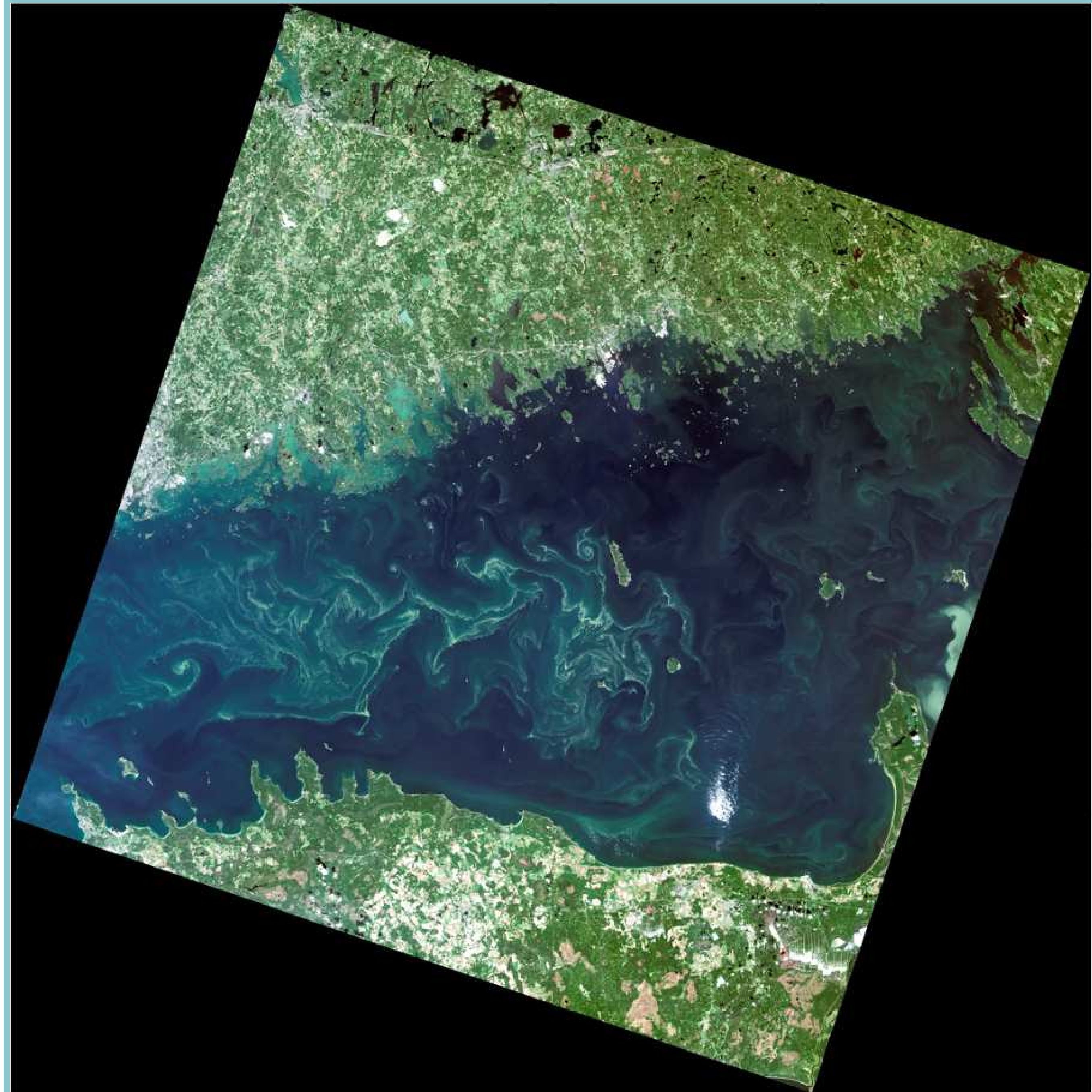


Landsat 8, 22.08.2015, Original picture: USGS/NASA Landsat program, prosessing: SYKE

Eutrophication of the Baltic Sea

Petri Ekholm

Finnish Environment Institute (SYKE)

SYKE

My career

Quantifying riverine nutrient fluxes

Societal welfare W

$$W_t = \sum_{t=0}^{\infty} \beta^t \left(B(e_t, p_t) - D(C_t)\right)$$

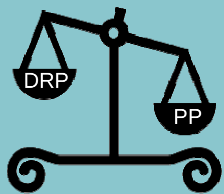
Searching optimal abatement of P

Estimating algal-available P by bioassays

Understanding sediment processing of P

Testing novel agricultural P abatement measures

Which P form should we reduce?



Coupled biogeochemical cycles of N, P, C, Fe, Mn, S

Photos: Jouni Lehtoranta, Seppo Knuuttila, Ari Langi, Janne Artell

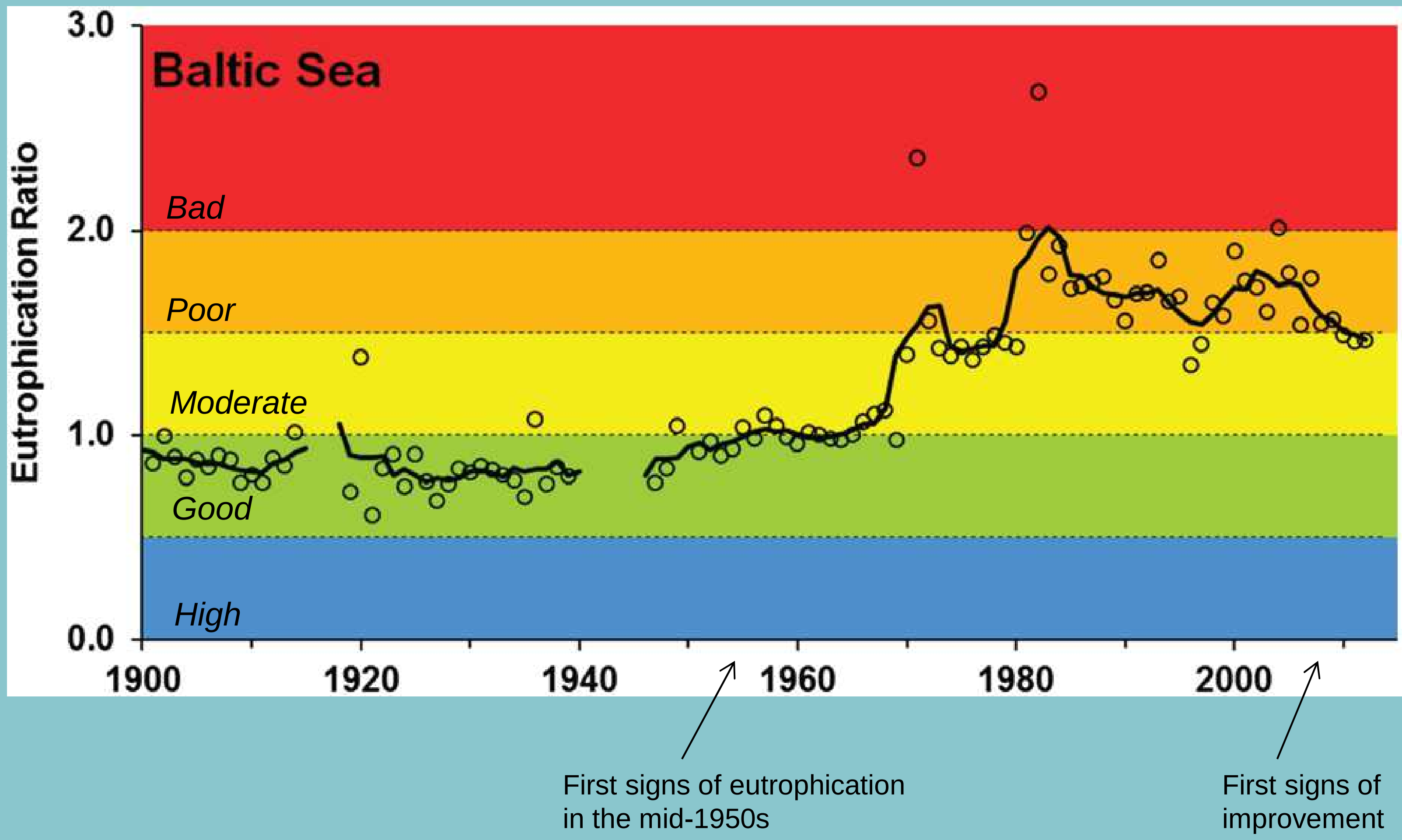
Facts about the Baltic Sea

- The catchment
    - 2 130 000 km^2
    - 14 countries
    - 85 million inhabitants
    - Geology, land use, population density etc. vary from south to north
- The sea
    - A brackish semi-enclosed area of 412 560 km²
    - 21 631 km³
    - Average depth 52 m
    - Maximum depth 459 m
    - N load increased by about 2.5 times, P load 3.7 times since the year 1900
    - All areas affected by eutrophication
    - The degree of eutrophication varies among sub-basins and coastal areas

http://www.vliz.be/v/images/9/9d/Balticsea_Fig2.jpg

Integrated assessment of eutrophication

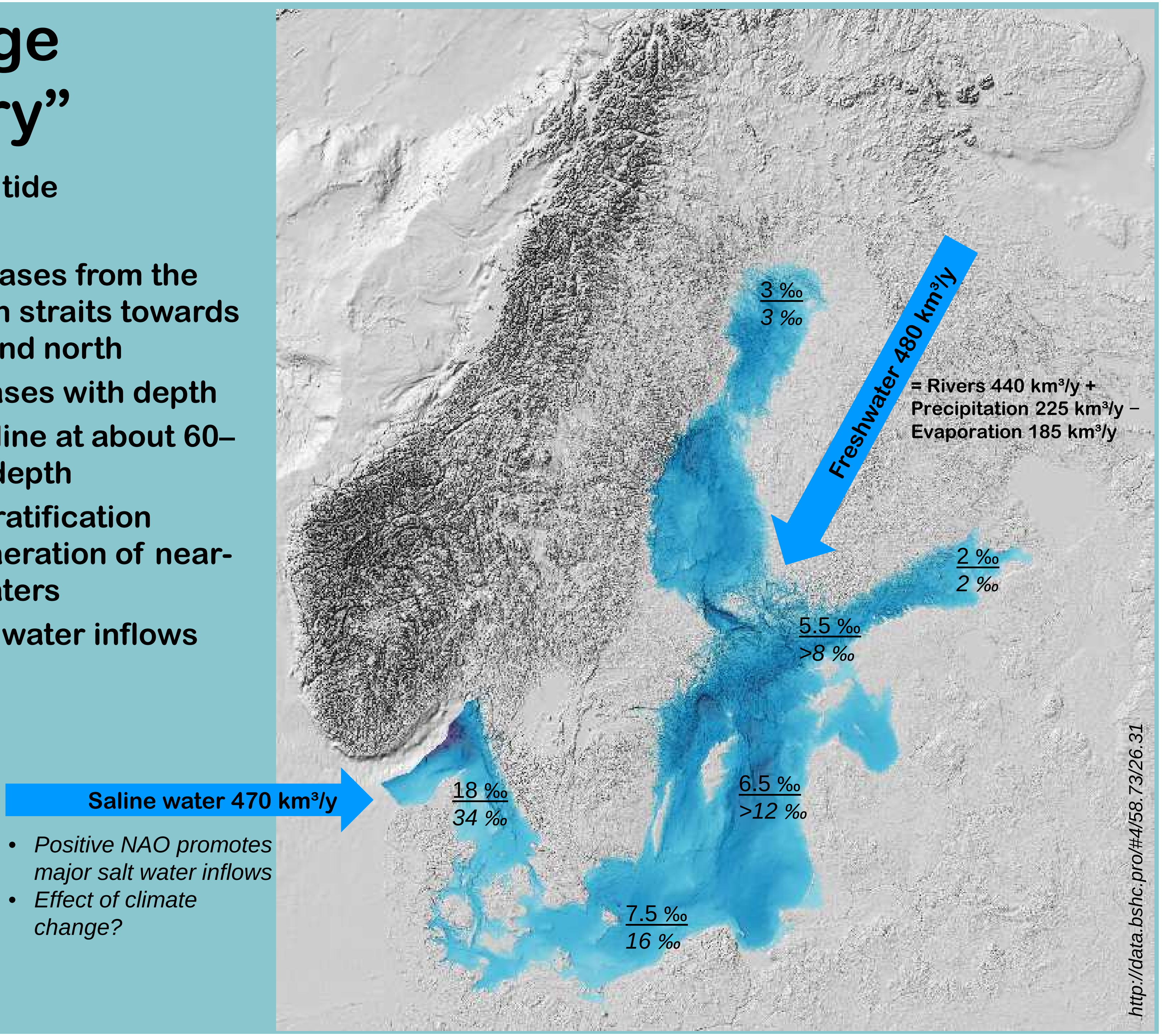
HELCOM Eutrophication Assessment Tool (HEAT 3.0)



Andersen JH, Carstensen J, Conley DJ, Dromph K, Fleming-Lehtinen V, Gustafsson BG, Josefson AB, Norkko A, Villnäs A, Murray C. 2017. Long-term temporal and spatial trends in eutrophication status of the Baltic Sea. Biol. Rev. 92:135-149.

“A large estuary”

- Except no tide
- Salinity
  - Decreases from the Danish straits towards east and north
  - Increases with depth
  - Halocline at about 60–80 m depth
- Salinity stratification prevents aeration of near-bottom waters
- Major salt water inflows supply O_2



- *Positive NAO promotes major salt water inflows*
- *Effect of climate change?*

“Very good news for the Baltic Sea – the largest salt pulse in 60 years”

Erittäin hyvä uutinen Itämereltä – suurin suolapulssi 60 vuoteen

KOTIMAA 8.1.2015 19:32

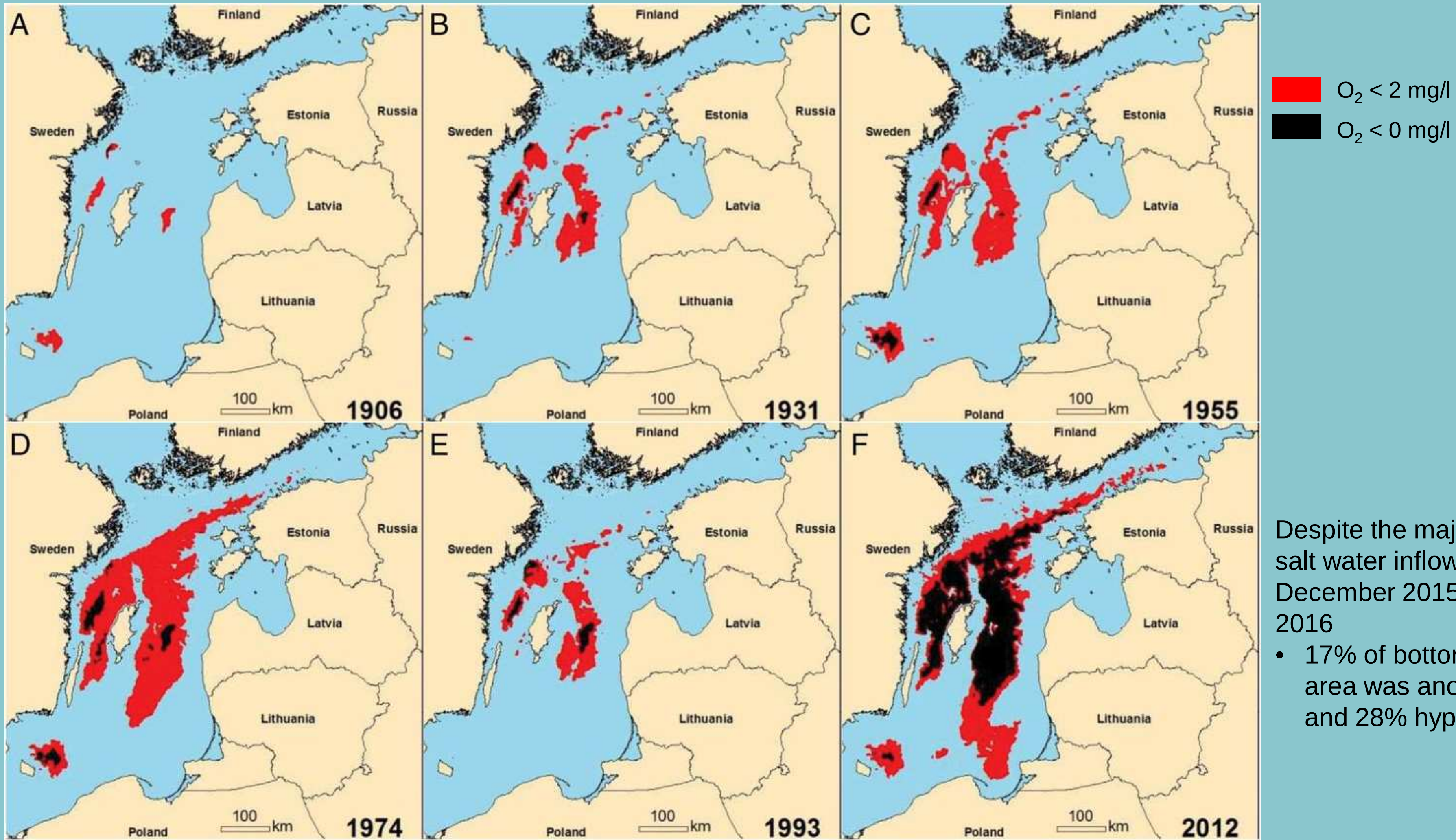
Juha-Pekka Raeste HELSINGIN SANOMAT

HEIKKI SAUKKOMAA / LEHTIKUVA

Rehevöityvän Itämeren tila paranee, mutta Suomenlahden jama voi väliaikaisesti heiketä. Kuva Kaivopuiston rannalta joulukuussa.

Helsingin Sanomat 8.1.2015

Deoxygenation of the near-bottom waters



Despite the major salt water inflow in December 2015, in 2016

- 17% of bottom area was anoxic and 28% hypoxic*

Carstensen J, Andersen JH, Gustafsson B, Conley DJ. 2014. Deoxygenation of the Baltic Sea during the last century. PNAS111:5628-5633.

*Hansson M, Andersson L. 2016. Oxygen survey in the Baltic Sea 2016 – Extent of anoxia and hypoxia, 1960-2016. Report Oceanography 58, 2016. Swedish Meteorological and Hydrological Institute.

PNAS

P release from marine sediments:
1. Prevalence of microbial Fe reduction and a coupled Fe and P cycling

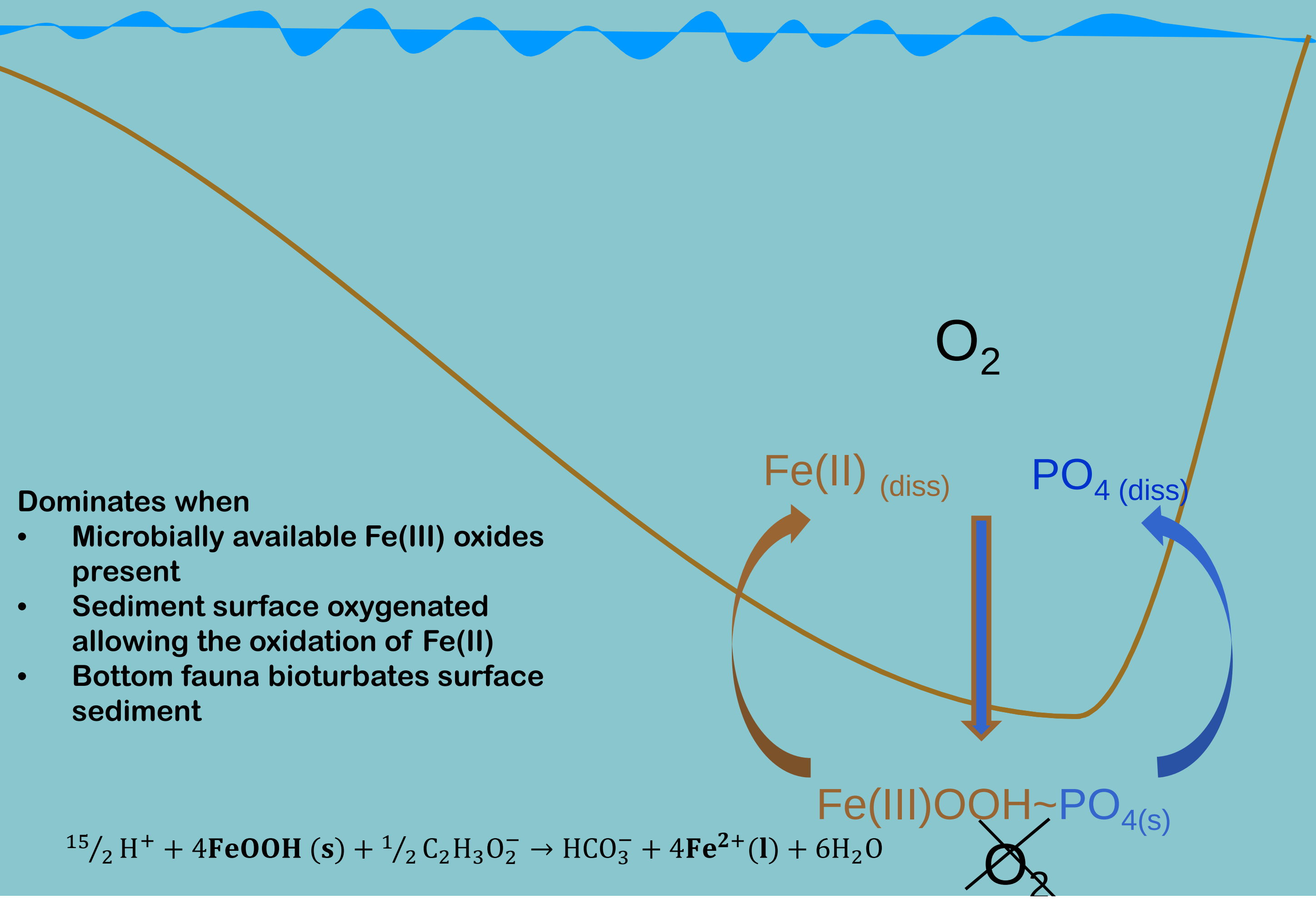


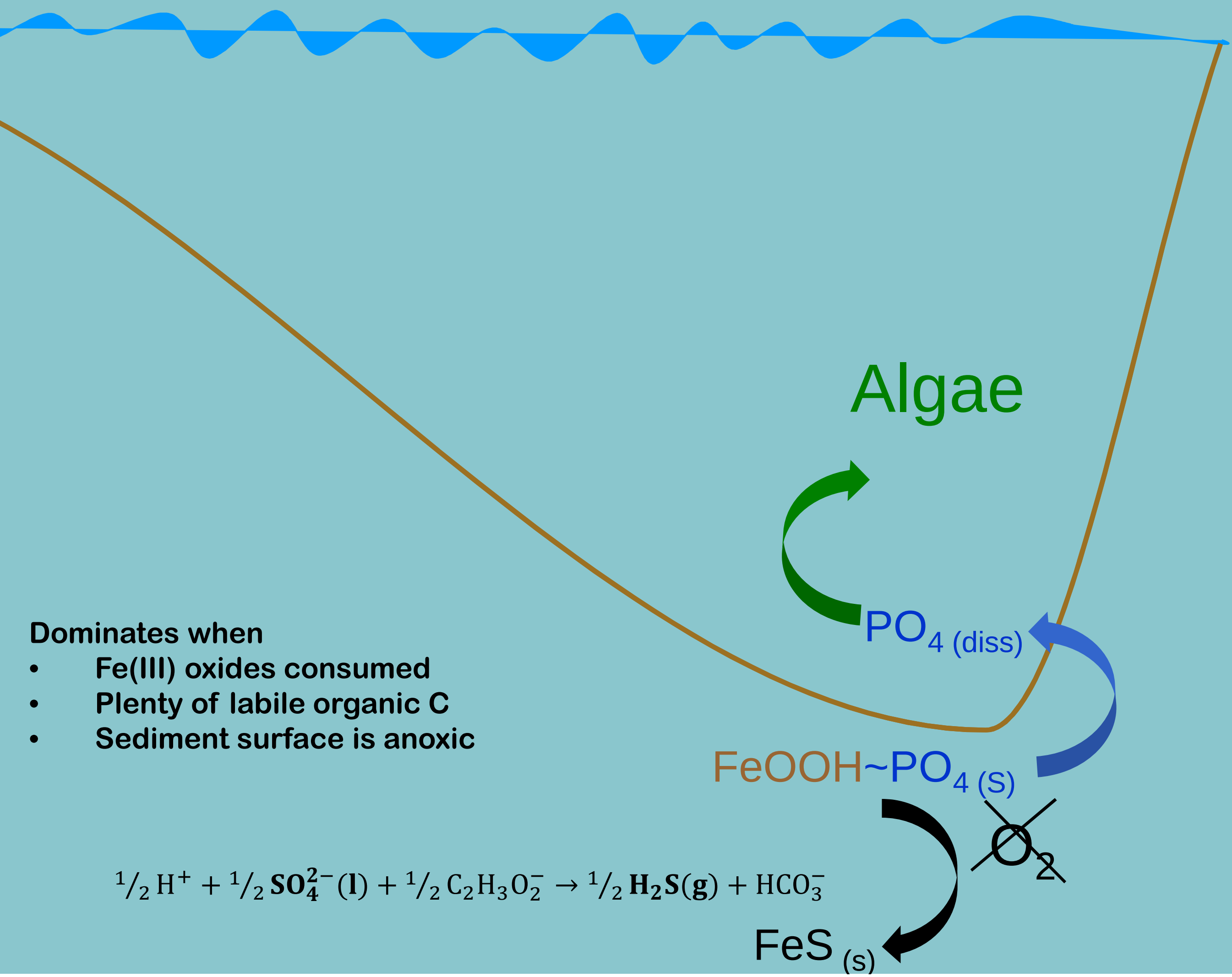
Photo: Seppo Knuuttila

Dominates when

- **Microbially available Fe(III) oxides present**
- **Sediment surface oxygenated allowing the oxidation of Fe(II)**
- **Bottom fauna bioturbates surface sediment**

$$^{15}/_{2}\,H^{+} + 4\mathbf{FeOOH}\,(\mathbf{s}) + {}^{1}/_{2}\,C_2H_3O_2^{-} \rightarrow HCO_3^{-} + 4\mathbf{Fe^{2+}}(\mathbf{l}) + 6H_2O$$

P release from marine sediments:
2. Prevalence of microbial SO_4 reduction and an uncoupled Fe and P cycling



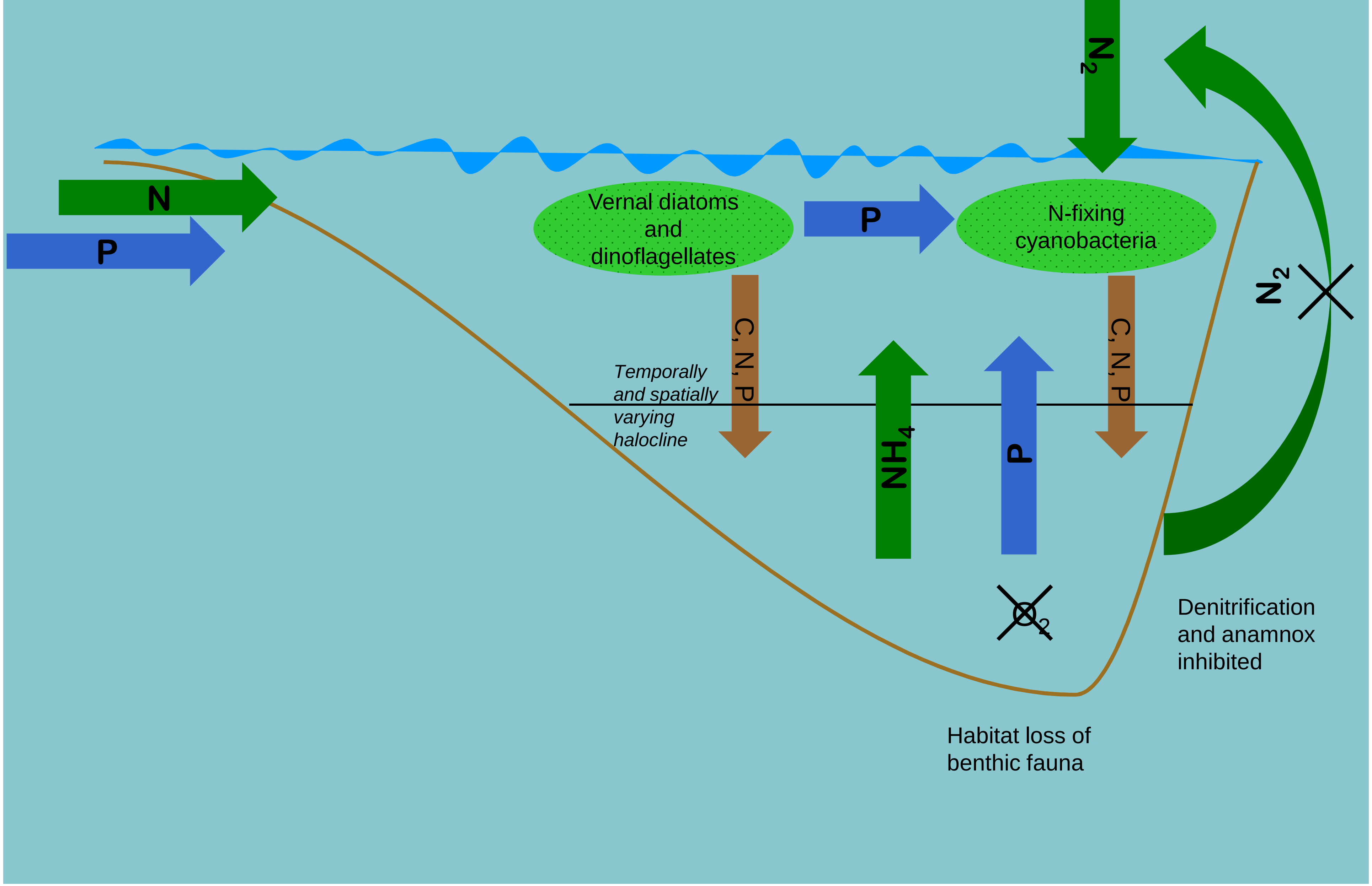
Dominates when

- **Fe(III) oxides consumed**
- **Plenty of labile organic C**
- **Sediment surface is anoxic**

$$\tfrac{1}{2}\,H^+ + \tfrac{1}{2}\,\mathbf{SO_4^{2-}(l)} + \tfrac{1}{2}\,C_2H_3O_2^- \rightarrow \tfrac{1}{2}\,\mathbf{H_2S(g)} + HCO_3^-$$

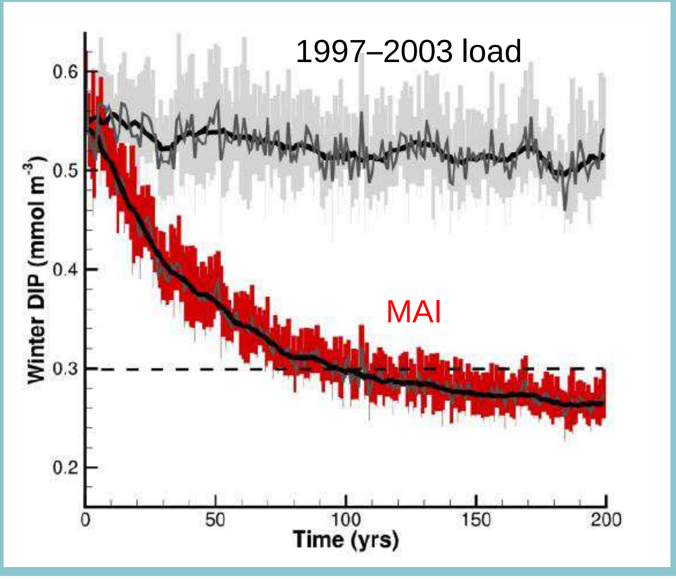
Photo: Seppo Knuttila

The vicious circle



Baltic Sea Action Plan

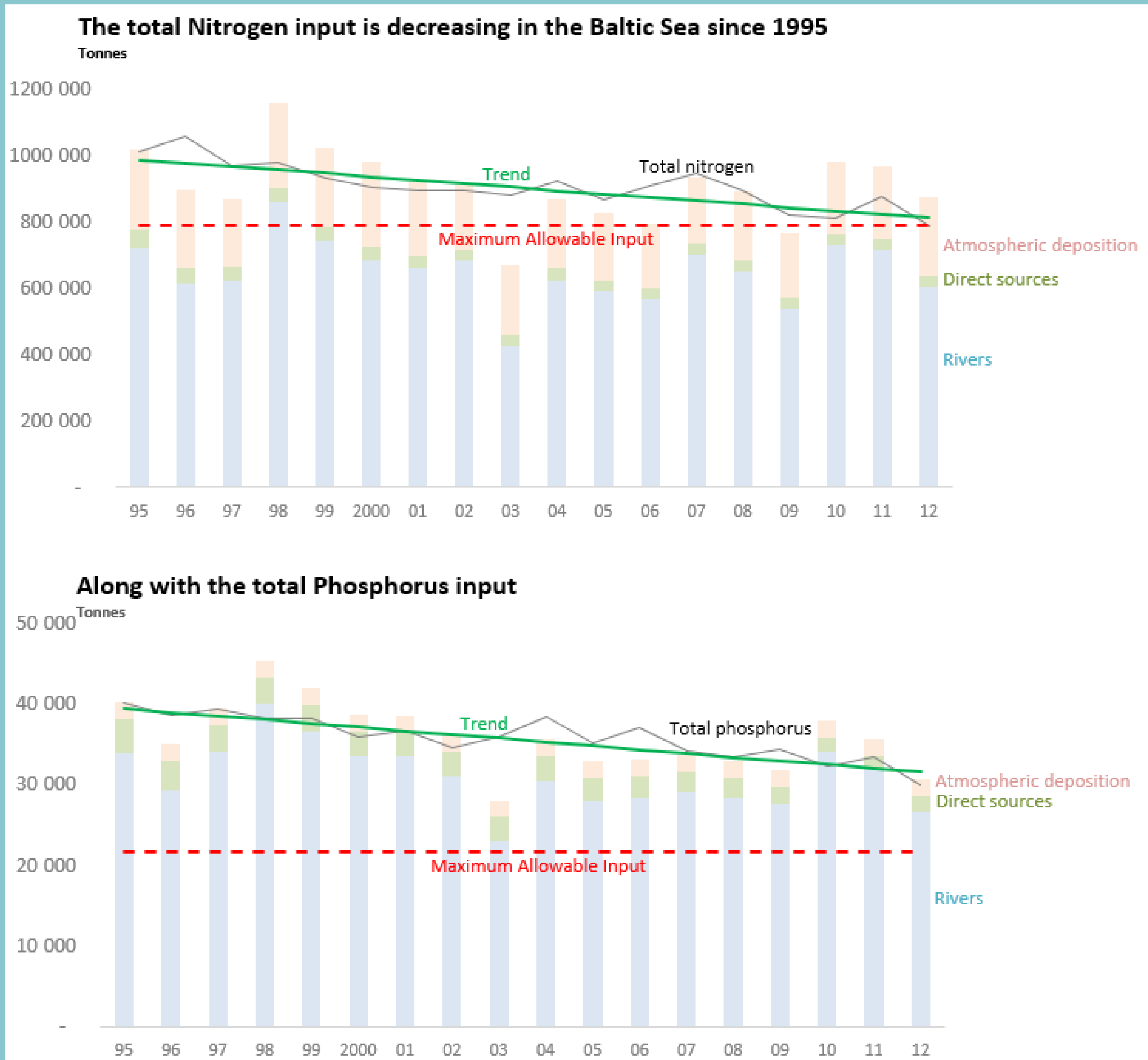
- **HELCOM* target: a good ecological status till 2021**
- **Baltic Sea Action Plan eutrophication targets**
  - **The levels of nutrients, O_2 and algal blooms close to natural levels**
  - **Clear water**
  - **Natural distribution and occurrence of plants and animals**
- **Requires a decrease in P load by 40% and in N load by 13% from the mean level of 1997–2003**
- **Maximum Allowable Input (MAI)**
  - **792 209 t/y N (372 kg/km^2/y)**
  - **21 716 t/y P (10 kg/km^2/y)**
- **Country Allocated Reduction Target (CART)**
  - **Finland has to decrease the load by**
    - **3030 t/y N**
    - **356 t/y P**



Baltic Nest Institute

*Baltic Marine Environment Protection Commission

Load of N and P to the Baltic Sea



http://www.helcom.fi/baltic-sea-trends/pollution-load-compilations/

- Nutrient load
  - Decreased from the mid-1980s
  - Presently at the level of early 1960s
  - Diffuse load dominates

A drastic decrease in the P load to the Gulf of Finland

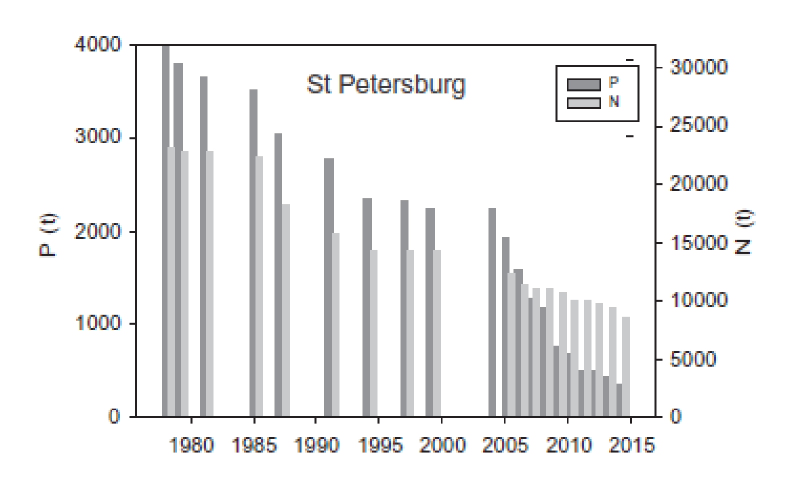
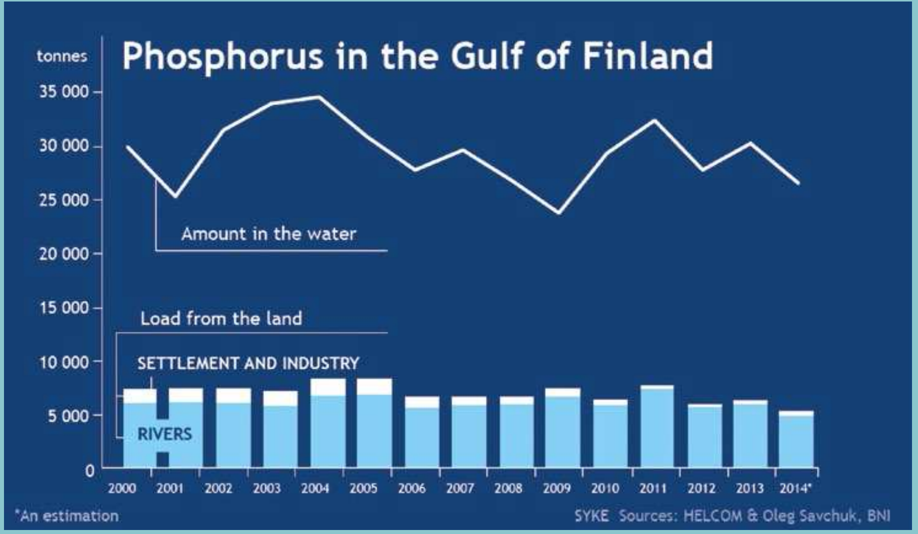
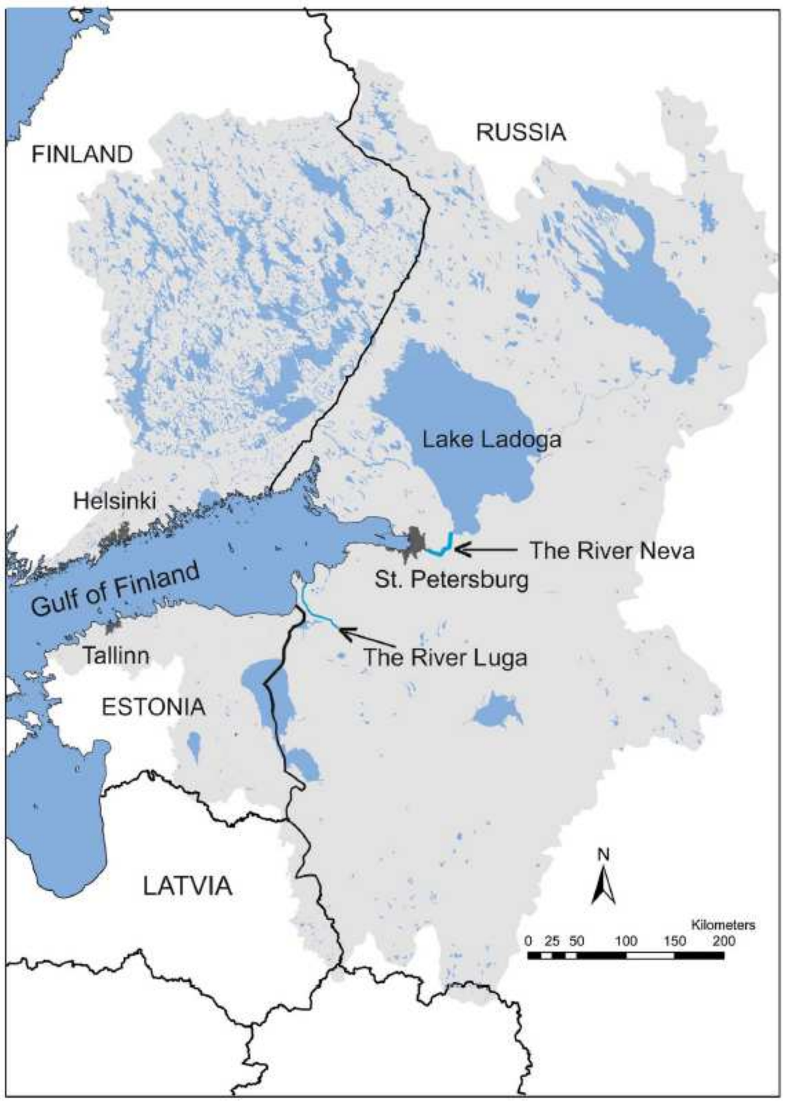


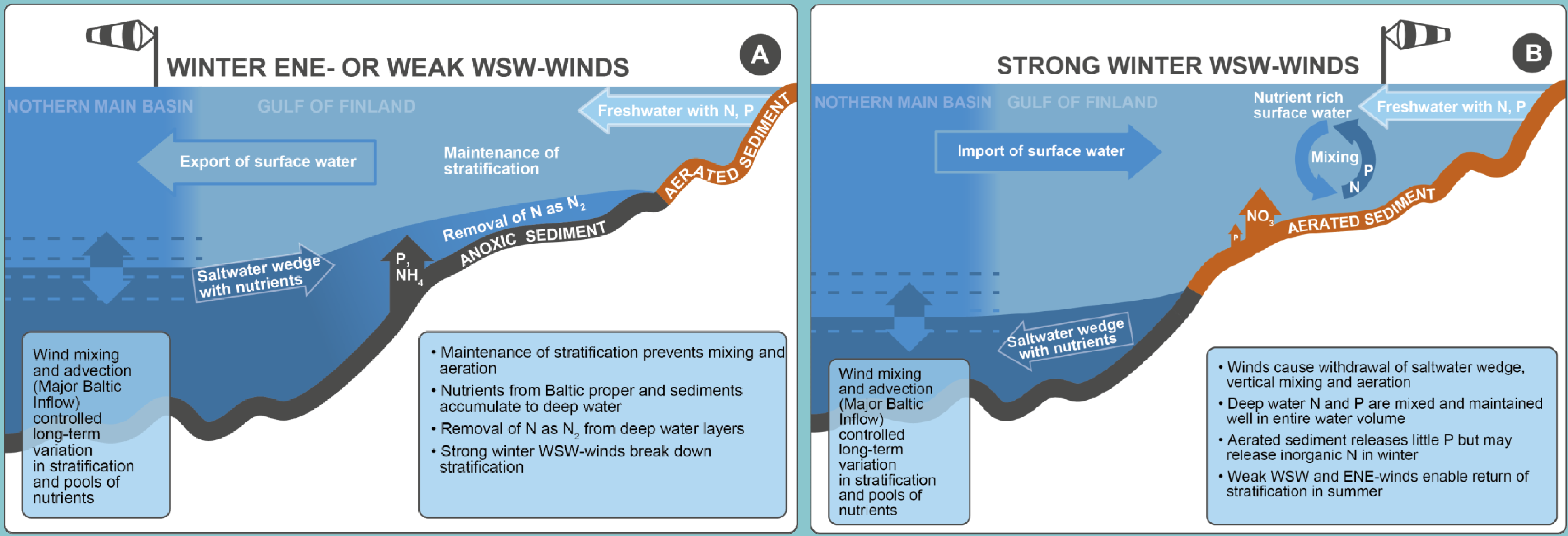
Fig. 2. Annual P and N load from the WWTPs of St. Petersburg into the GOF (Vodokanal, 2015).





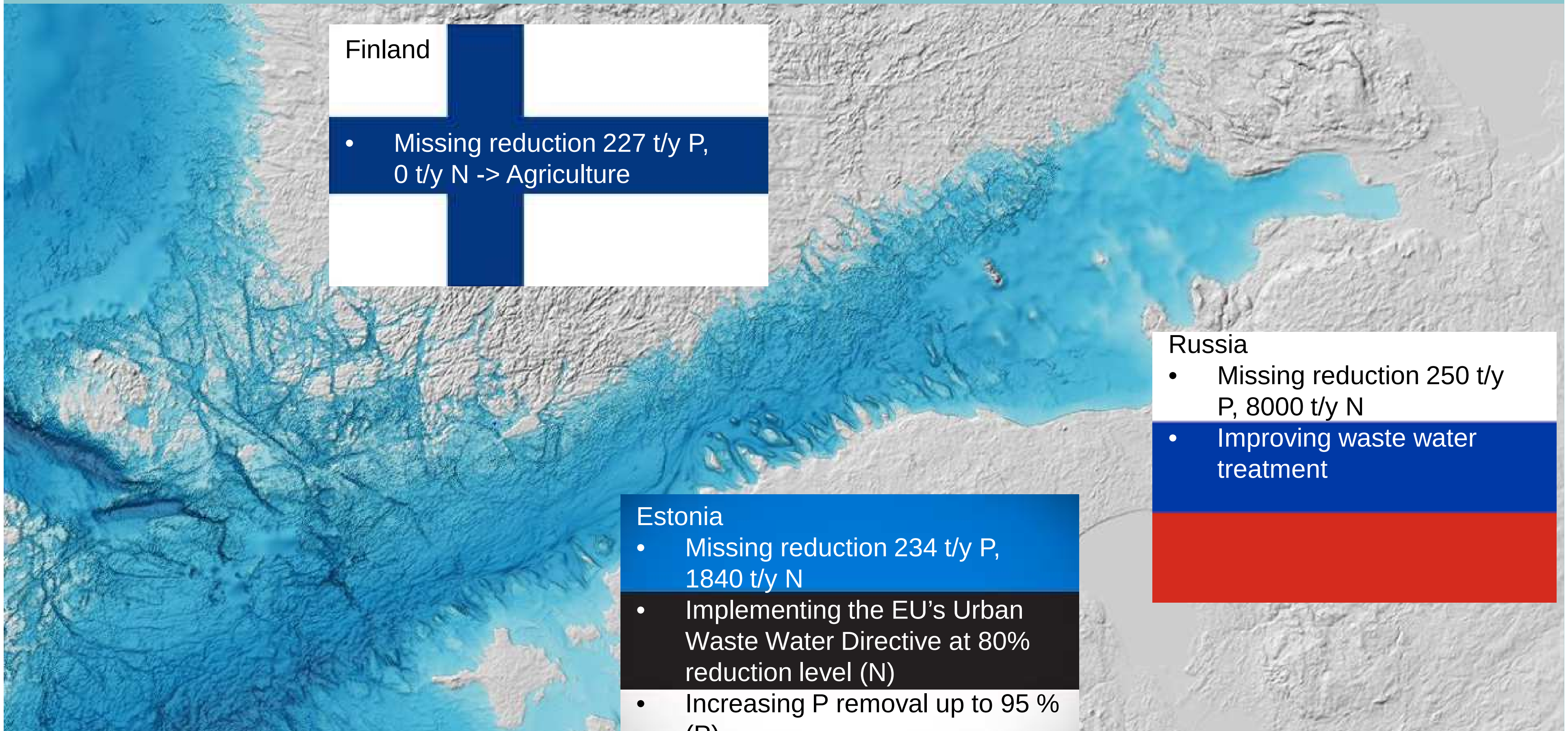
Knuuttila S, Räike A, Ekholm P, Kondratyev S. 2016. Nutrient inputs into the Gulf of Finland: Trends and water protection targets. Journal of Marine Systems (In press.)

Nutrient pools in the Gulf of Finland vary from year to year



Lehtoranta J, Savchuk OP, Elken J, Dahlbo K, Kuosa H, Raateoja M, Kauppila P, Räike A, Pitkänen H. 2016. Atmospheric forcing controlling inter-annual nutrient dynamics in the open Gulf of Finland. Journal of Marine Systems (in press).

Potential for load reduction



Finland

- Missing reduction 227 t/y P, 0 t/y N -> Agriculture

Russia

- Missing reduction 250 t/y P, 8000 t/y N
- Improving waste water treatment

Estonia

- Missing reduction 234 t/y P, 1840 t/y N
- Implementing the EU's Urban Waste Water Directive at 80% reduction level (N)
- Increasing P removal up to 95 % (P)

Ollikainen M. 2016. Cost efficient protection of the Gulf of Finland. Raateoja M, Setälä O (Eds.). The Gulf of Finland assessment. Reports of the Finnish Environment institute 27/2016.

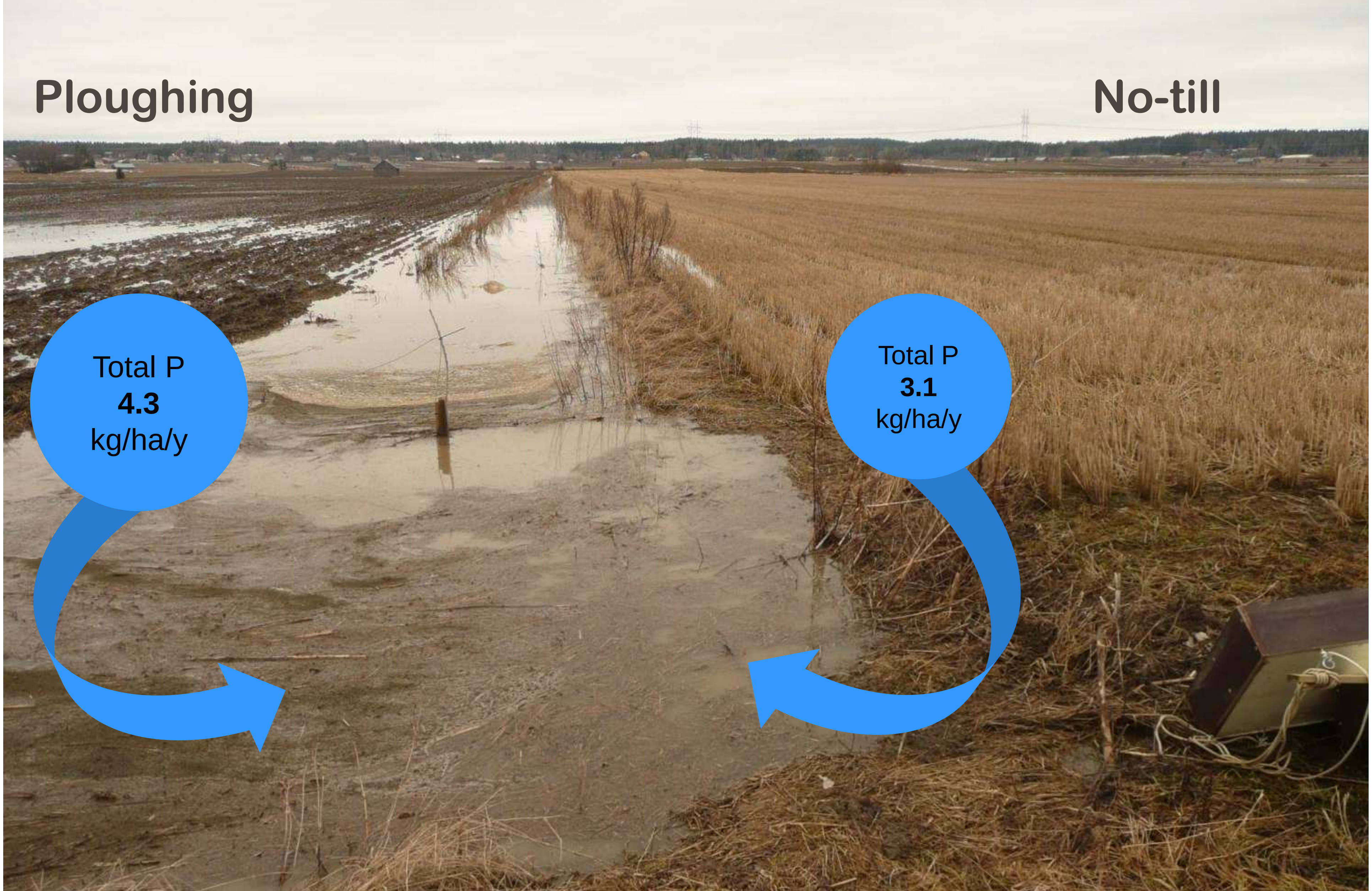
Knuuttila S, Kondratyev S, Lips U, Ekholm P. 2016. Nutrient load: targets and required reductions. Raateoja M, Setälä O (Eds.). The Gulf of Finland assessment. Reports of the Finnish Environment institute 27/2016.

Reducing agricultural P load in Finland

- **Finnish agri-environmental programme the main measure targeting agricultural nutrient load**
- **Focus on erosion control**
    - **Particulate P dominates in agricultural runoff**
- **At least 20% of field area has to be under ”winter green cover”, subsidy increasing till 80%**

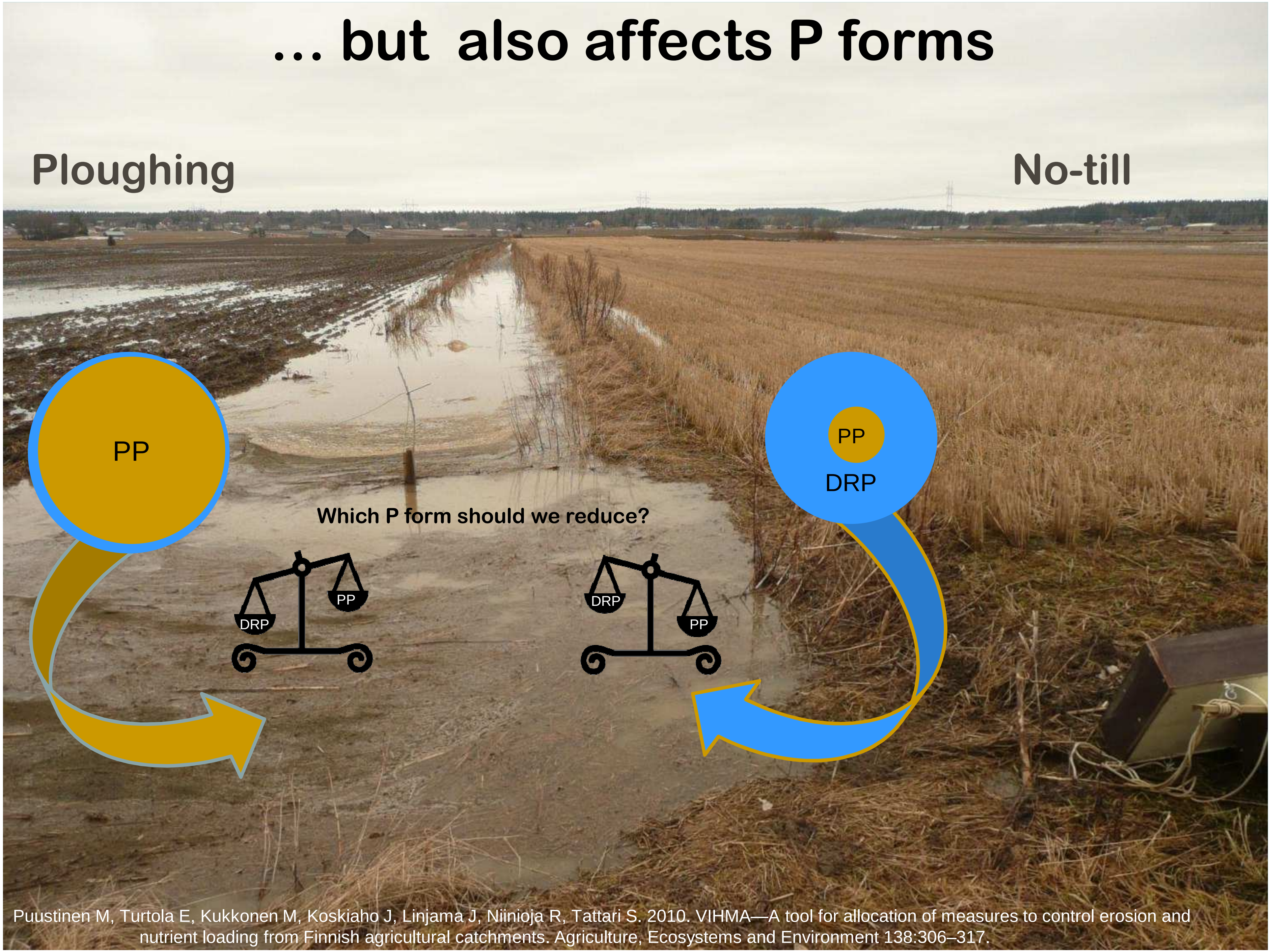
Photo: Janne Artell

Reduced tillage cuts down total P losses…



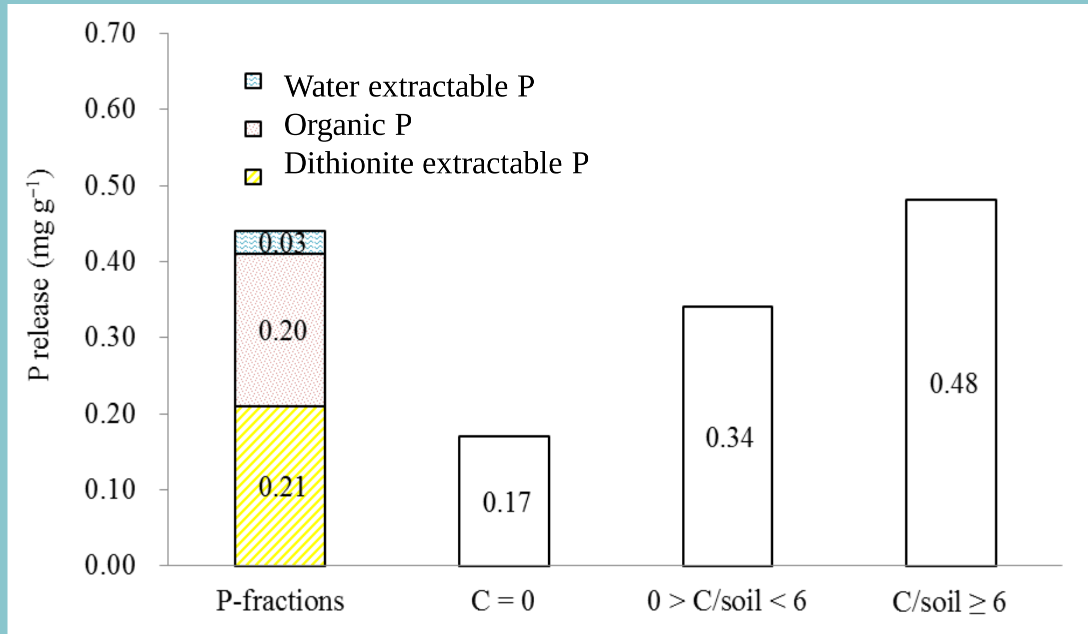
Puustinen M, Turtola E, Kukkonen M, Koskiaho J, Linjama J, Niinioja R, Tattari S. 2010. VIHMA—A tool for allocation of measures to control erosion and nutrient loading from Finnish agricultural catchments. Agriculture, Ecosystems and Environment 138:306–317.

… but also affects P forms



Puustinen M, Turtola E, Kukkonen M, Koskiaho J, Linjama J, Niinioja R, Tattari S. 2010. VIHMA—A tool for allocation of measures to control erosion and nutrient loading from Finnish agricultural catchments. Agriculture, Ecosystems and Environment 138:306–317.

Release of soil P in anoxic brackish water

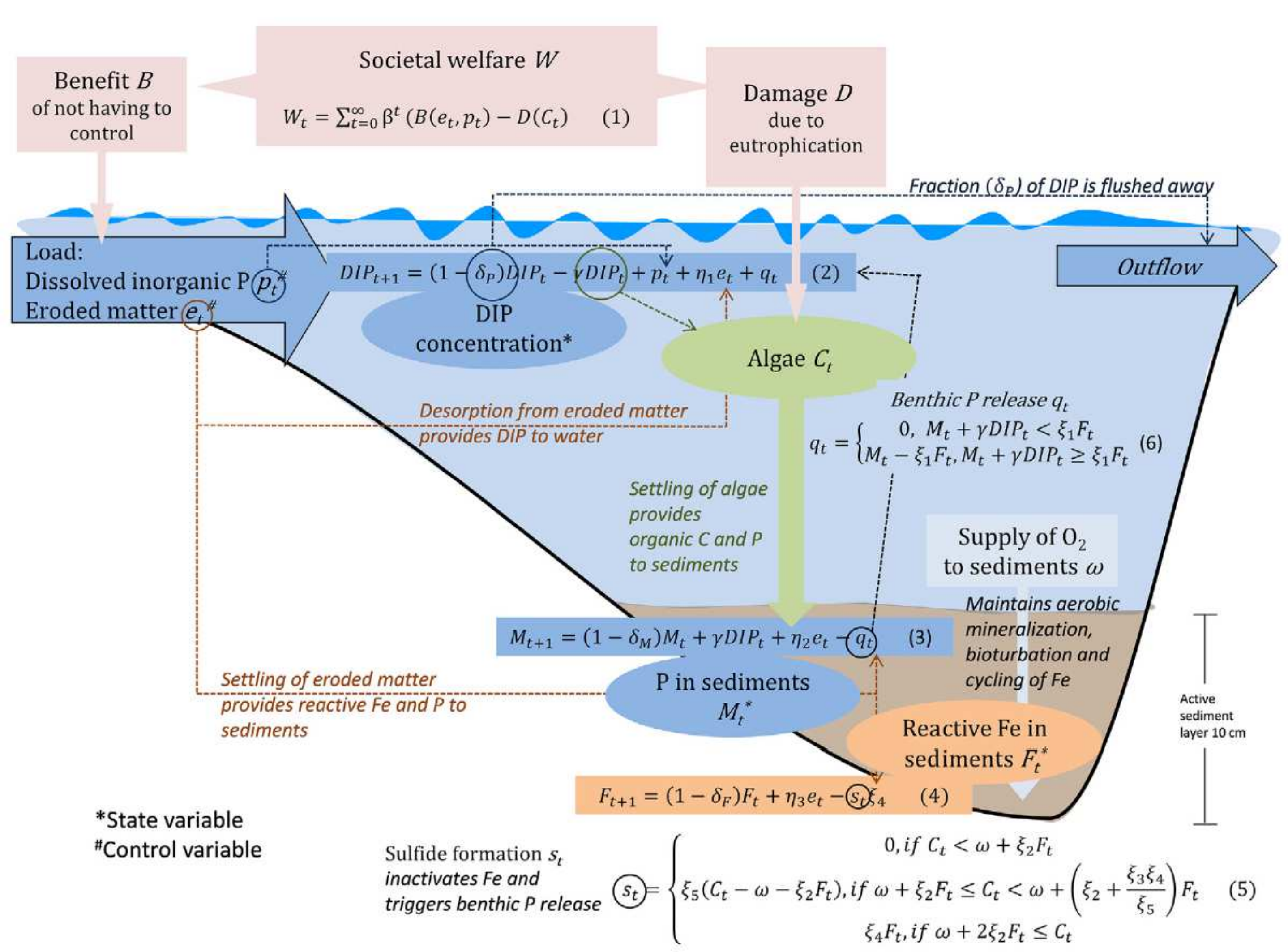


Photos: Seppo Knuuttila, Jouni Lehtoranta

- **Increase in organic C enhanced the release of P from soil (up to 44% of total P)**
- **Does Fe in eroded soil have an effect?**
  - **Agricultural rivers: 6.1–6.5% Fe in total suspended solids**
  - **Can eroded soil maintain Fe reduction and inhibit SO_4 reduction?**

Ekholm P, Lehtoranta J. 2012. Does control of soil erosion inhibit aquatic eutrophication? Journal of Environmental Management 93:140–146.
Lehtoranta J, Ekholm P, Wahlström S, Tallberg P, Uusitalo R. 2015. Organic carbon regulates phosphorus release from eroded soil transported into anaerobic coastal systems. AMBIO 44:263–273.

Optimal P abatement accounting for coupled element cycles



"Optimal management puts more weight on mitigating DRP than PP, especially in eutrophic SO_4 containing water bodies."

Iho A, Ahlvik L, Ekholm P, Lehtoranta J, Kortelainen P. 2017. Optimal P abatement redefined: Insights from coupled element cycles. Ecological Economics 137:13–19.

”Massive emissions from Russian fertilizer plant”

Venäläiseltä lannoitetehtaalta jättipäästöt Suomenlahteen

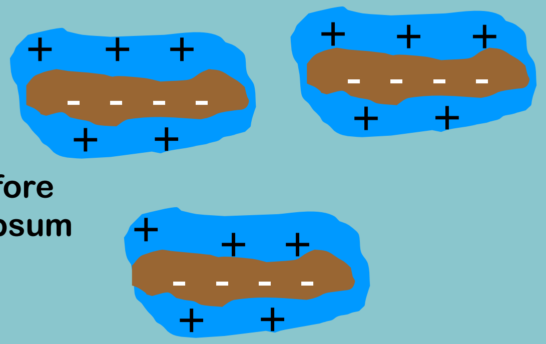
KOTIMAA 18.1.2012 5:00 Päivitetty 18.1.2012 15:04

Heli Saavalainen HELSINGIN SANOMAT

SEPPO KNUUTTILA

Helsingin Sanomat 18.1.2012

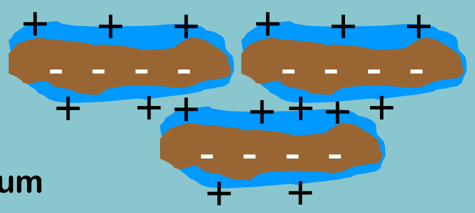
Gypsum ($CaSO_4 \cdot 2H_2O$) reduces particulate and dissolved P from clayey soil



Before gypsum

The TraP project*

- 100 hectares of clayey soil amended with phosphogypsum
- 60% reduction in particulate P and 30% in dissolved P
- Effect lasted about 4 years
- The most cost-effective P abatement measure
- No negative effects on yield



After gypsum

After dissolution the ionic strength of soil solution increases

- Electrical double layer is suppressed
- Particles can come closer, form larger aggregates and become less sensitive to erosion
- Desorption tendency of P also reduced

The SAVE project

- 1550 hectares amended with gypsum in 2016

SAVE

Photos: Janne Artell

*Ekholm P, Valkama P, Jaakkola E, Kiirikki M, Lahti K, Pietola L. 2012. Gypsum amendment of soils reduces phosphorus losses in an agricultural catchment. Agricultural and Food Science 21:279–291.

Conclusions

- Temporally and spatially varying physical conditions affect the state of the Baltic Sea
  - Major salt water inflows will not rescue the sea
- The sea appears to respond to nutrient load reductions
  - Internal processes slow down the recovery
- N and P load should be further reduced
  - Measures in agriculture required
    - Lack of knowledge on eutrophying nutrients
    - Traditional measures slow or controversial
    - Novel methods?
- Sea-based measures?

Signs of recovery?

Benthic algae off the city of Helsinki

Untypically clear water in the eastern Gulf of Finland

Photos: Seppo Knuuttila