Post-nitrate bloom elemental cycling in spring in the central Baltic Sea

Evidence from high resolution nutrient data

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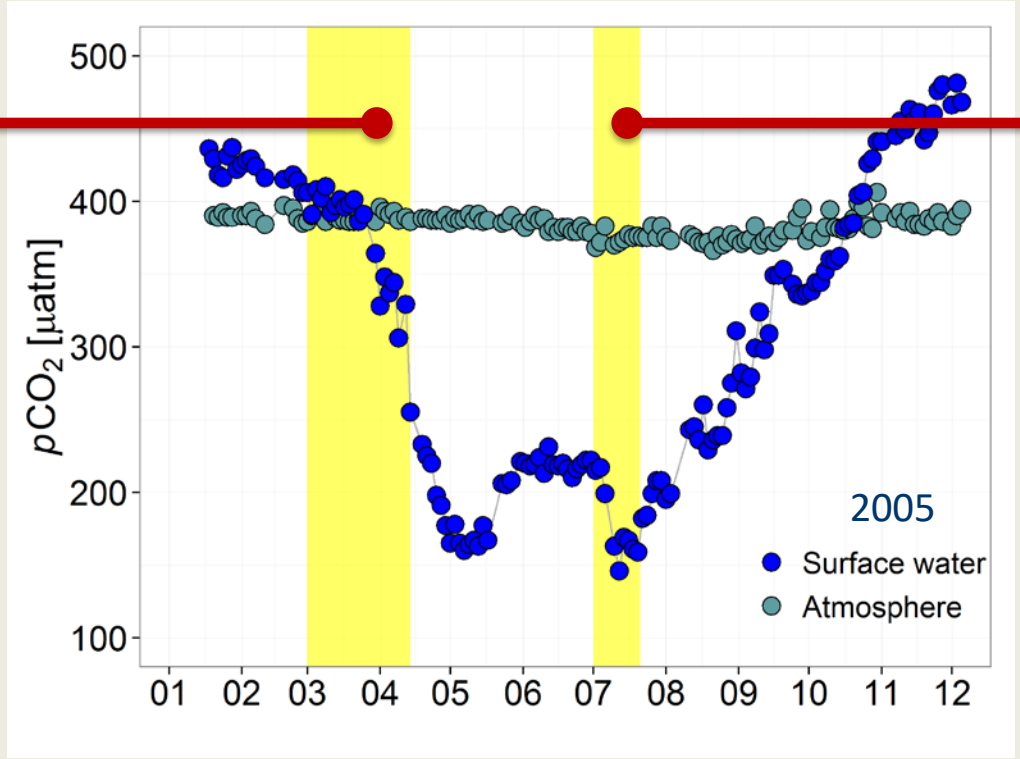
Seasonal net community production - a look through "CO_2 glasses" -

nitrate-fueled spring bloom (March/April)



mid-summer cyanobacteria bloom (June/July)

High resolution pCO_2 data since 2003 from a fully automated system on a cargo ship (FINNMAID)

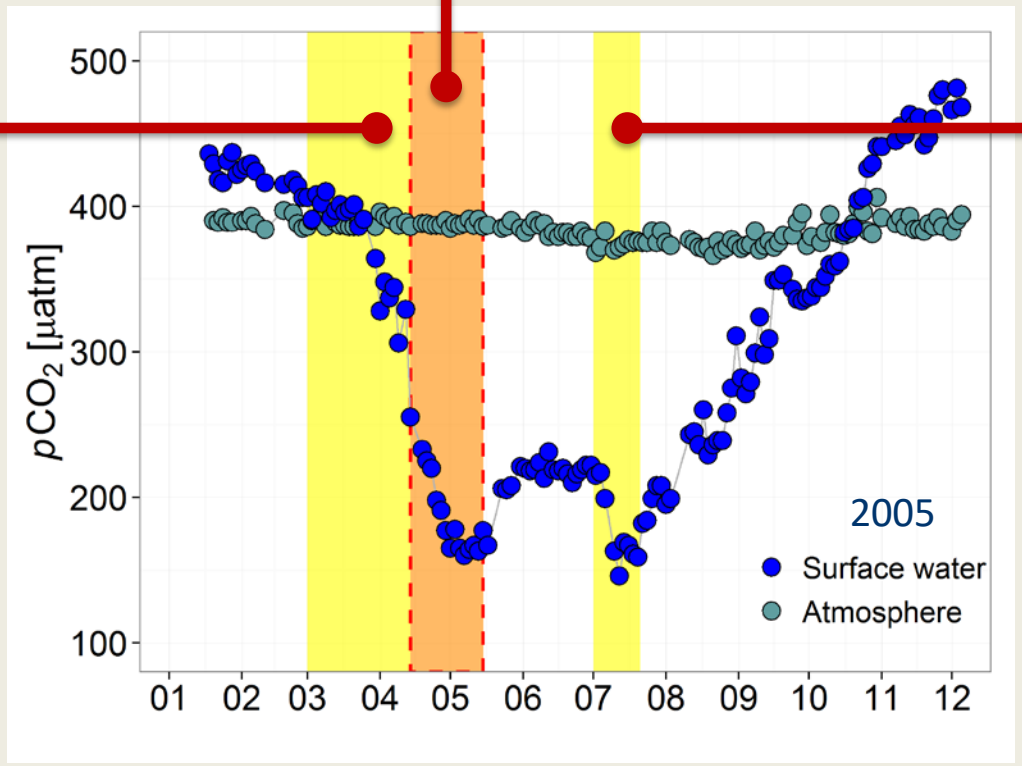
Phytoplankton blooms in spring and mid-summer

Seasonal net community production - a look through "CO_2 glasses" -

post-nitrate bloom

nitrate-fueled spring bloom (March/April)

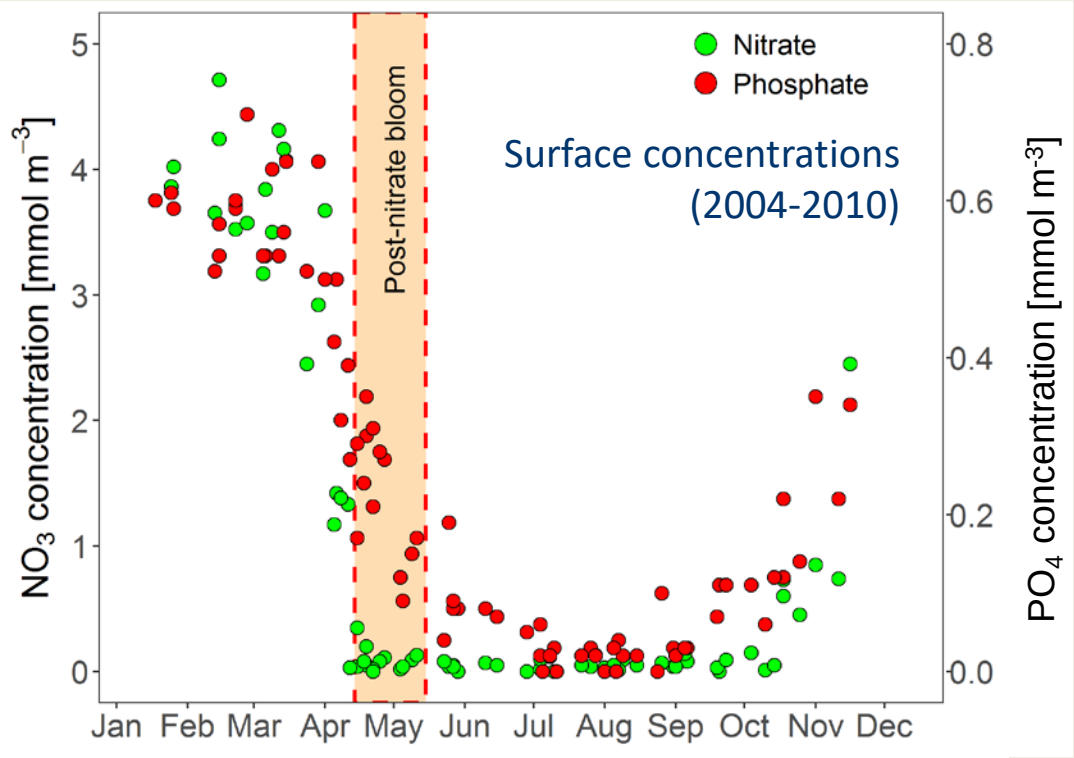
mid-summer cyanobacteria bloom (June/July)



High resolution pCO_2 data since 2003 from a fully automated system on a cargo ship (FINNMAID)

Continuation of the net community production in late April/May !

Seasonal net community production - dissolved nutrients -



Compiled nutrient data from Finnish Environment Institute (SYKE), Alg@line project.

Continuation of the net community production at zero nitrate

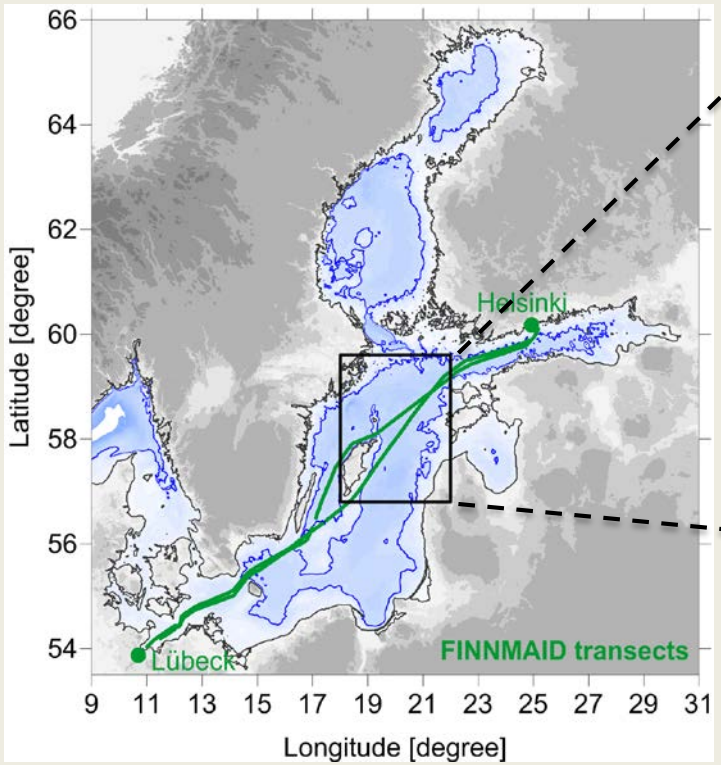
Which processes control the observed pCO_2 signal during the post-nitrate bloom?

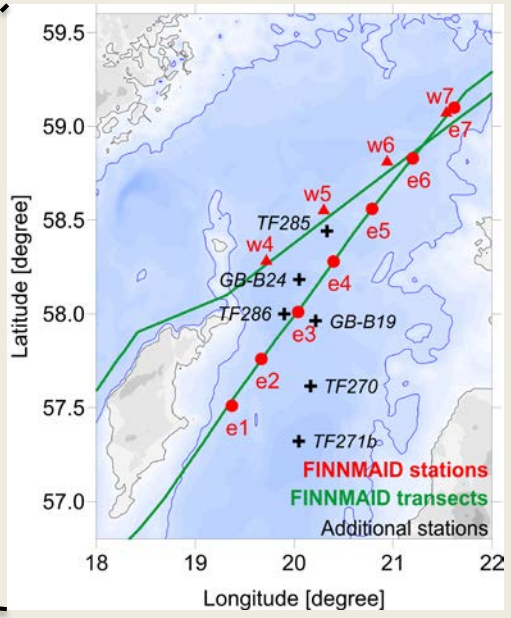
- Net community production based on a nitrogen source of unknown origin (Eggert & Schneider 2015)
- Autotrophic production by the mixotrophic ciliate *Mesodinium rubrum*, which shows marked vertical migration and exploits nitrate pools below the halocline (Lips & Lips, 2017)
- Variable, non-Redfieldish elemental stoichiometry of phytoplankton (Kreus et al. 2014)
  - luxury nitrogen uptake during nitrate bloom
  - surplus carbon fixation during post-nitrate bloom

Study high-resolution surface water pCO_2 and nutrient data

Daily surface water pCO_2 and nutrient data 12-April until 15-May 2015

12 April is NOT start of the nitrate bloom!

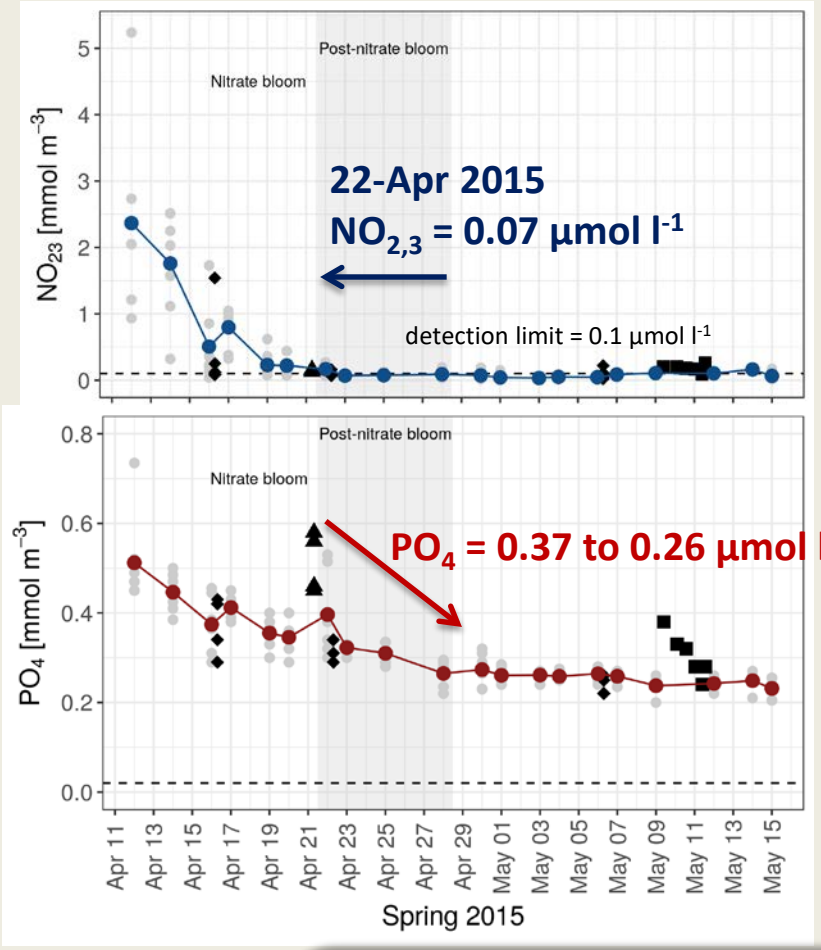


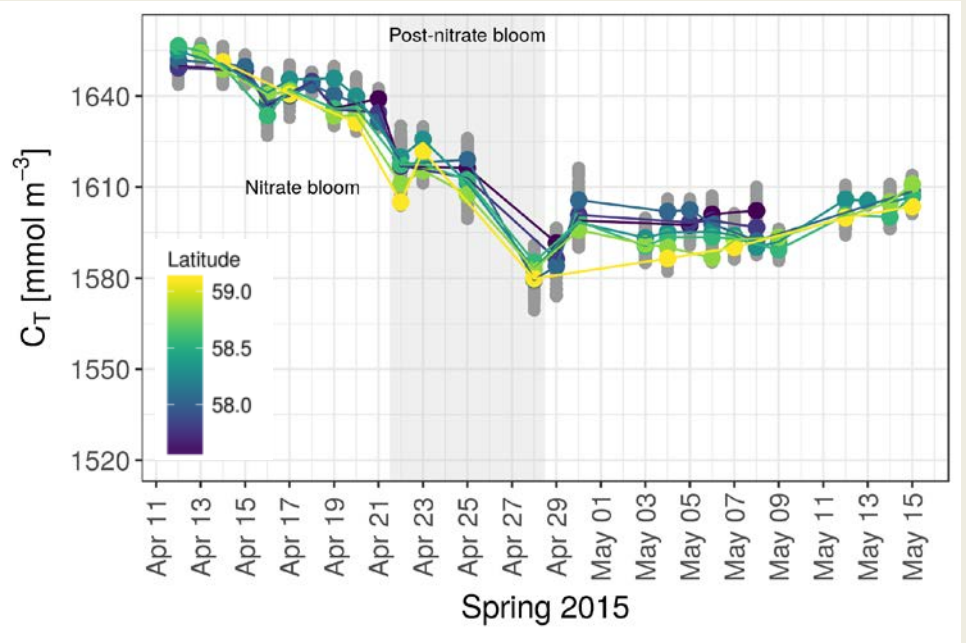


Flow through system: pCO_2

Discrete water samples:
TP, TN / POP, PON / NO_{2+3} , PO_4

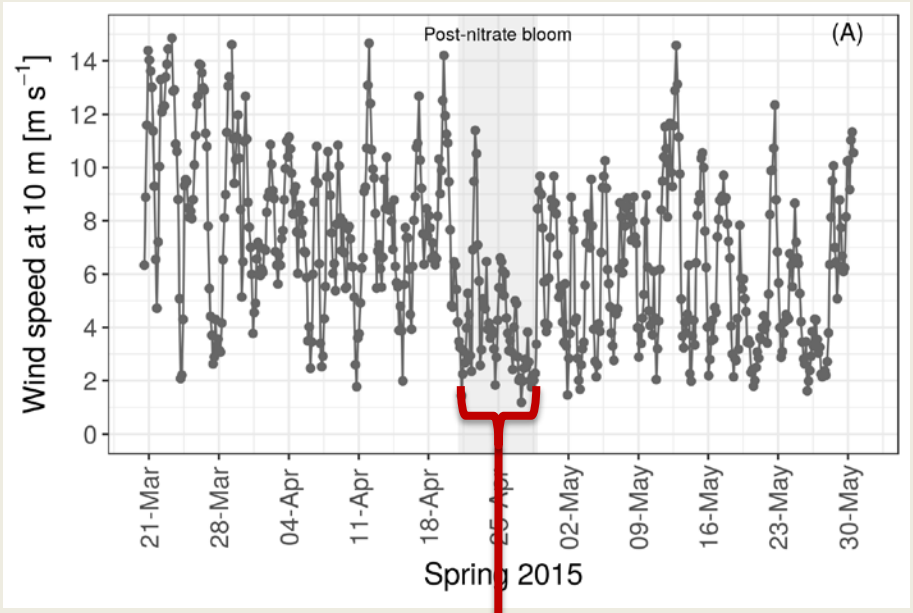
Defining the post-nitrate bloom period 2015



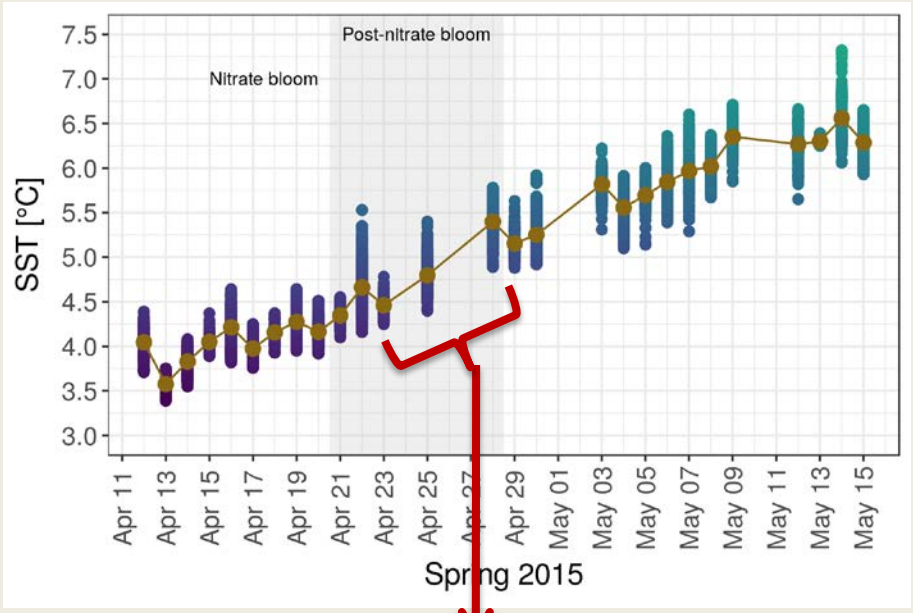


Poorly developed post-nitrate bloom: 22-28 April 2015

Late spring 2015 was cold and windy



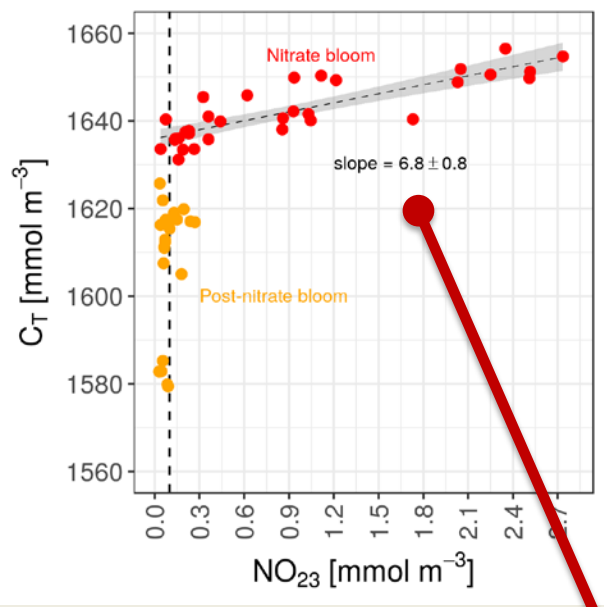
Short calm period

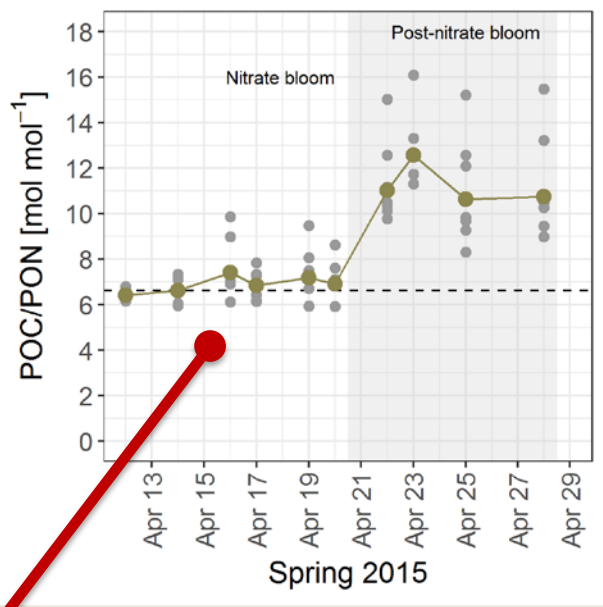


Heating of surface water

Heating of the surface water and wind determine the degree of the post-nitrate bloom

Non-Redfieldish elemental composition of particulate organic matter?

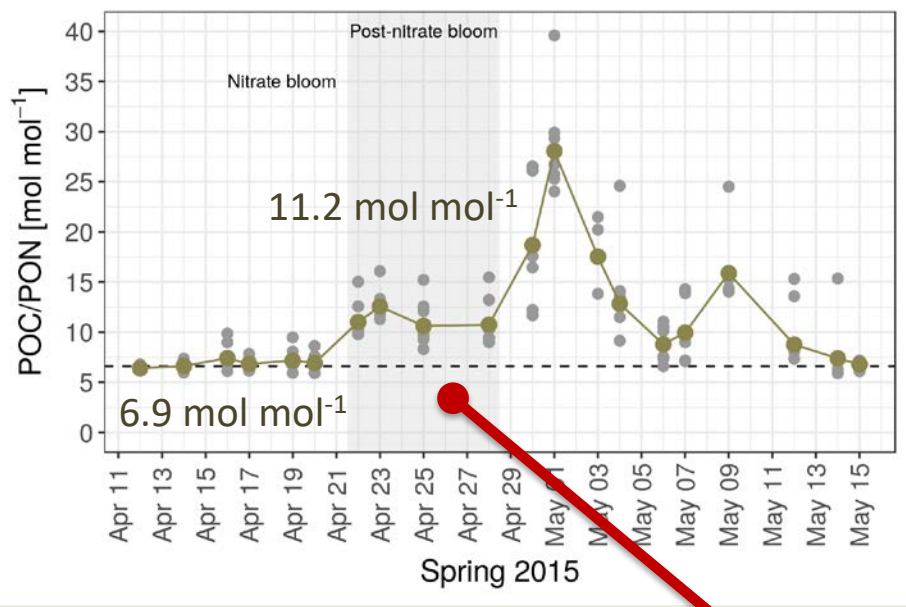


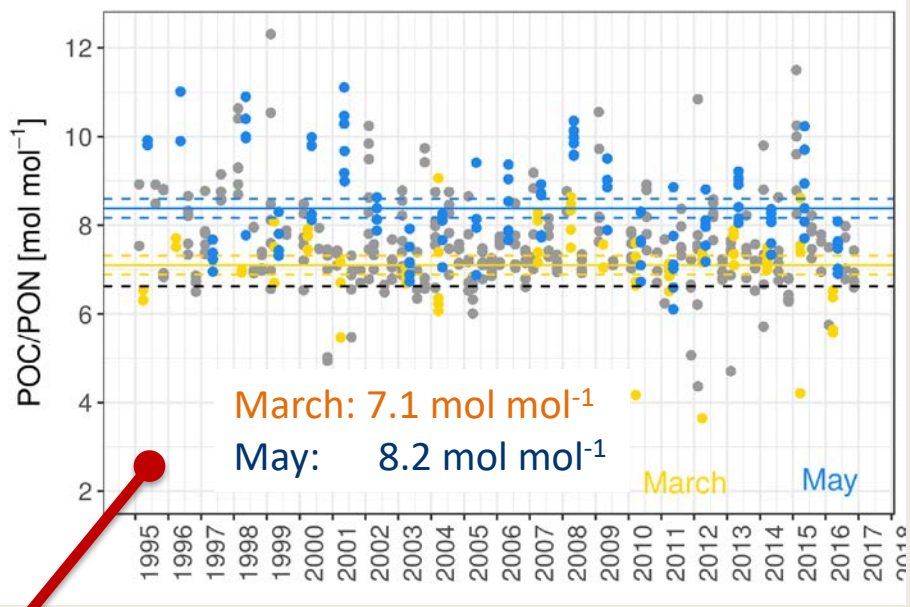


Build-up of organic matter during the nitrate bloom
very close to the Redfield C/N ratio of 106/16

No preferential N-uptake during nitrate bloom, but..

Non-Redfieldish elemental composition of particulate organic matter?



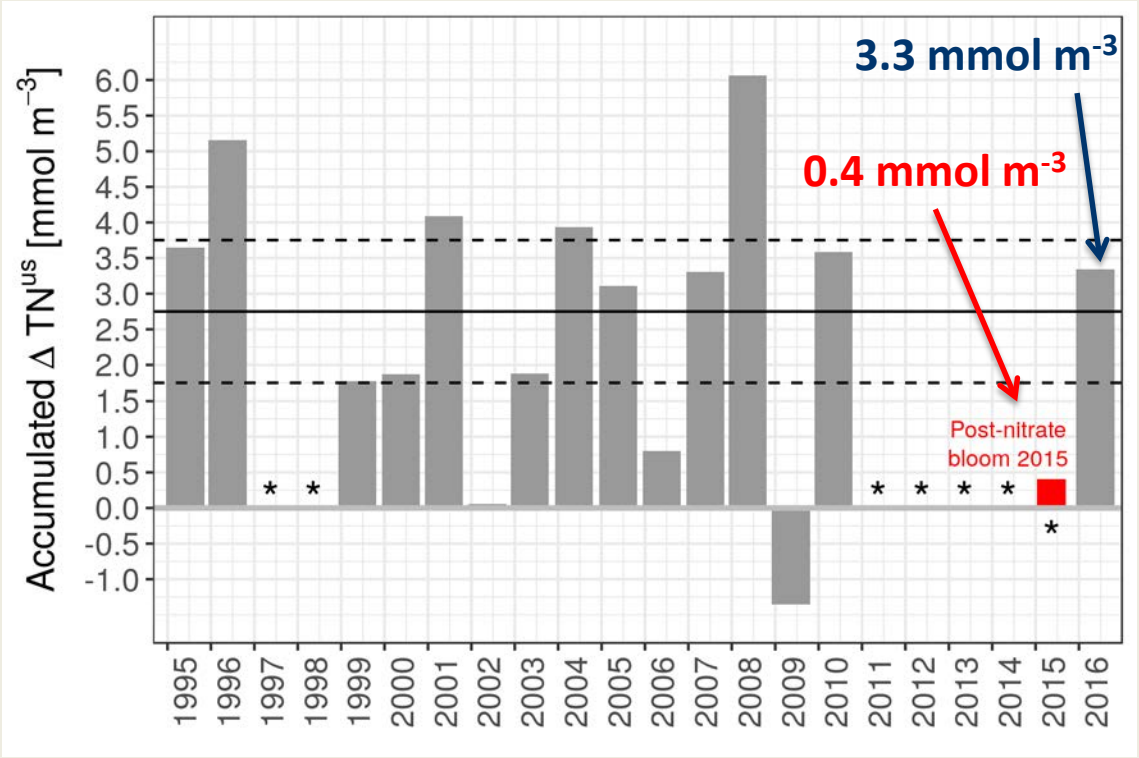


Sudden increase in POC/PON during post-nitrate bloom & higher POC/PON values in May vs. March (long-term observations of the IOW monitoring program)

... production of C-richer organic matter during post-nitrate period

Calculation of the unknown nitrogen source

Accumulated ΔTN^{us} in the surface water (0–15 m) in **May**, based on monthly SMHI monitoring data at BY15. Figure extended from Eggert & Schneider (2015).



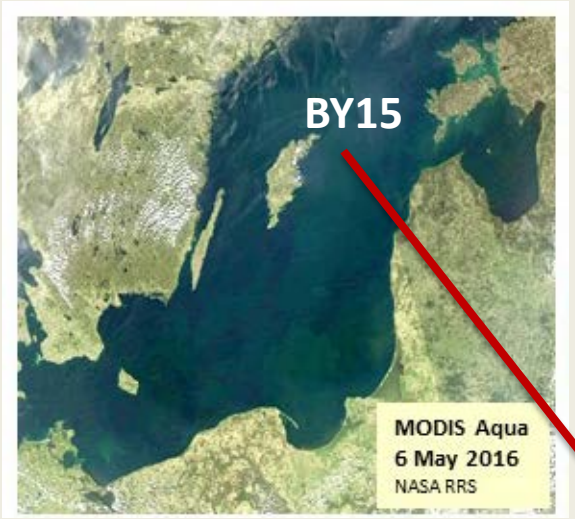
Long term mean = 2.7 mmol m^{-3}

* No data for 1997, 1998, 2011- 2015

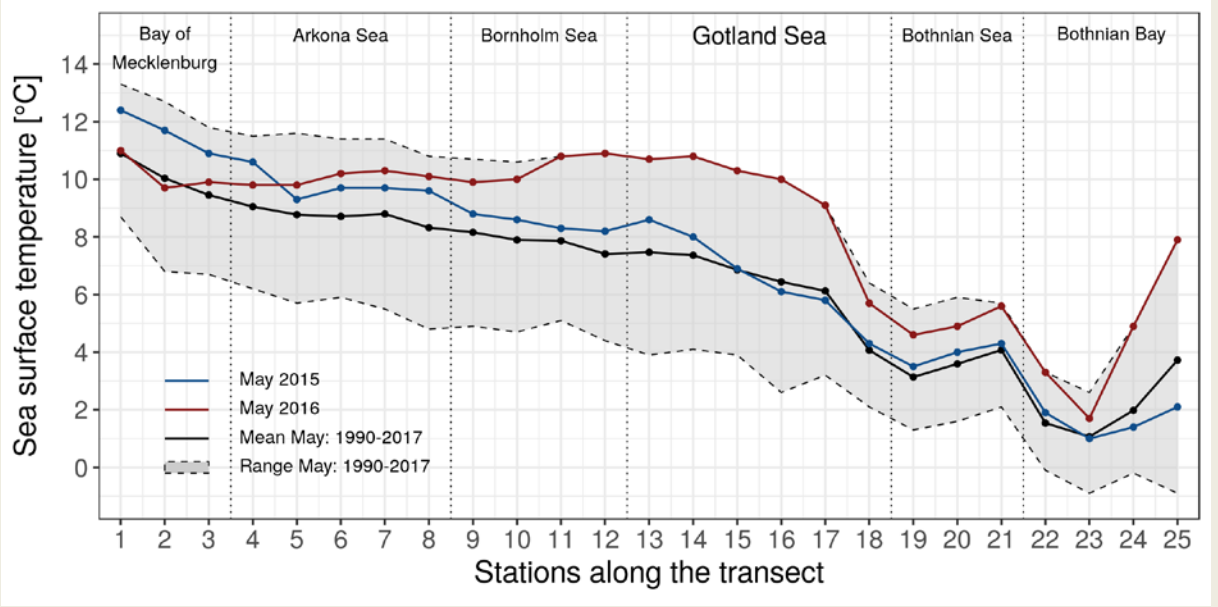
No nitrogen source in spring 2015, but above-average in 2016

A significant nitrogen source in early May 2016

2016: ΔTN^{us} = 3.3 mmol m^{-3}



MODIS Aqua satellite
6-May 2016
Cyanobacteria abundance in the entire Baltic Proper



SST derived from AVHRR and European MetOp satellites (provided by BSH).

- ***Aphanizomenon*** **biomass on 14-May 2016: 37.5 mg m^{-3}**
- **nitrogen fixation estimate = 0.3 mmol m^{-2} day^{-1}**
- **'needed' N-source = 5 mmol m^{-2} day^{-1}**

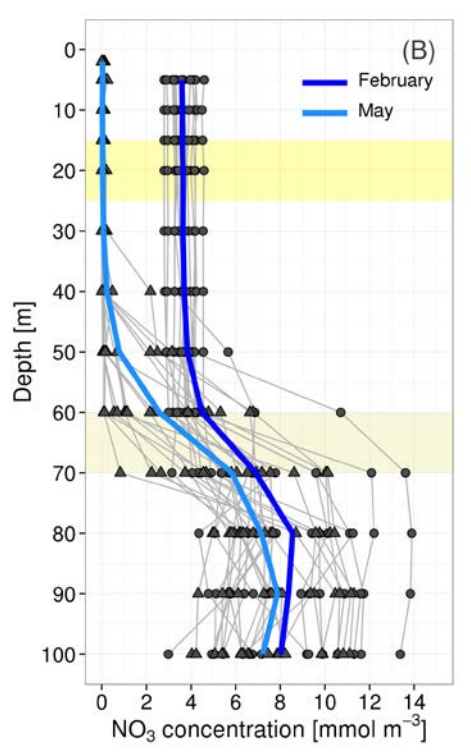
Cyanobacteria developed very early in the warm May 2016

Which processes control the observed pCO_2 signal during the post-nitrate bloom?

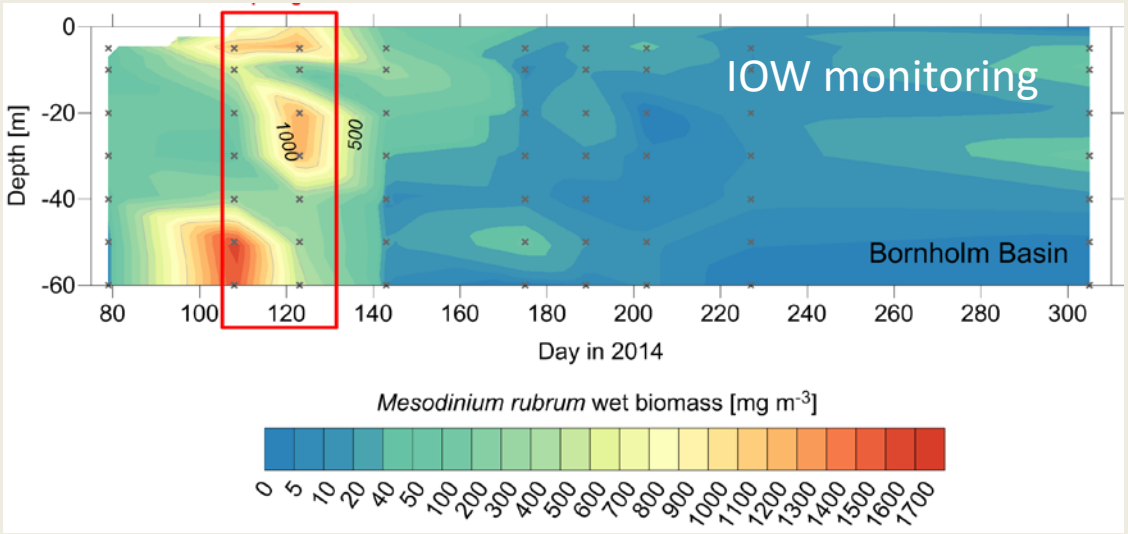
- Variable, non-Redfieldish nutrient stoichiometry of phytoplankton
  - No luxury nitrogen uptake during nitrate bloom
  - Surplus carbon fixation during post-nitrate bloom
- No significant nitrogen source in 2015 (cold windy), but in 2016 (warm and calm)
- Even in 2016, early cyanobacteria only explain 1/10 of nitrogen source

- Autotrophic production by the mixotrophic ciliate *Mesodinium rubrum*, which shows marked vertical migration and exploits DIN pools below the halocline (Lips & Lips, 2017)

Nitrate shuttle through vertically migrating plankton?



Long-term monitoring at IOW: 1995-2014



- ***M. rubrum*** **dominates autotrophic plankton in early May**
- **Highest proportion of 83% in 2011 and 86% in 2014**
- **High biomass of >1500 mg m^{-3} (110 µg C l^{-1}), down to 60 m**

High *M. rubrum* biomass – but no mechanistic proof

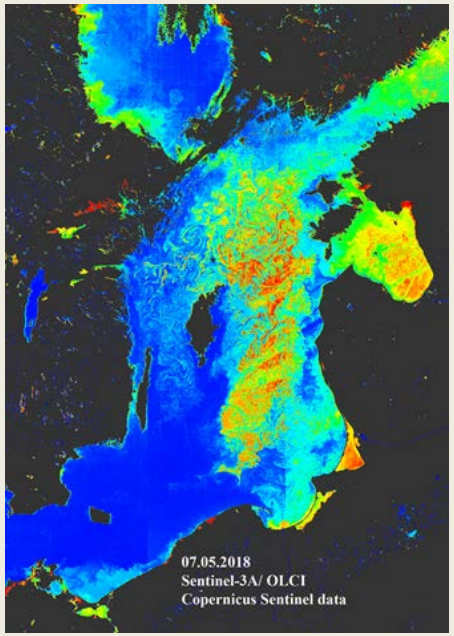
The post-nitrate productivity phase remains interesting!

True colour image

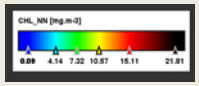
NASA-GSFC

May 9, 2018

Terra
MODIS



Chlorophyll [mg m^{-3}]



ESA-COPERNICUS

May 7, 2018

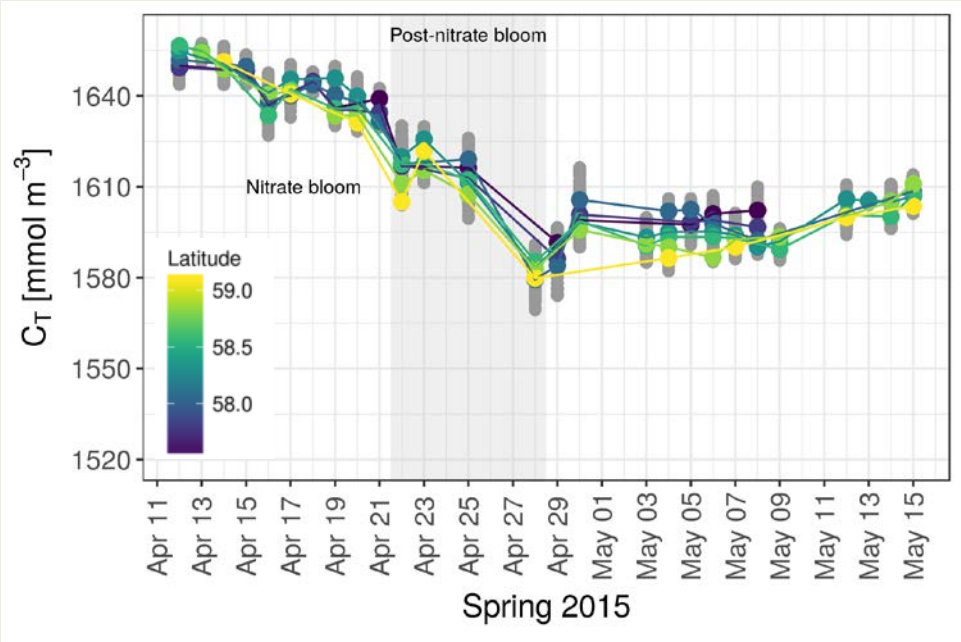
Sentinel-3A
Ocean and Land
Colour Instrument

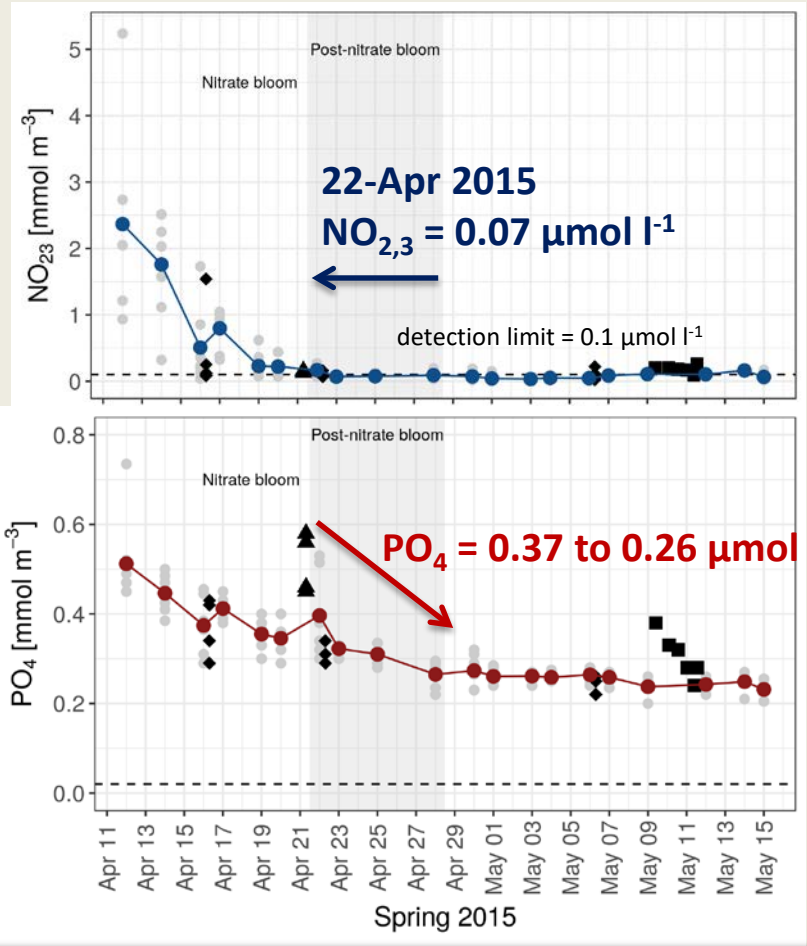
Defining the post-nitrate bloom period 2015

12 April is NOT start of the nitrate bloom!

winter NO_{23}-value: ~3.2 µmol l^{-1}

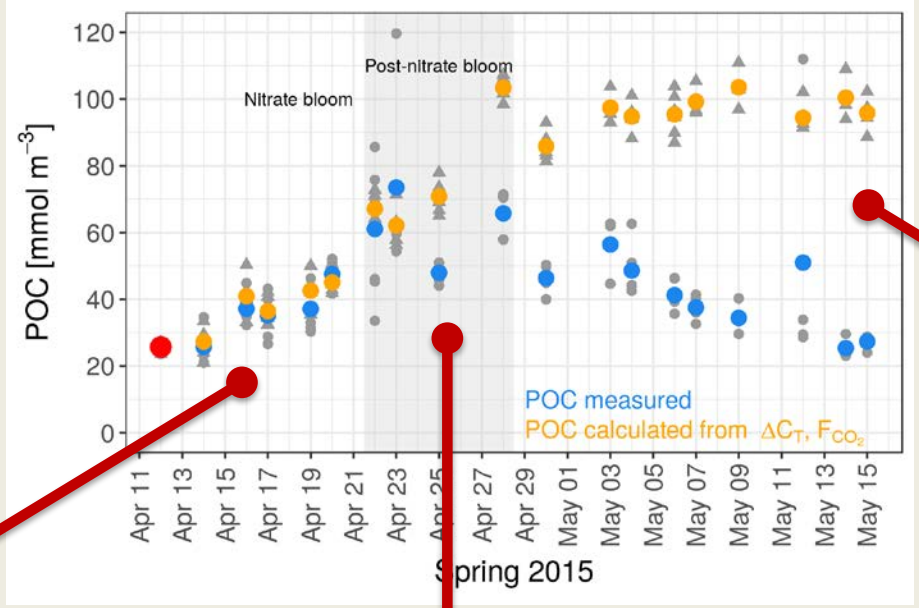
winter PO_4-value: ~0.62 µmol l^{-1}





Poorly developed post-nitrate bloom: 22-28 April 2015

Export of particulate organic carbon



last 10 days of nitrate bloom:
measured = calculated POC
➢ **insignificant POC export**

post-nitrate bloom:
only calculated POC
further increased
➢ **POC export starts**

after post-nitrate bloom:
➢ POC export continued to increase

Increasing POC export after terminated nitrate bloom

Mesodinium rubrum can dominate autotrophic plankton community in early May