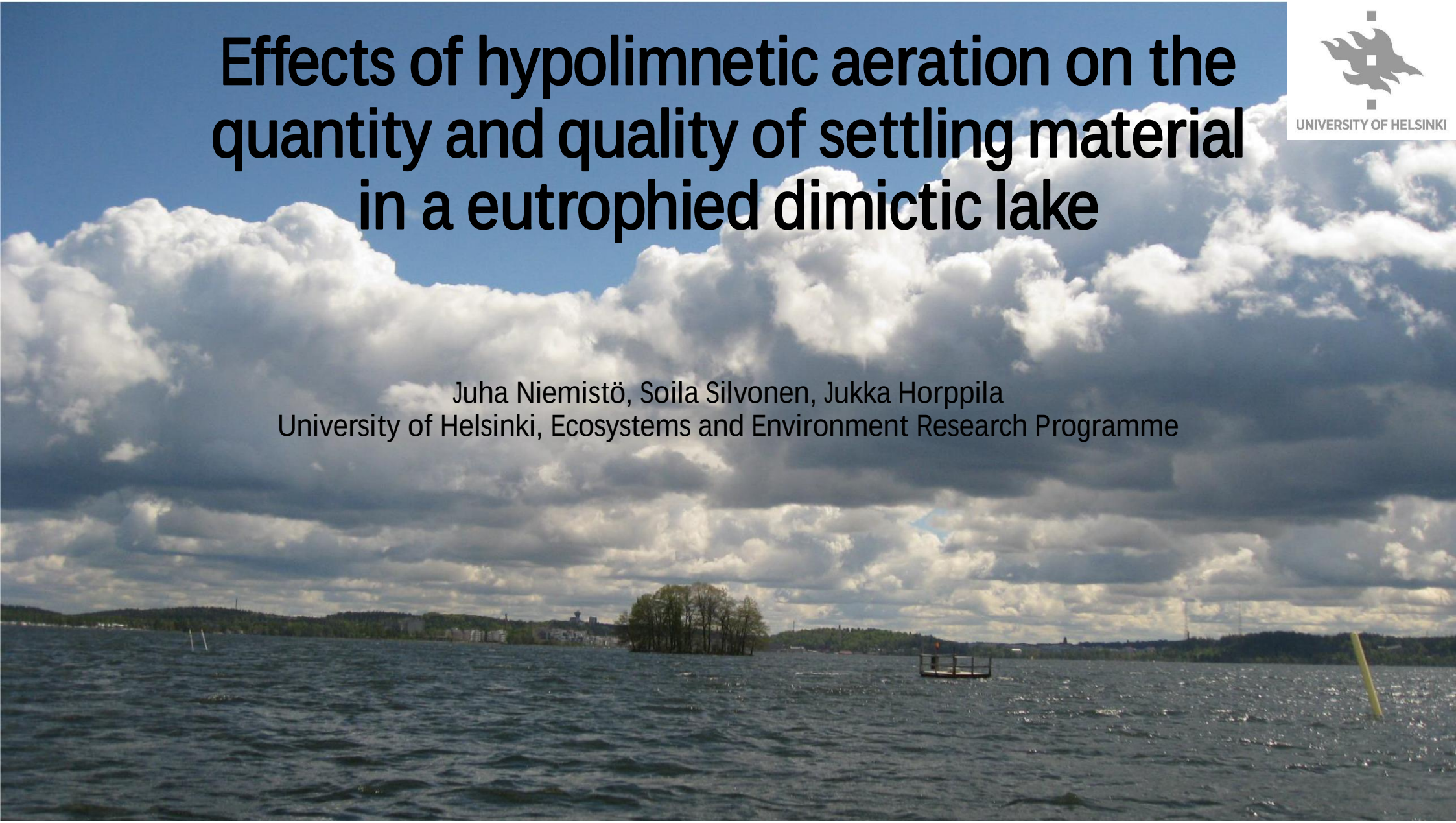
Effects of hypolimnetic aeration on the quantity and quality of settling material in a eutrophied dimictic lake



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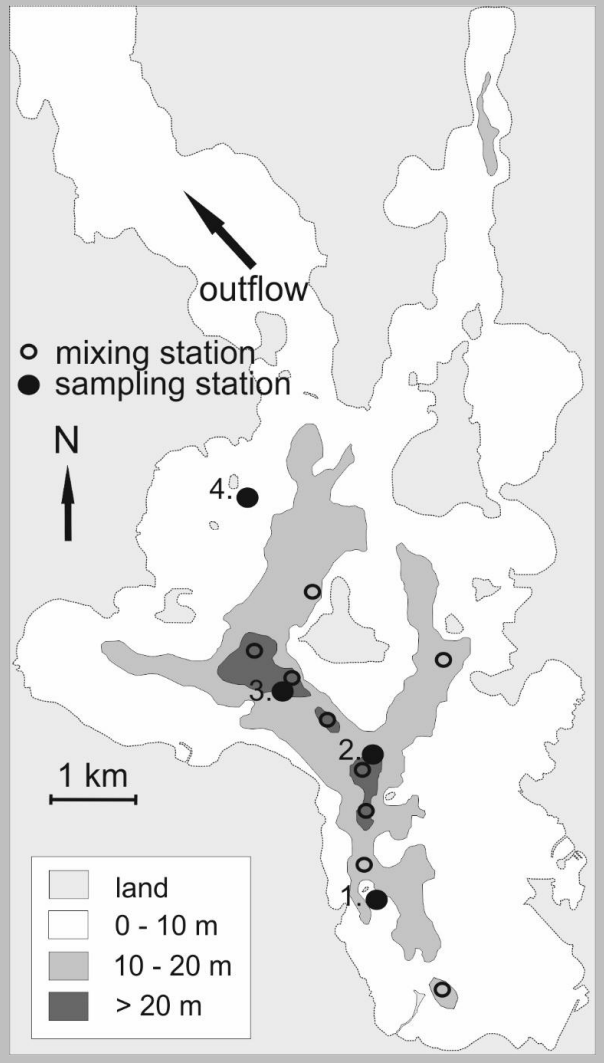
Introduction

Lake Vesijärvi, Enonselkä basin:

- Anthropogenic eutrophication, sewege effluents of City of Lahti until 1970s
- Successful biomanipulation and diffuse load reductions in the late 1980s and early 1990s (Keto and Sammalkorpi, 1988)
- Water quality degraded again in early 2000s, oxygen depletion in the deeps of the lake (Keto et al., 2005)
- Oxygen rich epilimnetic water pumped to hypolimnion (Mixox aerators, MC-1100)
  - Prevent hypolimnetic O_2-depletion
  - Enhance the O_2-conditions for benthic and pelagic fauna in the deep habitats
  - Decrease redox-dependent P-loading from the lake deeps
- Restoration implemented in winter 2010:
  - Aeration during winter and summer stratification in 2010-2017

Material and Methods

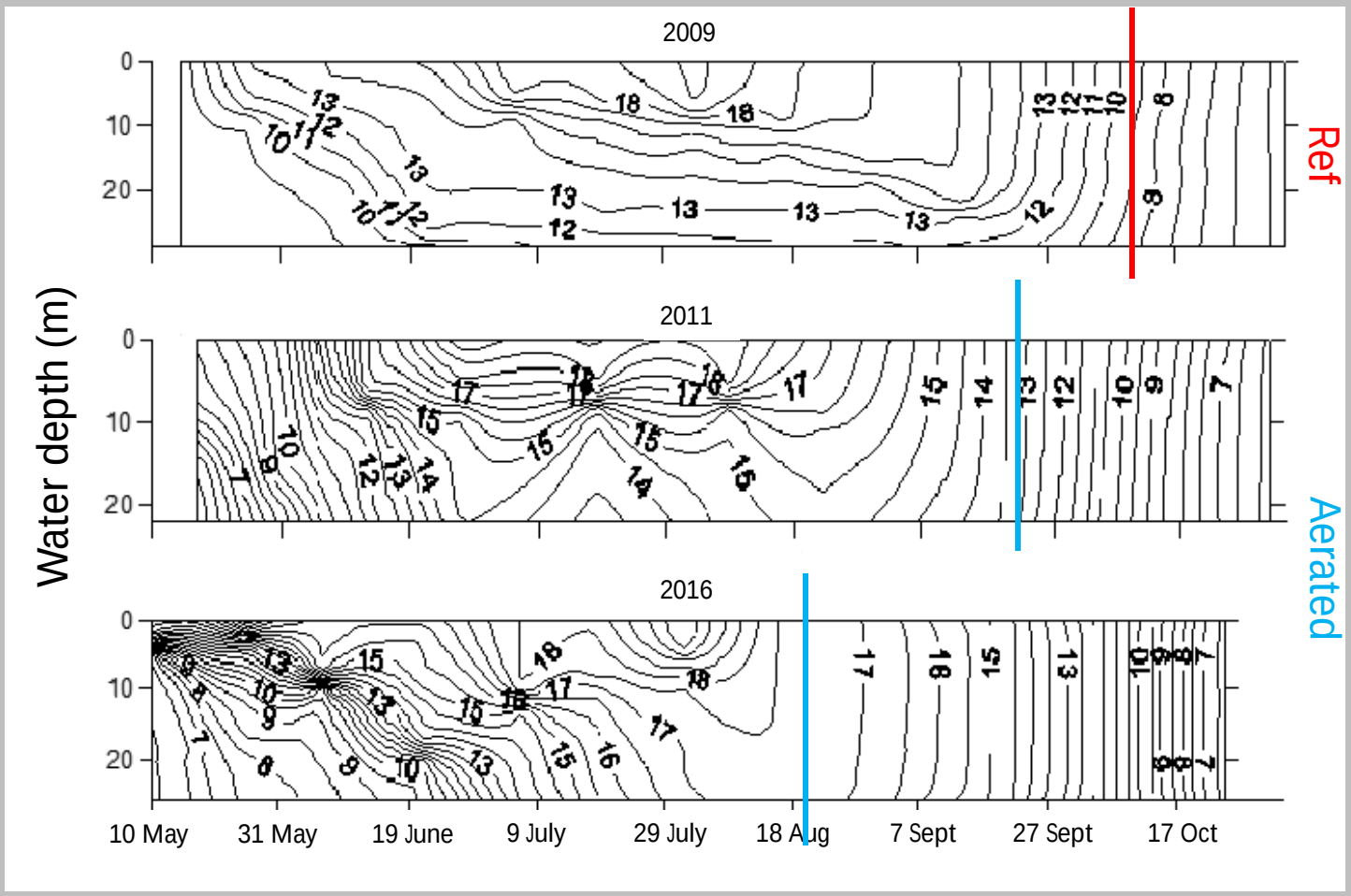


Aim of aeration: decrease the amount of organic material in the sediment à decrease benthic oxygen consumption

Quantity and quality of settling material?

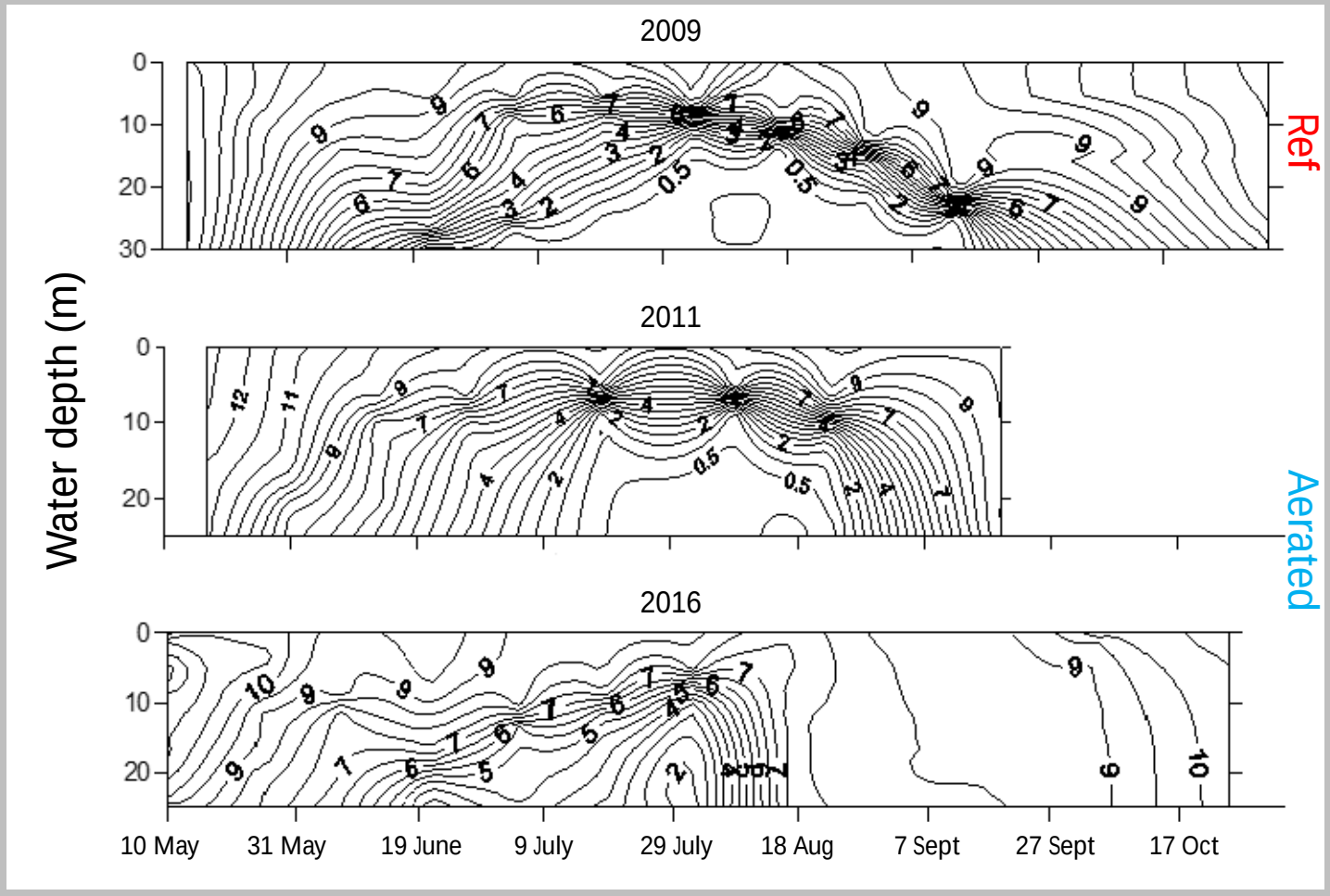
- Spatially comprehensive sedimentation measurements in 2009, 2011 and 2016 during the open water season
- 4 stations
  - Shallow areas: depth < 10 m (83 %), nonstratif.
  - Deep areas: depth 10-30 m (17 %), stratifying
- Sediment traps 2 m above the, emptied with 14-21 days interval (Bloesch and Burns, 1980)
- Determinations for the entrapped material and surface sediment: dry matter (GS), organic content as LOI (SPOM), C and N content
- Temperature profiles (YSI 6600 V2 sonde)

Results



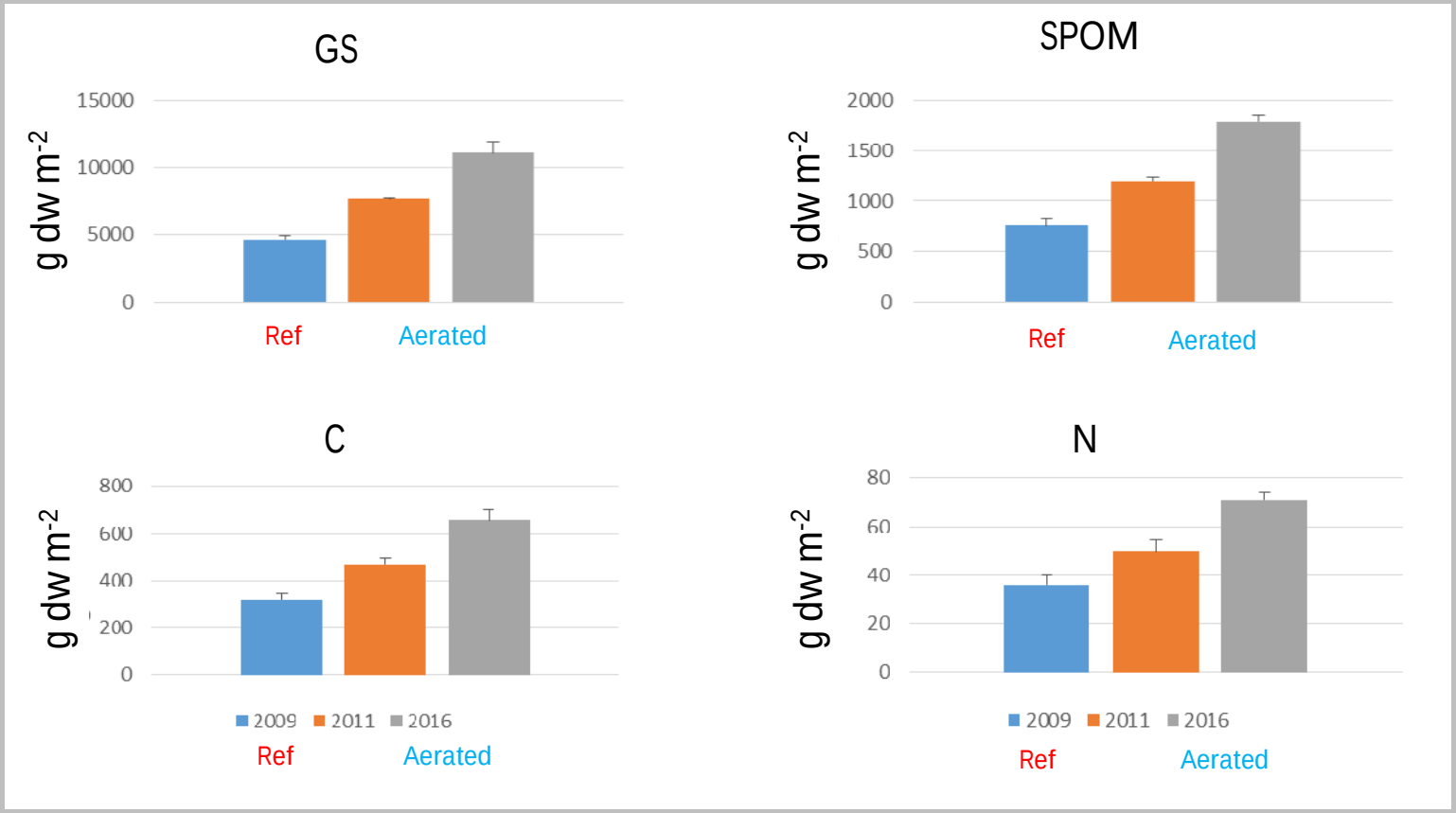
- Aeration resulted in warmer hypolimnion
- Earlier overturn in higher water temperature
- In 2016, overturn period started during the growth season

Results



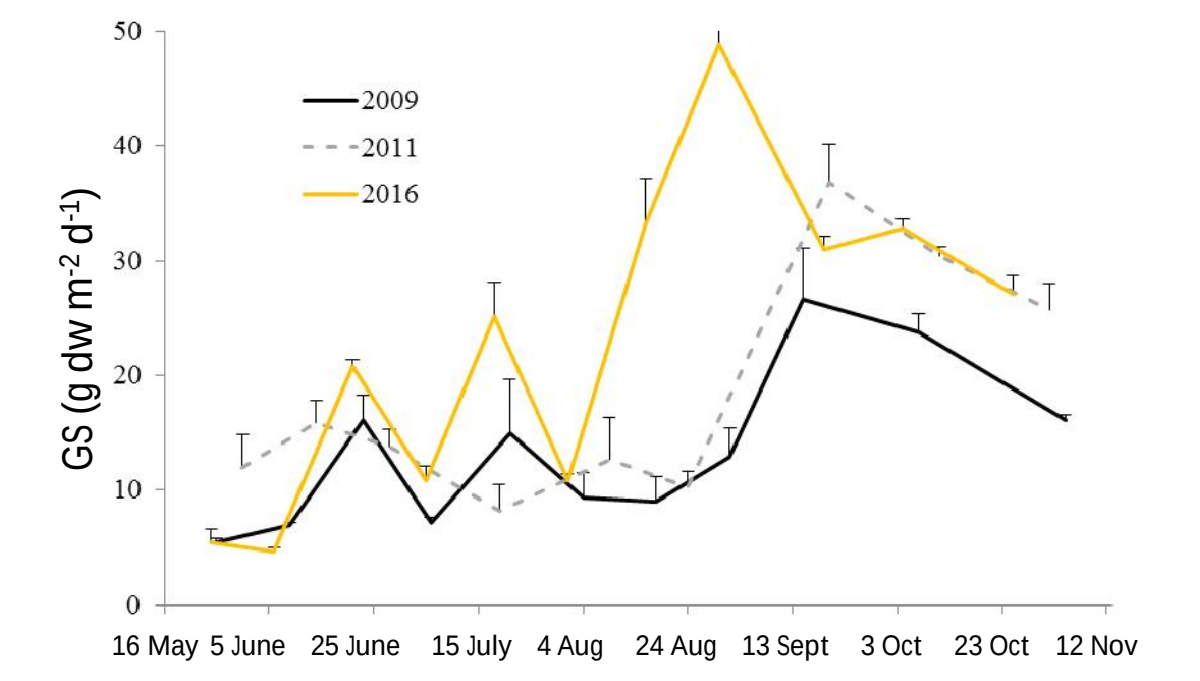
- Oxygen conditions in the hypolimnion improved
- However, oxygen deficit not avoided in warm summers
- Overturn efficiently aerated near-bottom water

Results, cumulative sedimentation rates as spatio-temporal averages



- Absolute amount of settling material as dry matter increased in aerated years
- Sedimentation rate of organic matter and thus also the amount of C and N settling onto lake bottom was significantly higher in aerated years
- Rates were highest in 2016, when overturn started earlier

Results, temporal variation of sedimentation



- Sedimentation rates peaked soon after the overturn
- Similar development for all measured parameters

Results, Deep and shallow areas separately

	Ref		Aerated				
	2009		2011		2016		
	g dw m^{-2} d^{-1}		g dw m^{-2} d^{-1}		g dw m^{-2} d^{-1}		2009 vs 2016
Deep areas	mean	SD	mean	SD	mean	SD	(%)
GS	27.8	1.9	45.9	0.6	66.7	5.5	140
SPOM	4.5	0.4	7.1	0.3	10.8	0.4	138
C	1.9	0.1	2.8	0.2	4.0	0.3	107
N	0.2	0.01	0.3	0.02	0.4	0.1	99
Shallow areas	mean	SD	mean	SD	mean	SD	2009 vs 2016 (%)
GS	11.9	4.5	14.7	3.1	14.6	0.8	23
SPOM	1.9	0.5	2.3	0.3	2.3	0.02	20
C	0.8	0.2	0.9	0.1	0.9	0.01	5
N	0.1	0.01	0.1	0.01	0.1	0.01	5

- Strongest increase in sedimentation rates in the lake deeps
- Increase in spatio-temporal averages and cumulative sedimentation rates were due to sediment focusing
- GS vs SPOM

Results, quality of surface sediment and settling material

	Ref		Aerated			
	2009		2011		2016	
Deep areas	median	range	median	range	median	range
Surf. sed., LOI (%)	14.0	13.1 – 17.9	14.8	11.5 – 15.7	13.8	12.8 – 16.5
Surf. sed., C/N	9.5	8.7 – 10.1	9.6	8.8 – 10.4	9.4	9.0 – 10.0
Trap, LOI (%)	16.2	14.6 – 24.4	15.4	13.6 – 18.7	17.3	12.6 – 26.4
Trap, C/N	9.1	7.7 – 10.5	9.6	8.8 – 12.0	9.3	7.2 – 10.1
Shallow areas						
Surf. sed., LOI (%)	11.9	10.8 – 14.3	11.9	11.0 – 15.0	12.0	10.9 – 14.6
Surf. sed., C/N	9.7	8.7 – 10.8	9.5	8.8 – 10.2	9.6	9.1 – 10.1
Trap, LOI (%)	17.6	12.4 – 42.8	15.3	13.0 – 40.4	16.2	12.4 – 27.6
Trap, C/N	8.9	8.0 – 10.3	9.3	5.9 – 12.0	9.0	7.0 - 101

Deep areas

Surface sediment:

- Organic content showed lowest values in 2016
- However, the decrease was only 0.2-1.0 %
- No change in C/N

Trap material:

- Organic content lowest and C/N highest in 2011, warm summer

Shallow areas

Surface sediment:

- No change in org. content, C/N highest in 2009

Trap material:

- Organic content lowest and C/N highest in 2011, warm summer

Discussion & Conclusions

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- Increased sedimentation rates were especially pronounced in the lake deeps indicating enhanced sediment focusing due to aeration.

- Increased sedimentation of organic material, C and N, reflected higher primary production during the aerated years

ß most likely attributed to increased temperature and turbulence and the subsequent regeneration and recycling of nutrients (Ashley 1983, Gantzer et al. 2009, Niemistö et al. 2016, Jørgensen and Revsbech, 1985)

In 2016, overturn period started in the middle of the growth season!

Discussion & Conclusions

- Increased C to N ratio and decreased organic content of the settling material in 2011 indicated enhanced degradation
- In 2016, similar development, however, statistically non-significant changes in the quality of the settling material, BUT the sedimentation rates were highest
- Warm summer vs. cooler summer, timing of the destratification critical

- FINAL CONCLUSIONS:

à Nutrient recycling enhanced

à Increased amount of organic material reaching the lake bottom contradicted the ultimate aim of the restoration measure

Thank you!

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