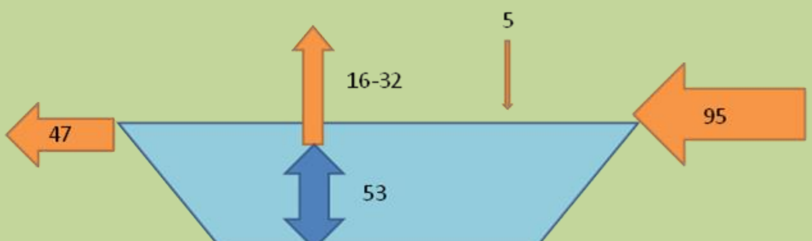






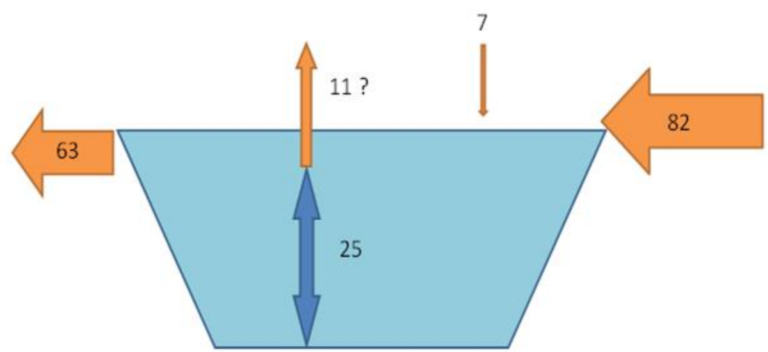

N storages (726 561 t N)
14.8
49.3
34.5
1.3
Forest
Peatland
Agricultural land
Water
Sediment
Loading/Sources
0.18%
Nitrogen loading (1 344 t N)
Kaipiainen et al. (2009)
22.3%
44.1%
20.6%
7.9%
Point source loading
Forestry
Storm water
Rural settlements
Natural background loading
Deposition
Agriculture
1.3%
0.4%
3.2%

Vanaja



Retention - 53 % of loading
Denitrification - from 31 to 60% of annual removal

Pääjärvi



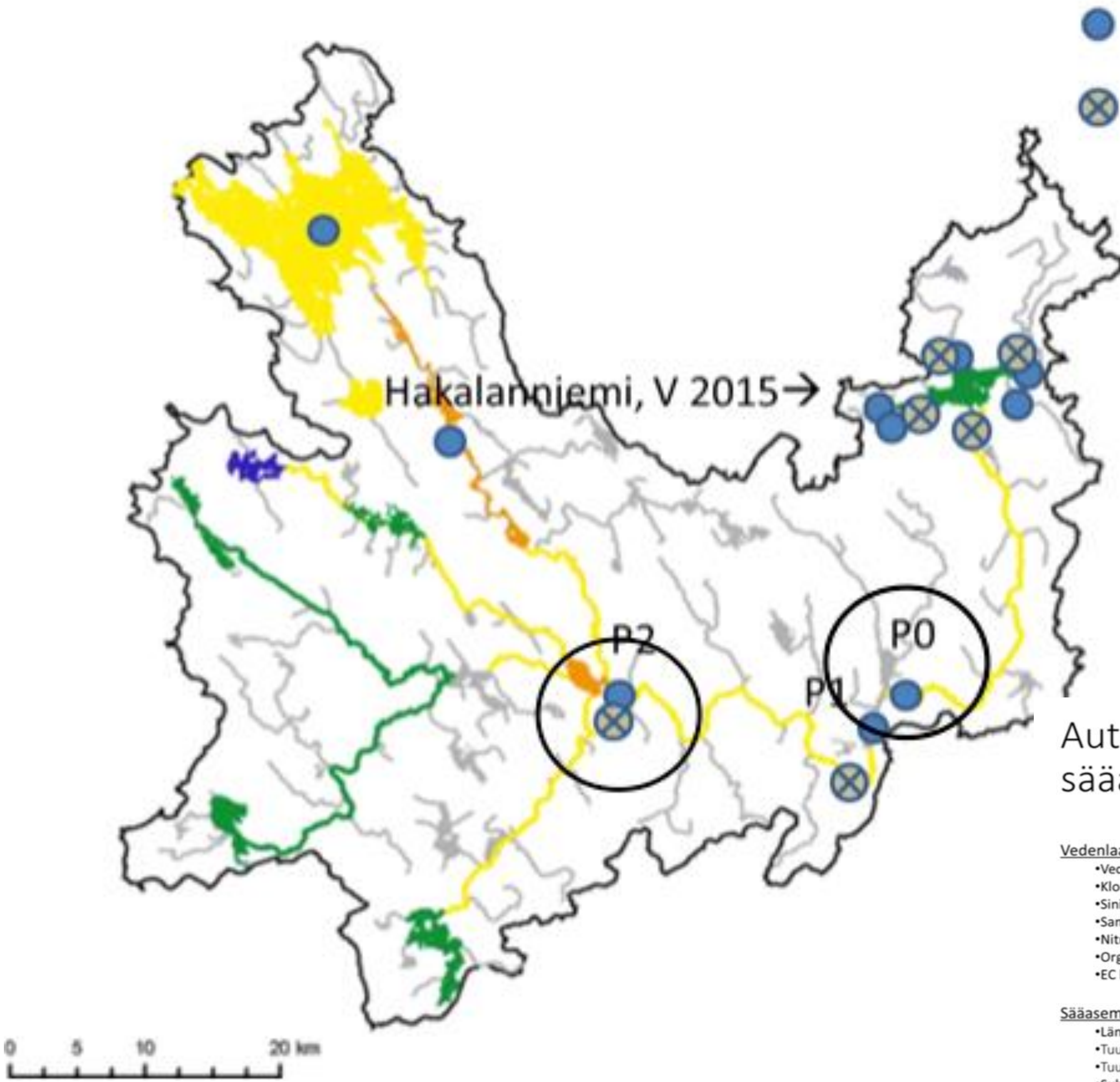
Retention - 28% of loading
Denitrification - 40% of removal?

Table 1. Annual retention efficiency (%) for the three nutrients.

Year	Tot-P	Tot-N	OrgC
1995	88.6	25.7	42.5
1996	71.0	39.7	53.8
1997	80.0	33.0	32.6
1998	82.6	41.4	58.9
1999	78.1	34.1	41.7
2000	72.7	35.4	41.0
2001	67.0	19.4	27.2
2002	71.6	21.9	23.3
2003	82.3	49.3	25.3
2004	77.2	11.6	31.3
2005	68.6	-0.5	10.7
2006	80.3	51.0	42.5
2007	68.7	14.2	28.0
2008	68.4	21.0	29.8
2009	68.8	5.1	22.5
2010	77.3	23.5	28.3
Mean	75.2	26.6	33.7
SD	6.5	15.0	12.3
CV%	8.6	56.3	36.5

From manual to high frequency monitoring by sensors

Automatic water quality and weather stations



Automaattiset vedenlaatu- ja sääasemat

Vedenlaatuasemat:
- Veden lämpötila ja happi
- Klorofylli
- Sinilevät
- Sameus
- Nitraatti
- Orgaaninen hiili
- EC kasvihuonekaasut

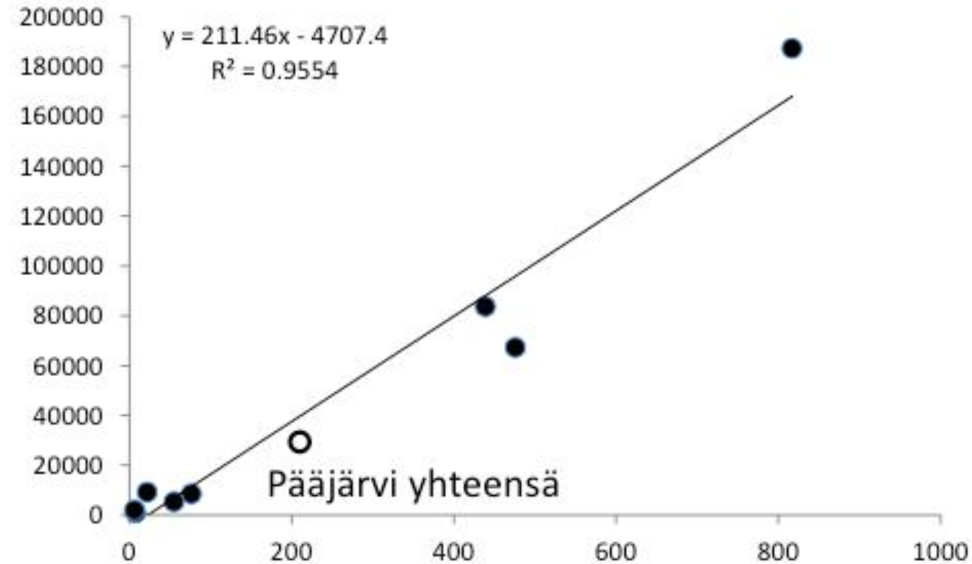
Sääasema:
- Lämpötila
- Tuulen nopeus
- Tuulen suunta
- Suhteellinen kosteus
- Ilmanpaine

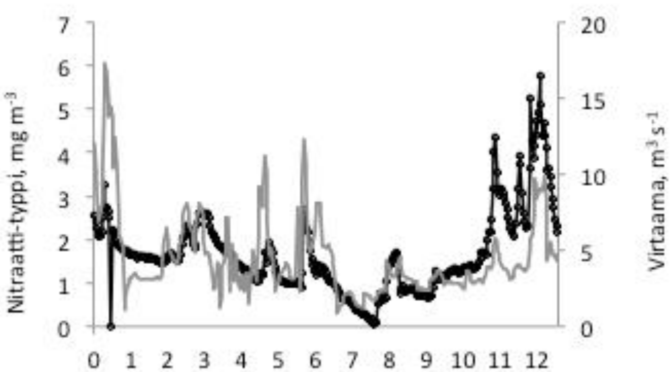
Tieto lähes reaaliaikaisesti käytettävissä

High Frequency Monitoring: Nitrate-N loading in River Teuro-Puujoki

Pääjärvi - Teuro - Puujoki, 2014

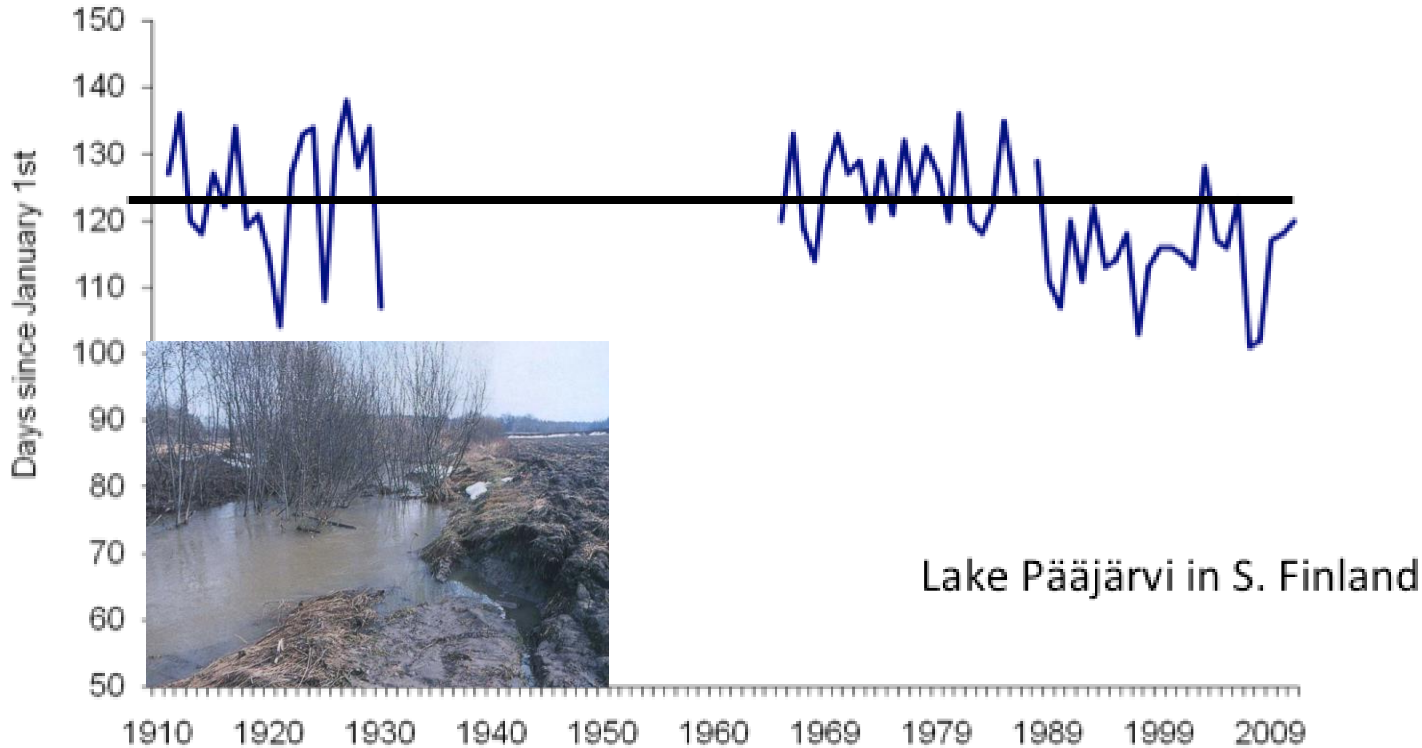
NO_3-N kg vs. VA pinta-ala (km^2)



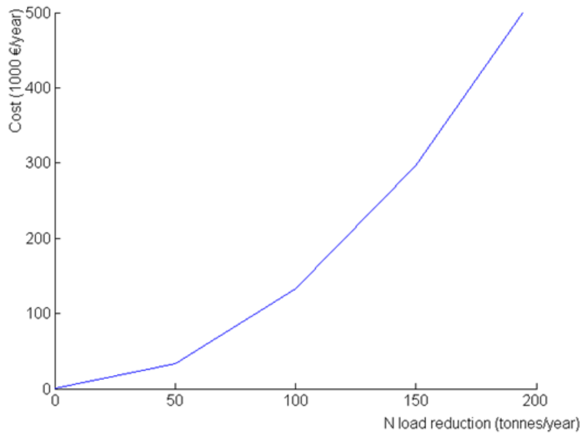


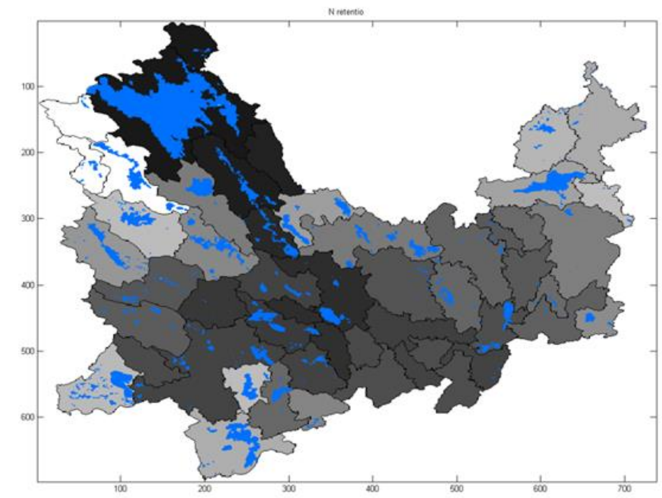
Puujoki (2) – Leppäkoski, 2014

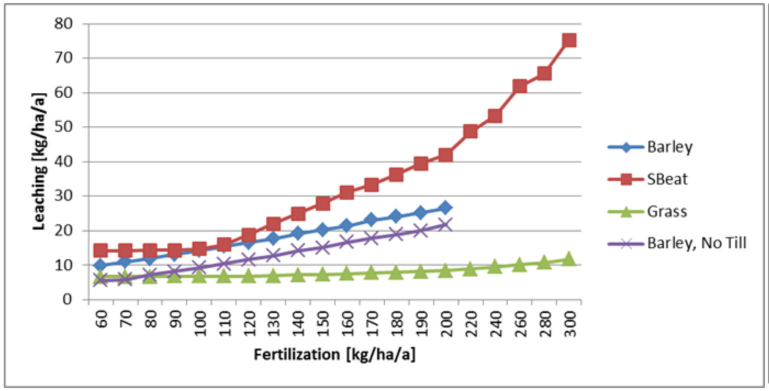
Climate Change -> New Challenges for Catchment Management

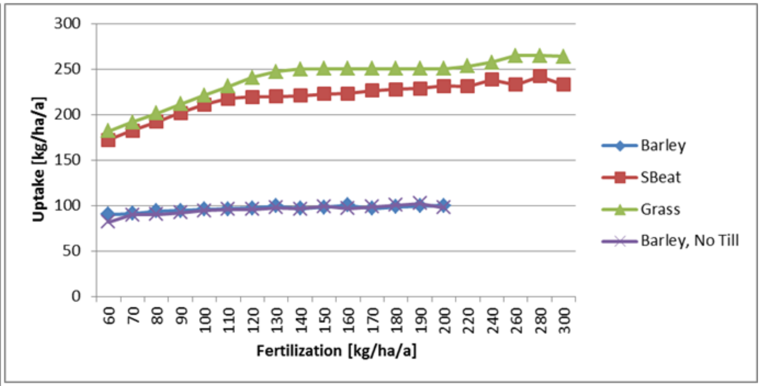


Nitrogen reduction measures in Vanaja catchment









New measures are needed

Wetlands remove nutrients

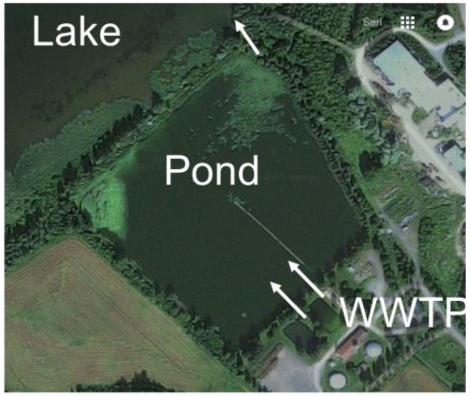
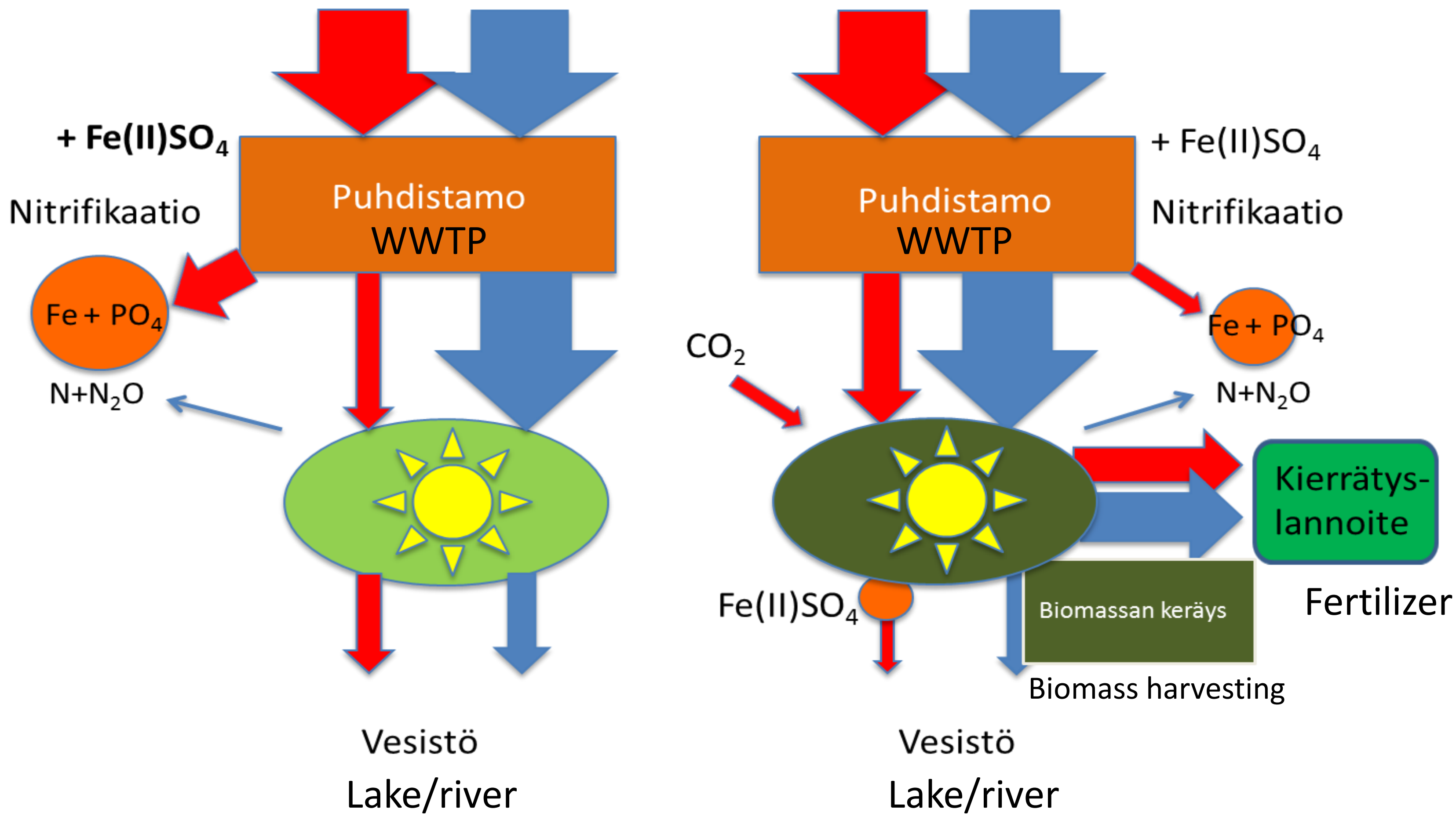


Fig. 1. Lammi WWTP. The surface area of the after-treatment pond is 4 ha and its mean depth 1 m with a hydraulic residence time of appr. 40 days.

Table 1. Retention (%) of N and P load during different seasons and annually.

Season	NH4-N	NO3-N	PO4-P	tot-N	tot-P
Spring	53	34	58	39	52
Summer	94	91	97	81	10
Autumn	85	78	87	64	-47
Winter	14	22	28	23	35
Annual	80	73	89	68	34

”New wastewater treatment plant”



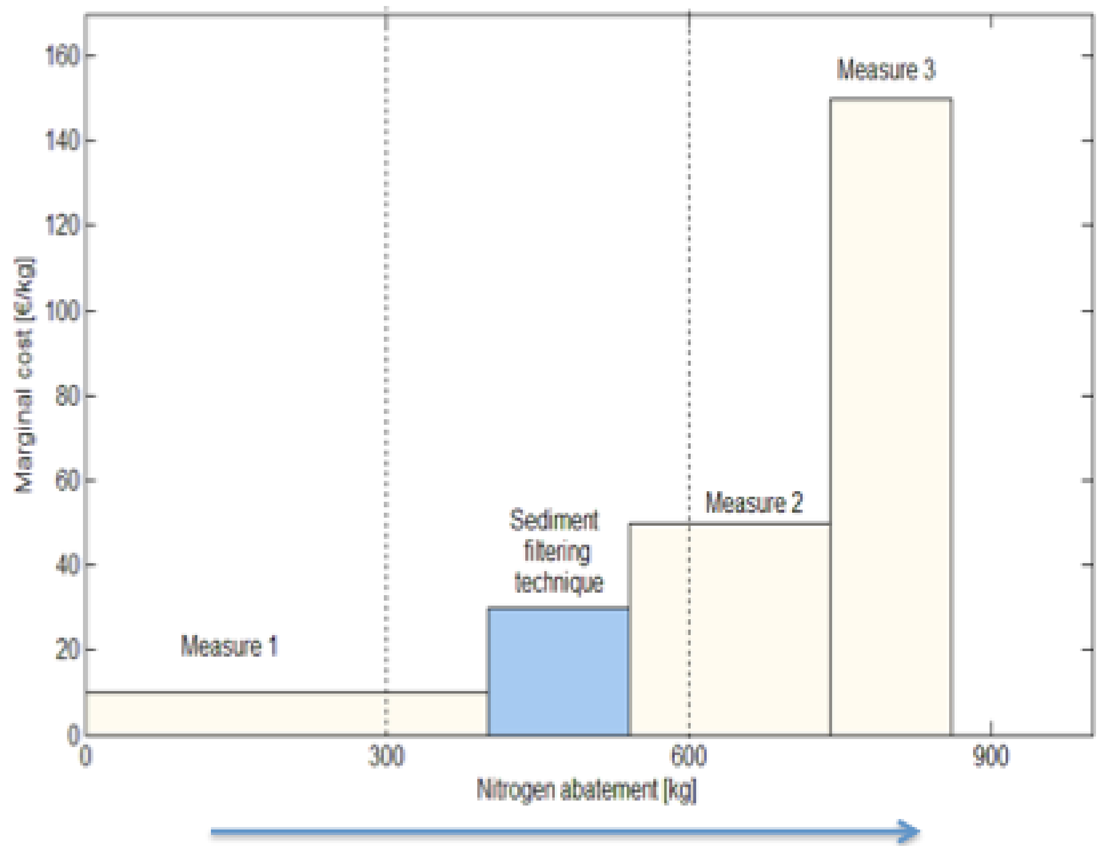
$Fe^{3+} + H_nPO_4^{-(3-n)} \rightarrow FePO_4(s) + nH^+$, (n = 0, 1, 2 tai 3)

$3Fe^{2+} + 2PO_4^{3-} \rightarrow Fe_3(PO_4)_2(s)$

The Cost-Effectiveness Principle – 4 Fictional Abatement Measures

Cost-effectiveness principle

- Height = Marginal cost
- Width = capacity of abatement measure
- According to the cost-effectiveness principle the measure with the lowest abatement cost (measure 1) is implemented first
- then sequentially moving to measures with higher abatement cost until the target is met
- total cost of reaching the goal is the total area left of that target (vertical line)



EU Life+ N-SINK project

2013-2017

Ahlvik *et al.* (2014) En economic-ecological model to evaluate impacts of nutrient abatement in the Baltic Sea. *Environmental Modelling and Software* 55, 164-175.

Conclusions

- Nutrient loading to the Baltic Sea is too high relative to its ”self-purification” capacity
- **Inland water transport** most of the loading
- Lakes can **remove a major part of nutrients** on the way from the drainage basins to the sea
- Catchment areas close to the basins (lakes, rivers and sea) have a key role
- **New thinking and measures** are urgently needed

- Better understanding of ecosystem processes is needed but even more **science based political and practical actions, i.e. improvements**

Thank you!