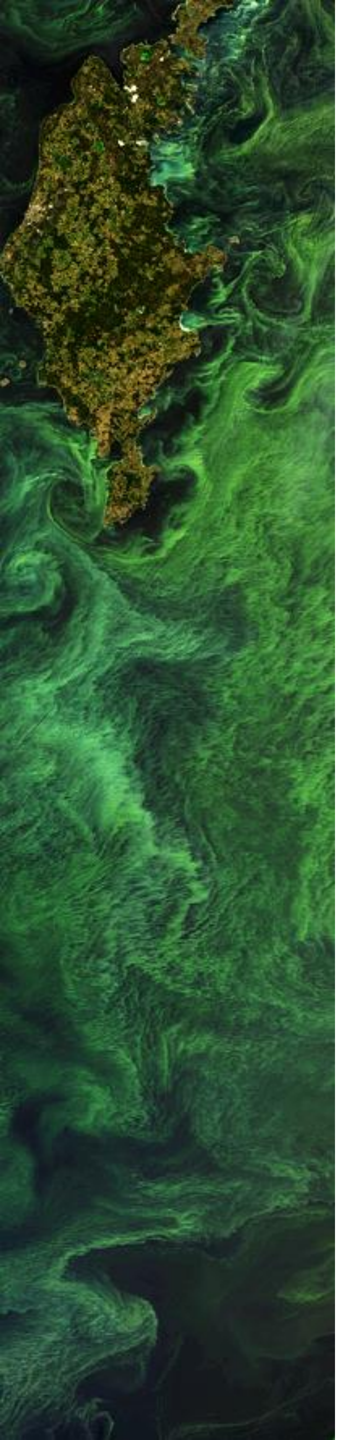
Getting rid of hypoxia in the Baltic Sea

Daniel Conley, Jacob Carstensen,
Bo Gustafsson, Caroline Slomp

Lund University, Aarhus University, Stockholm University, Utrecht University

Email: daniel.conley@geol.lu.se
Twitter: @DanielJConley

Supported by: FORMAS Multistressors, BONUS (HYPER, COCOA), BalticSea2020, Pew Marine Conservation Fellowship



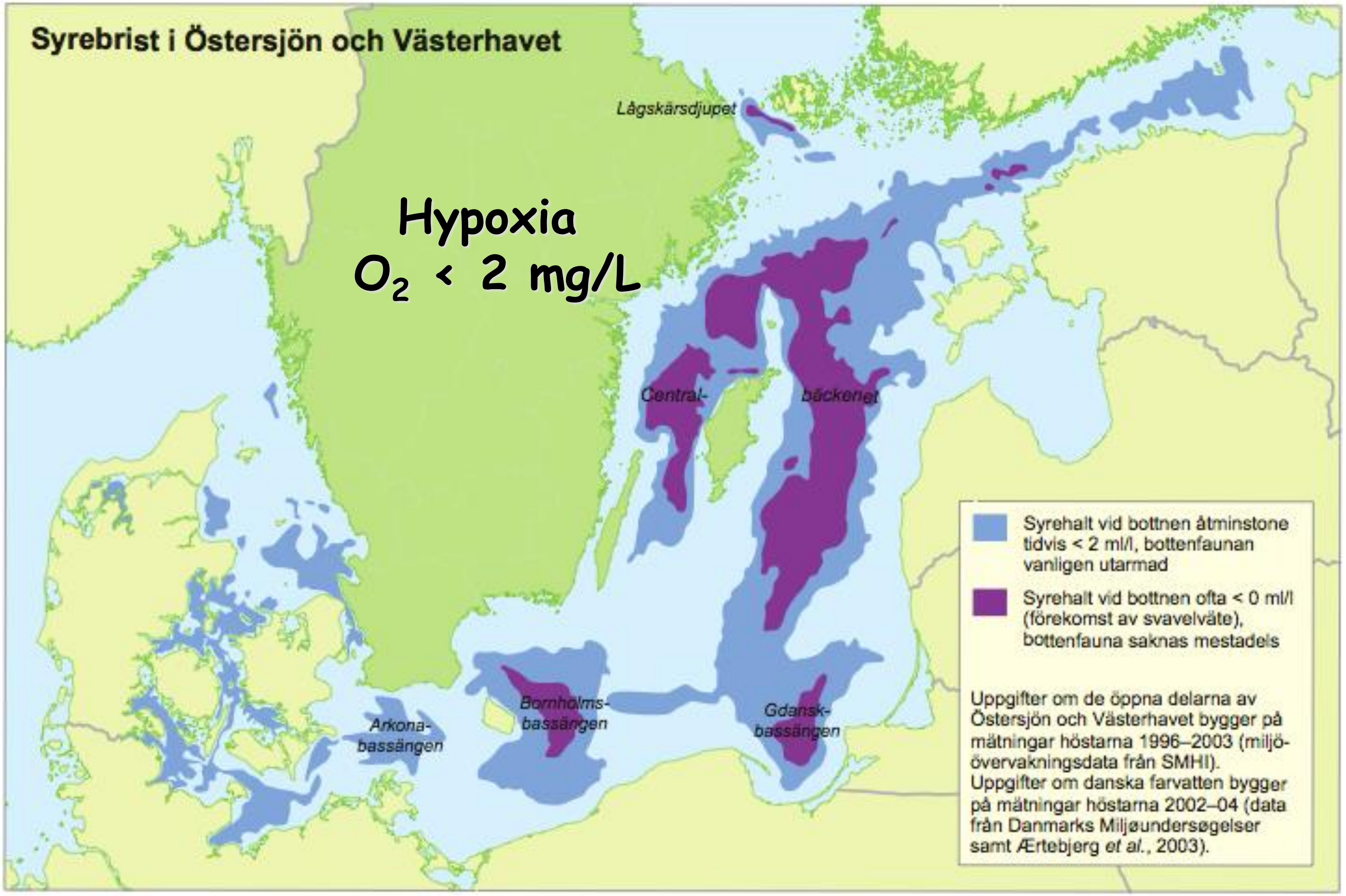
Introduction

Hypoxia: Why, where and when

Consequences of hypoxia in the Baltic

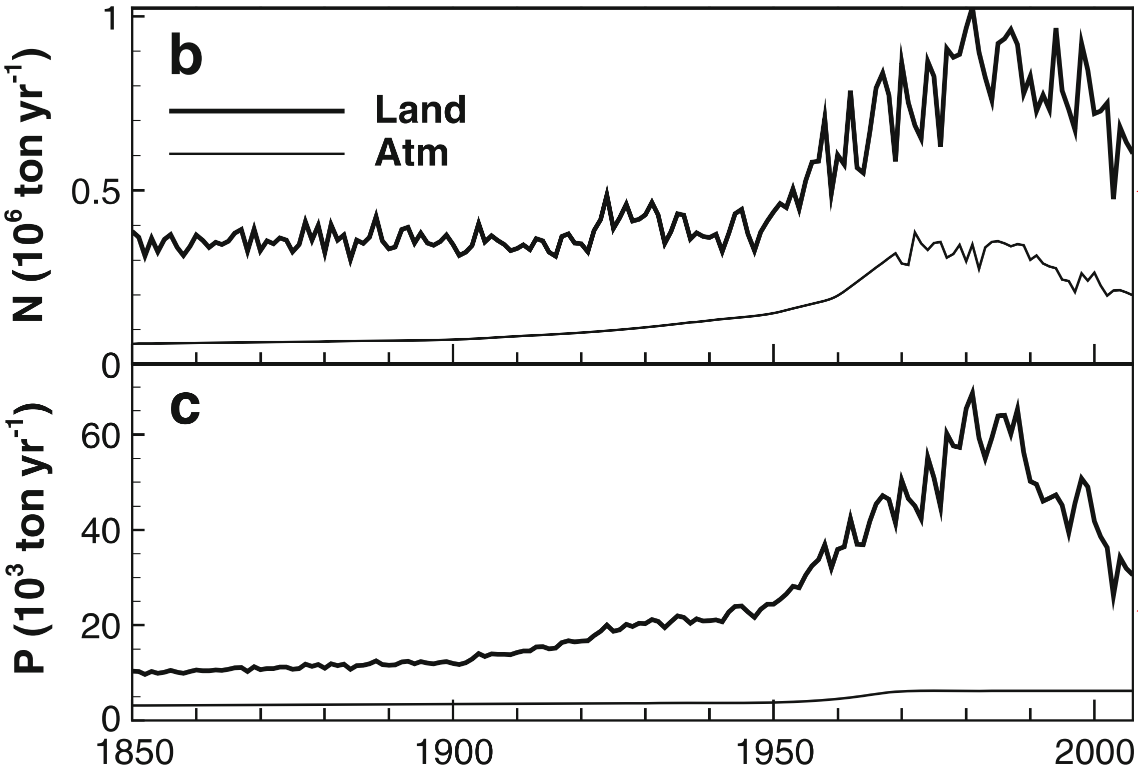
Perspectives for the future

Area with hypoxia averages ca. 49,000 km^2



Från *Förändringar under ytan* (Monitor 19).

Larger than the size of Denmark (43,000 km^2)



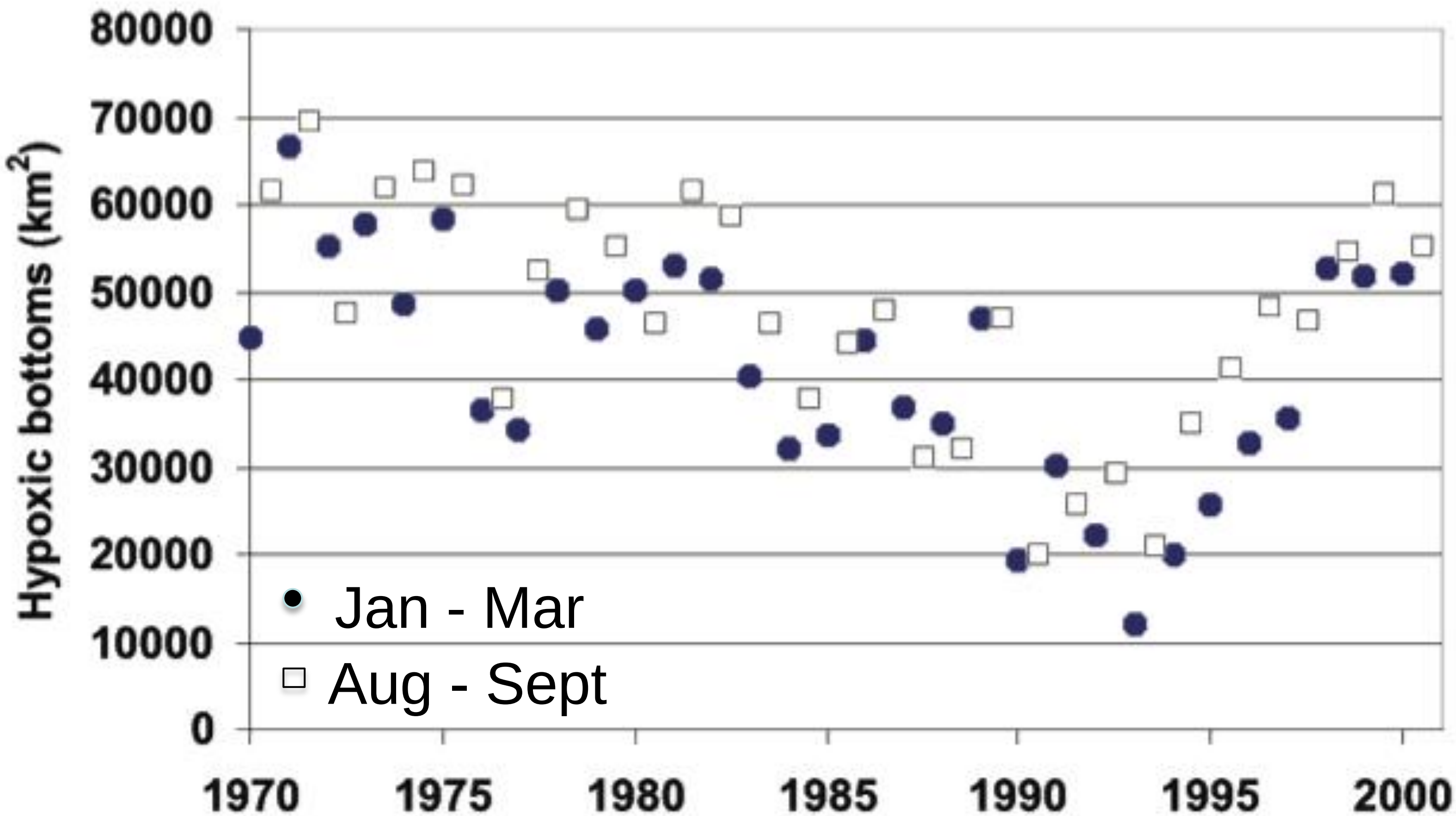
Target for the Baltic Sea Action Plan

Target for the Baltic Sea Action Plan

Fig. 2 Time series of annual average total river runoff (Q), nitrogen (N), and phosphorus (P) loads from land and atmosphere to the whole Baltic Sea

Gustafsson et al. 2012

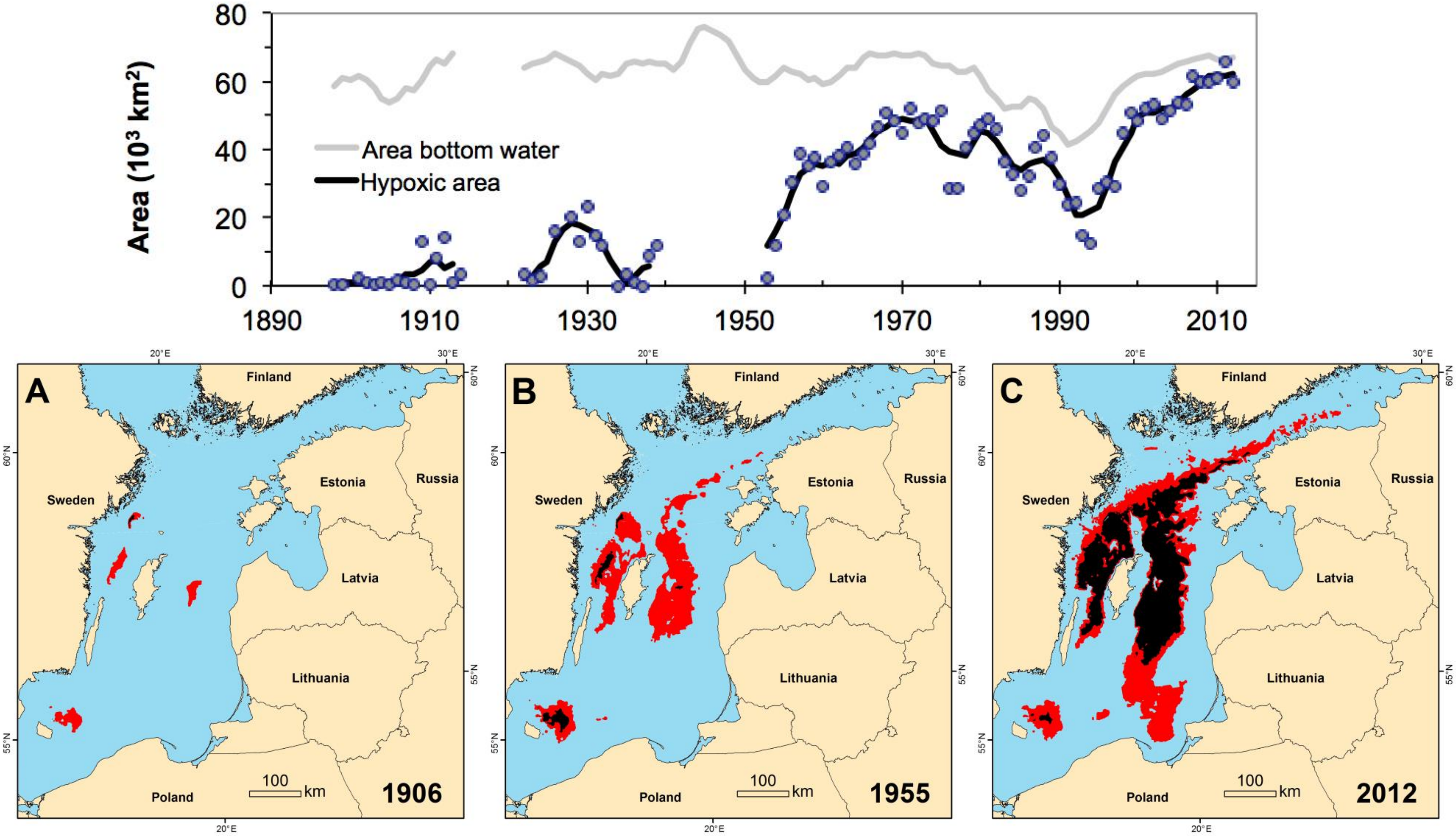
Baltic hypoxic area reasonably well defined from ca. 1970 to present from monitoring data



Conley et al. (2002)

Prior to 1970?

Development of hypoxic area through time from monitoring data

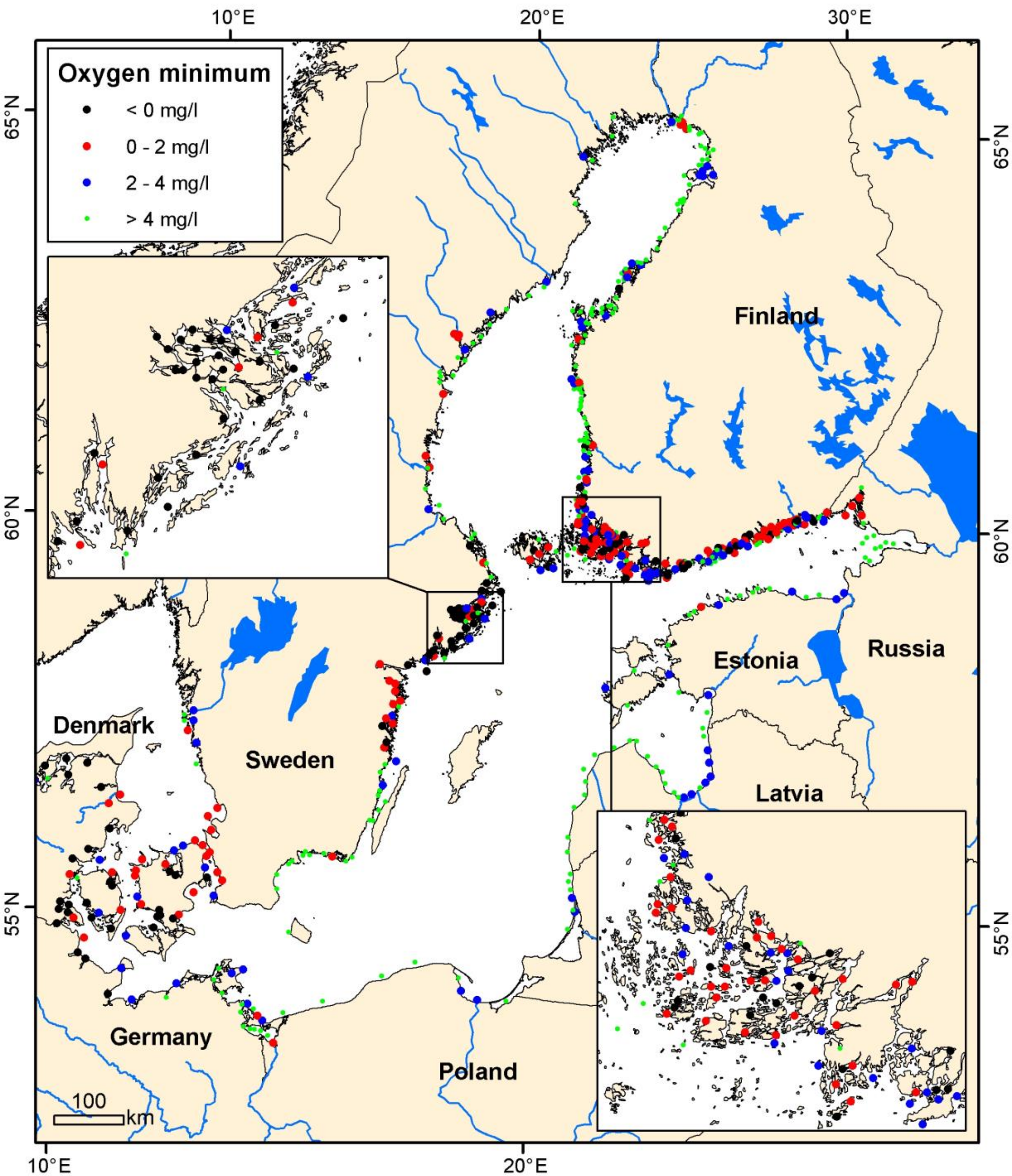


1,500 km²

25,000 km²

65,000 km²

Carstensen et al. (2014)



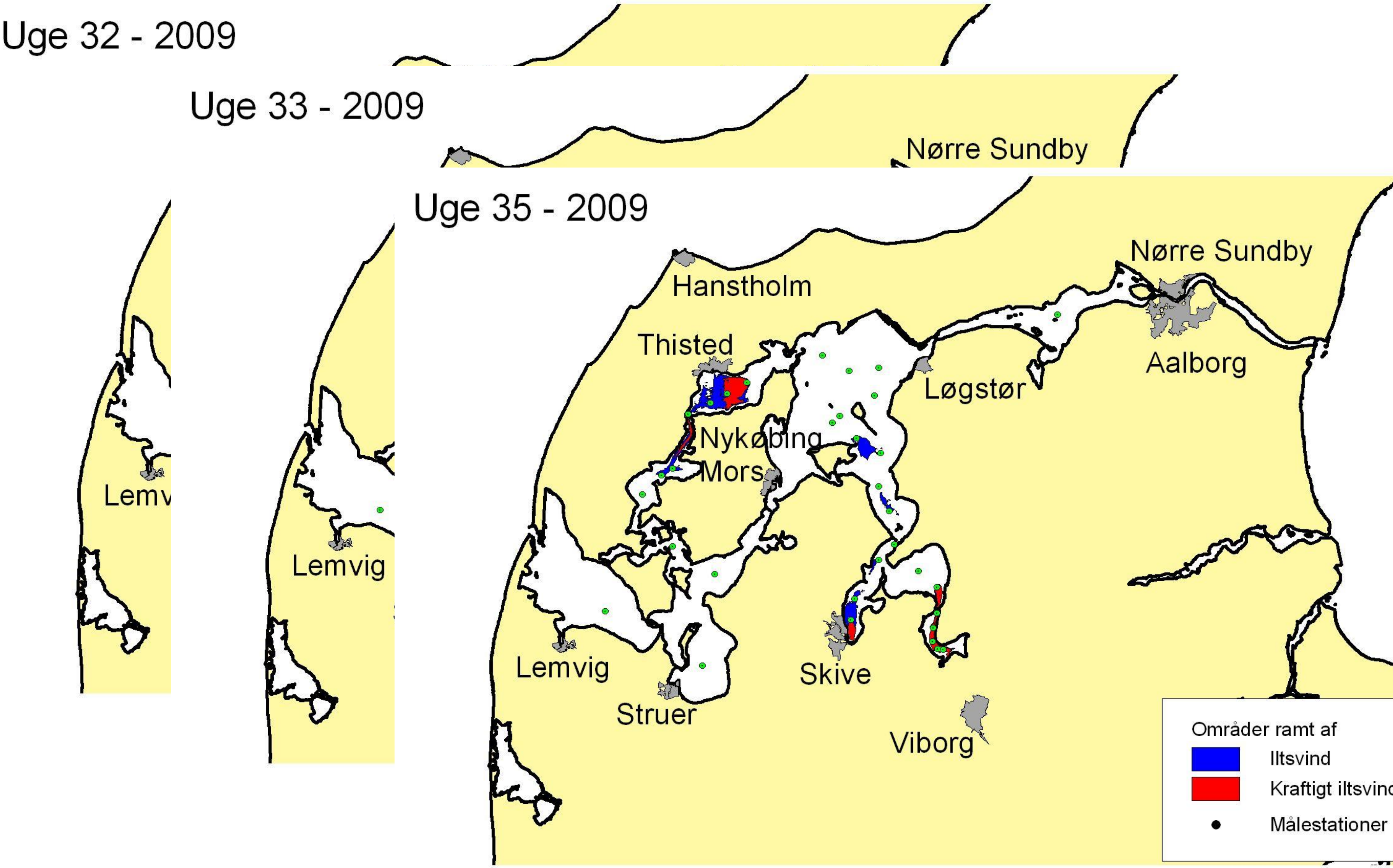
Mininum oxygen concentrations from monitoring data (1955-2009)

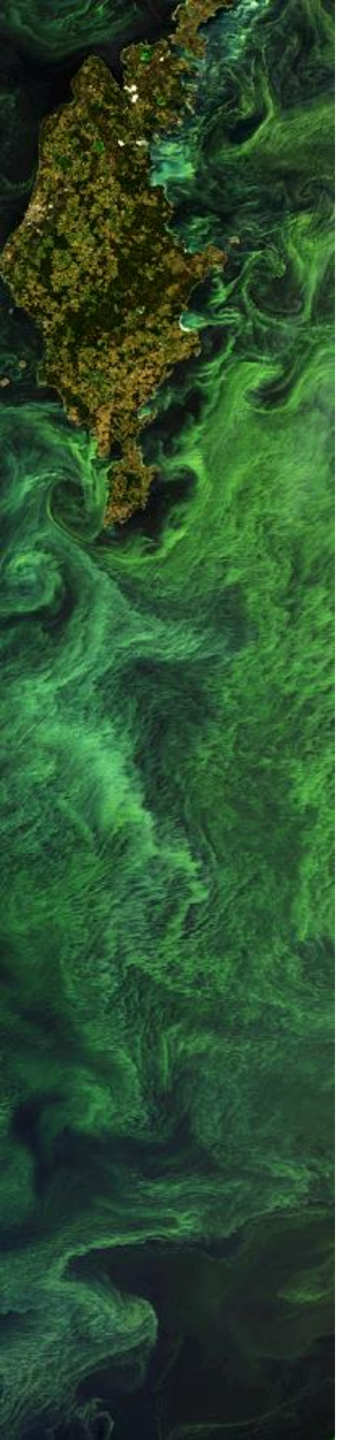
215 sites out of 613 coastal units have experienced hypoxia (O_2 < 2 mg/l)

…and there is a trend for decreasing O_2

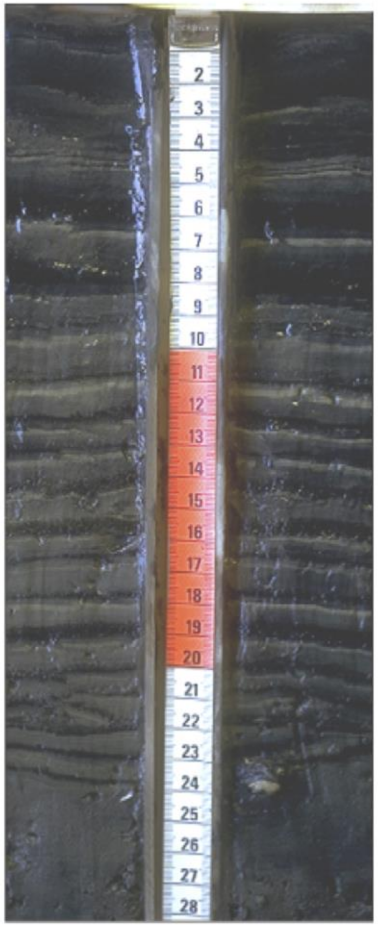
Conley et al. 2011 ES&T

Limfjorden: Hypoxia changes rapidly





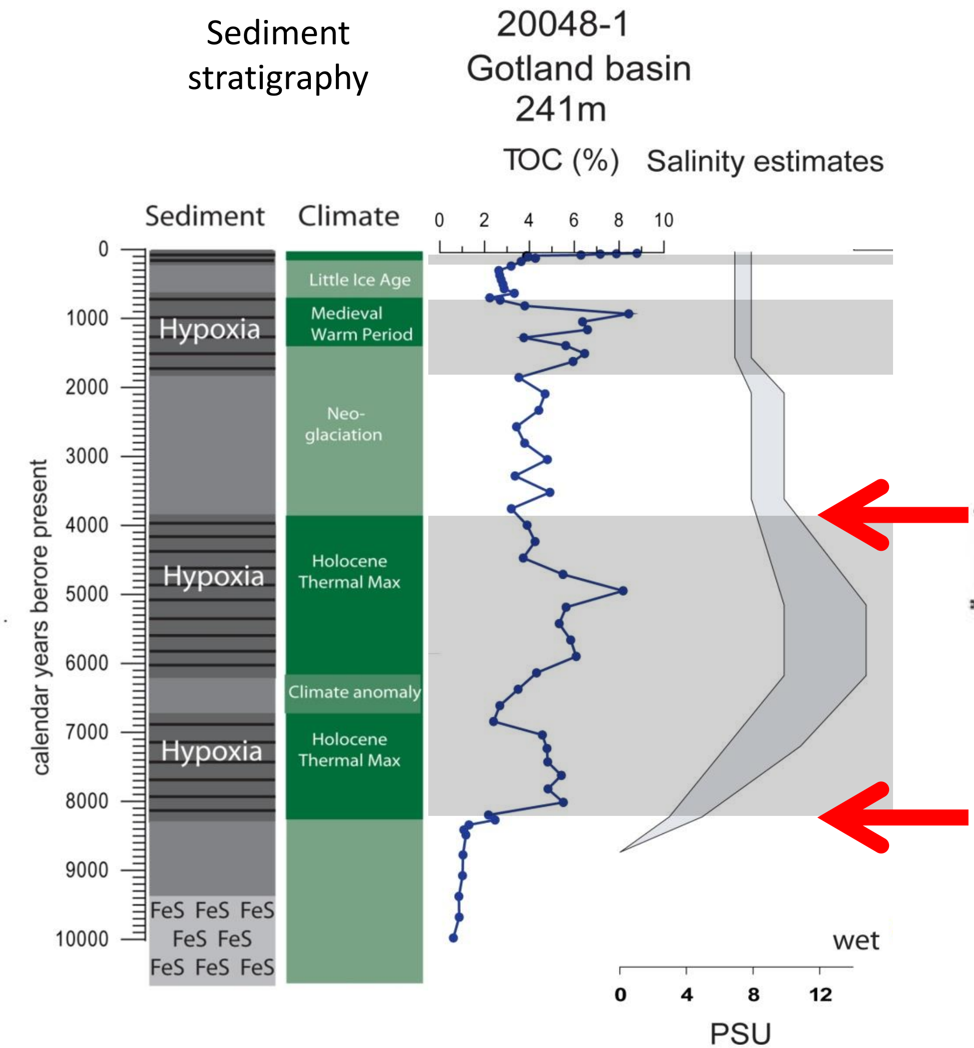
Is hypoxia a natural feature of the Baltic Sea?

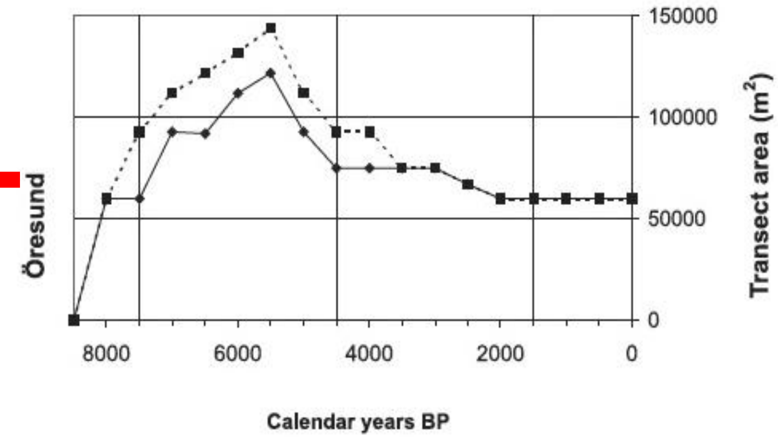


Hypoxia in the recent past
from geological data
(laminated sediments)

Hypoxia during the Holocene

(the last c. 10 000 yrs)

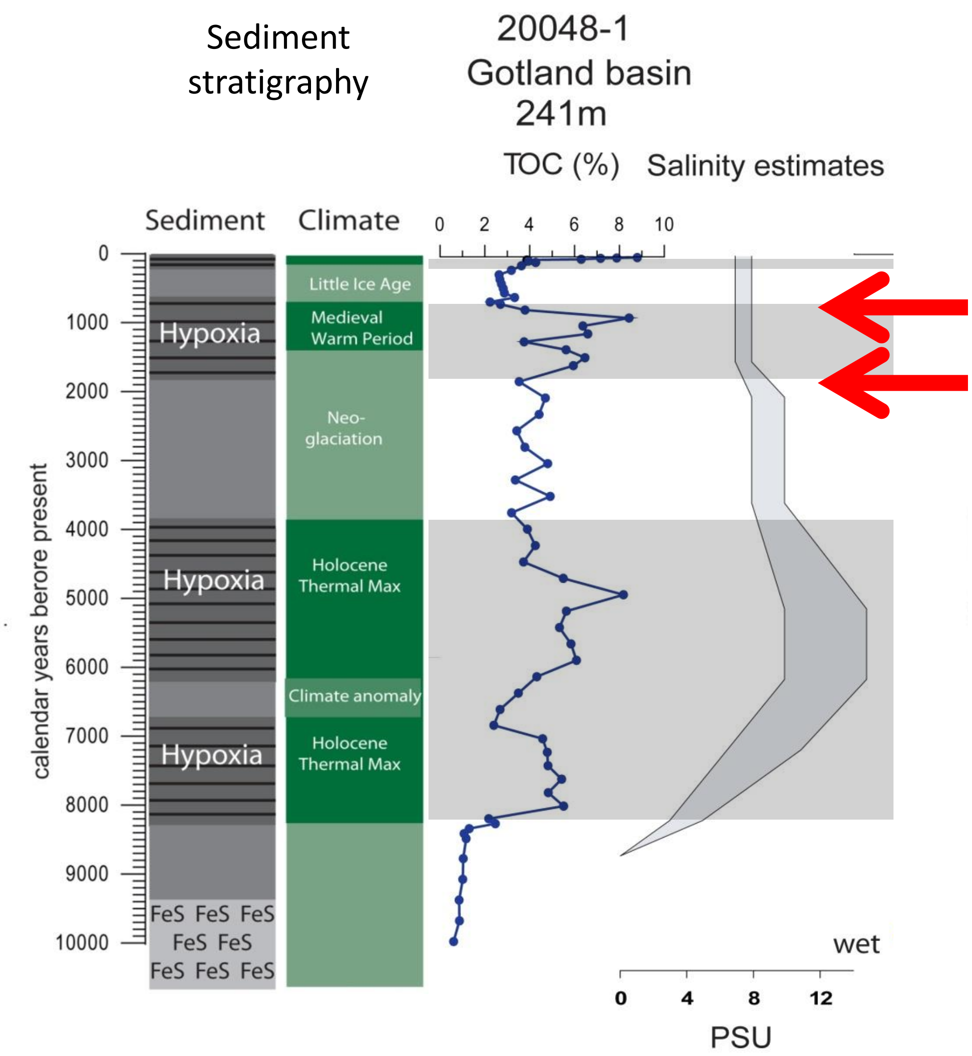




Zillén et al. 2008

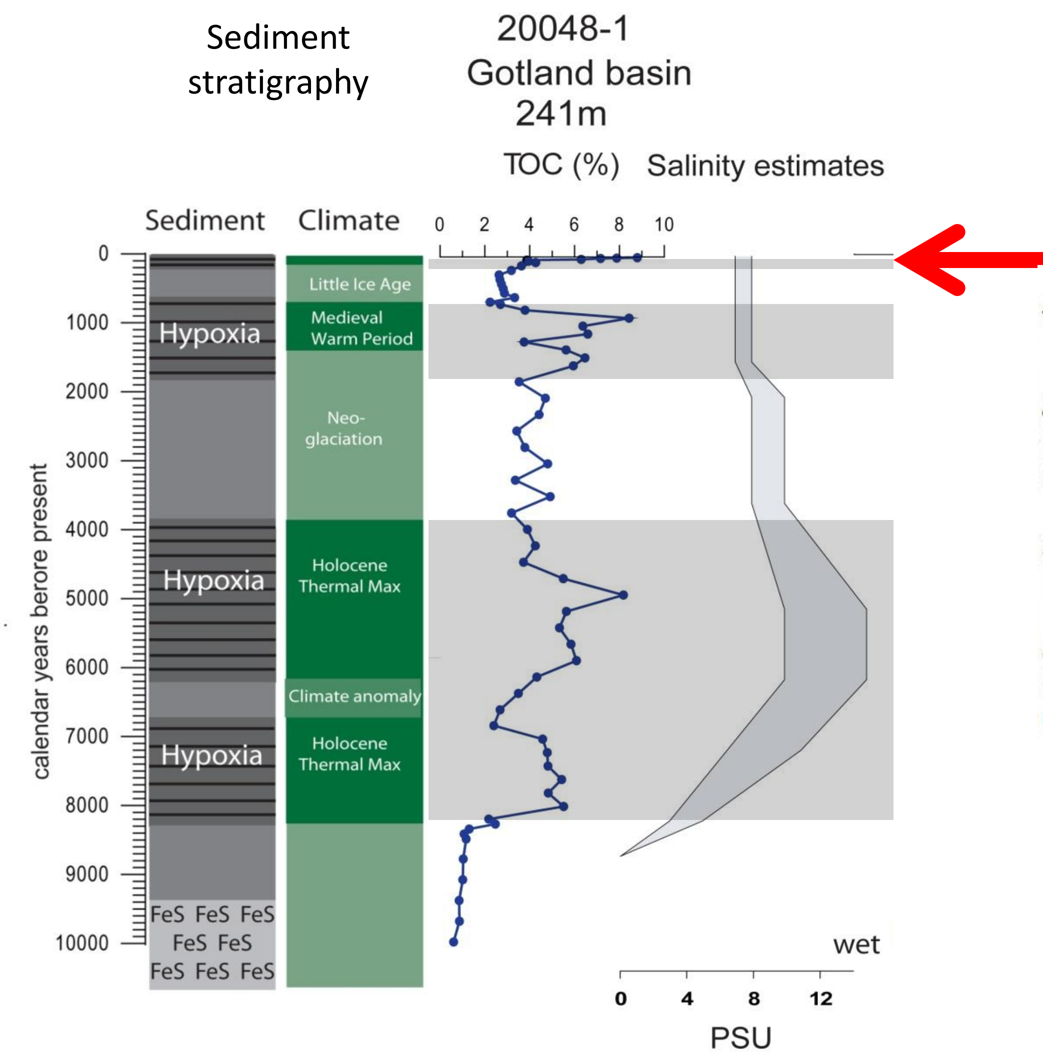
Zillén and Conley 2010

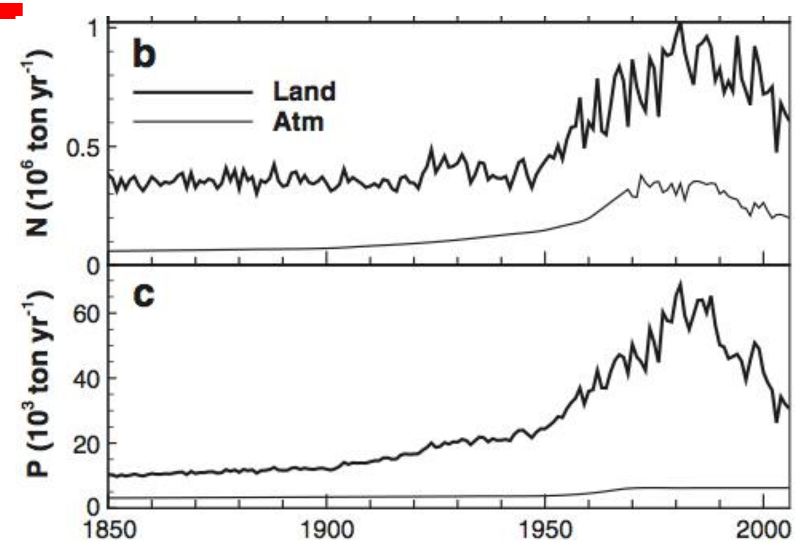
Hypoxia during the Holocene
(the last c. 10 000 yrs)



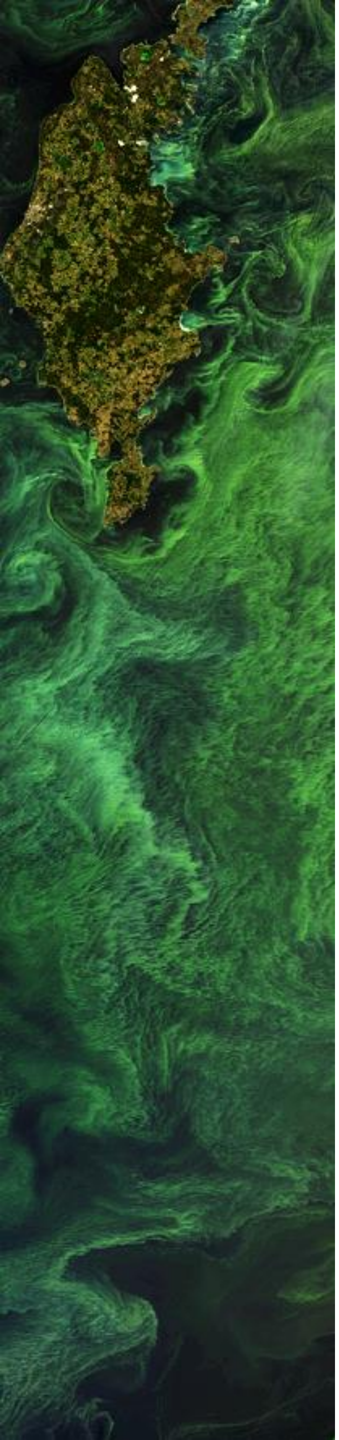
Zillén et al. 2008
Zillén and Conley 2010

Hypoxia during the Holocene
(the last c. 10 000 yrs)



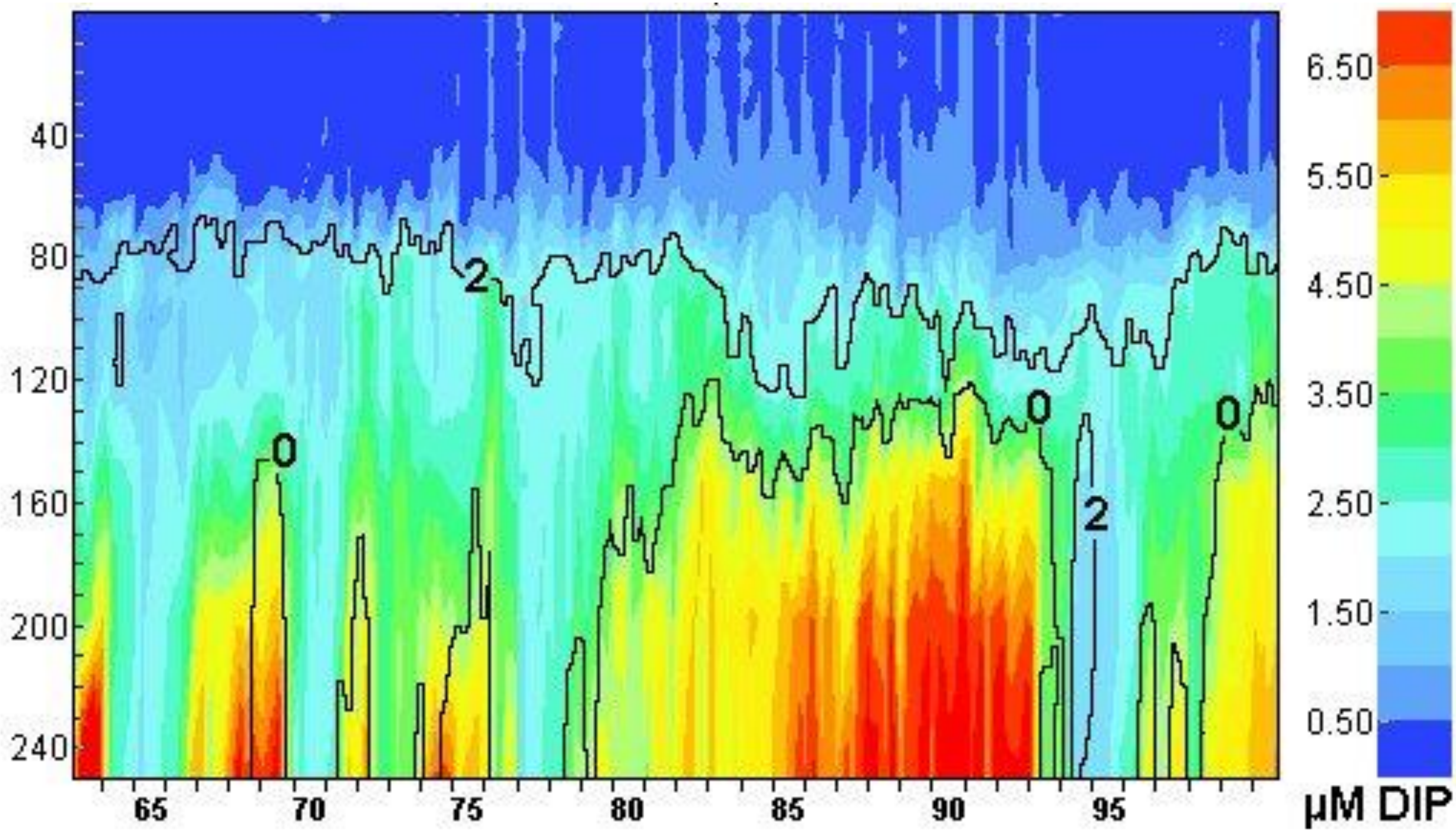


Zillén et al. 2008
Zillén and Conley 2010



Some consequences of hypoxic for the Baltic Sea

DIP and hypoxia through time in the Baltic



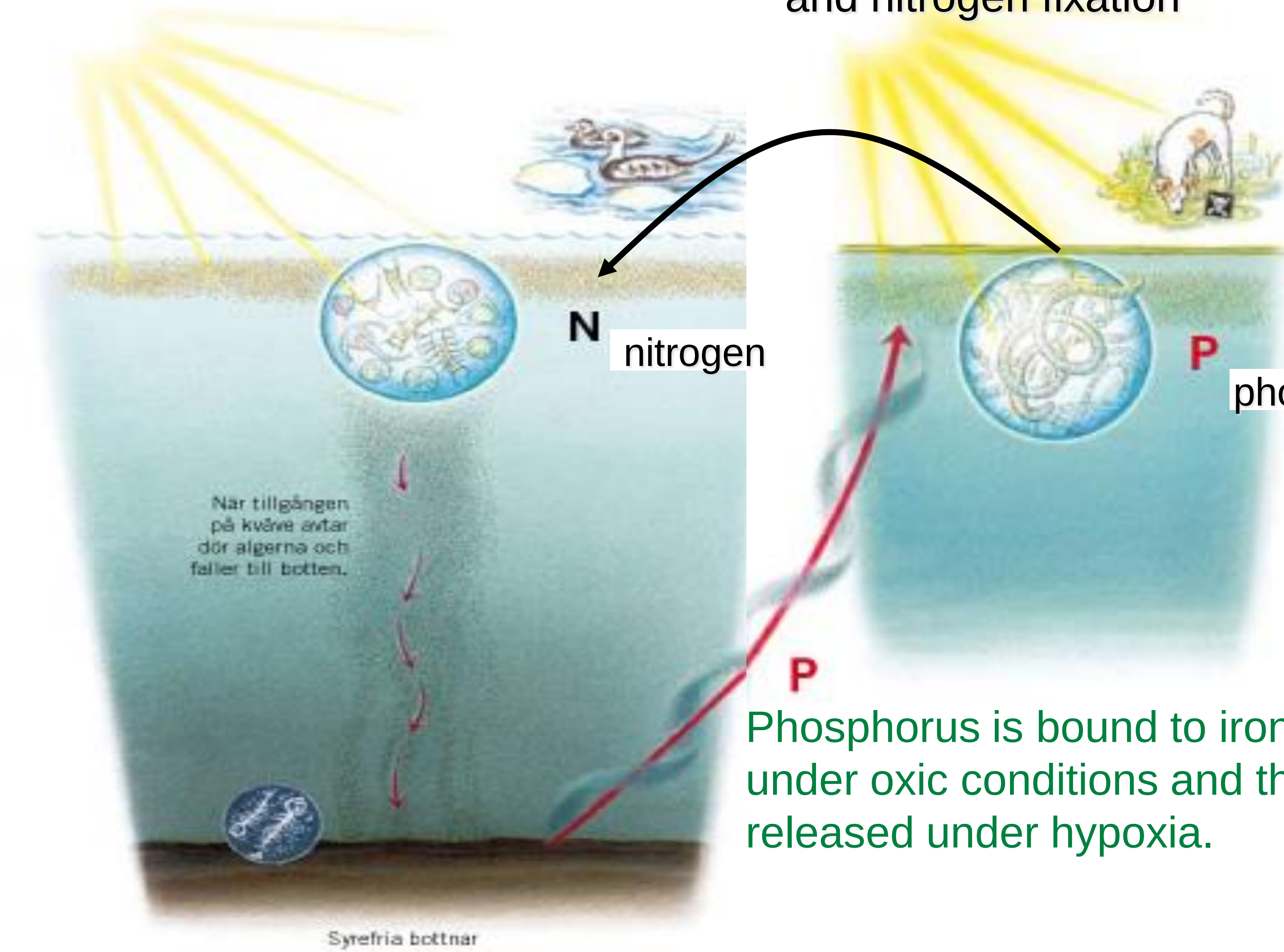
Note: Colors are DIP
Isopleths are oxygen concentrations

Conley et al. 2002

The ”viscious circle”

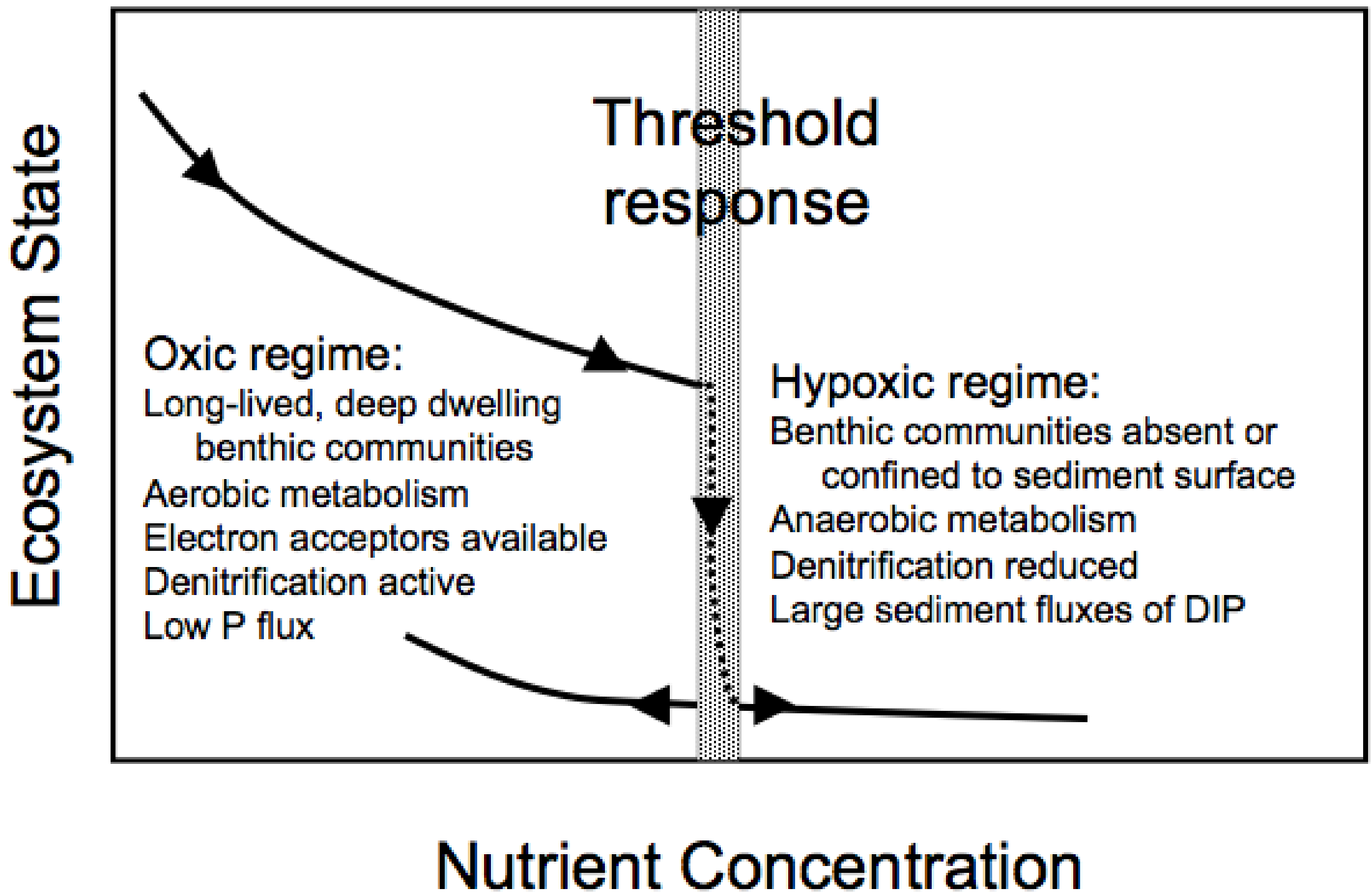
Spring bloom

Summer cyanobacteria blooms and nitrogen fixation



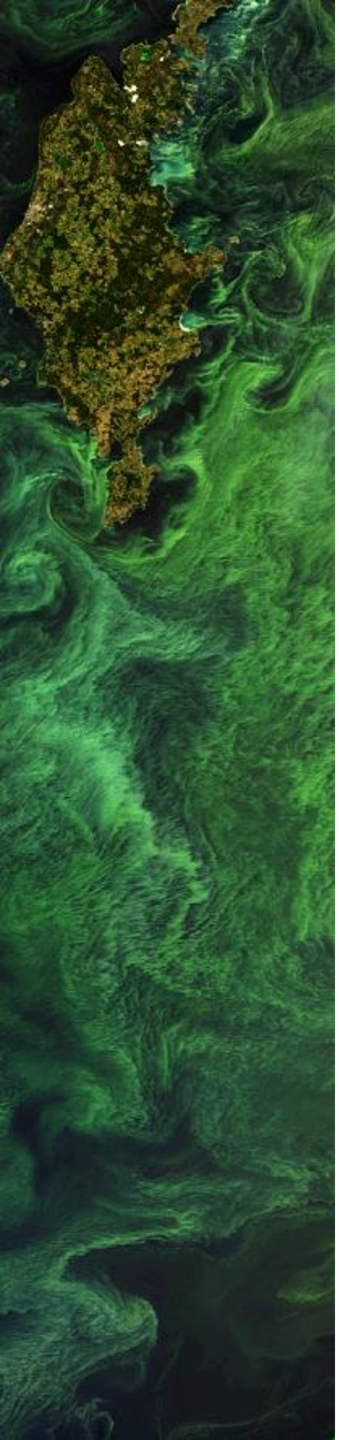
Phosphorus is bound to iron oxides under oxic conditions and then released under hypoxia.

Why are there thresholds with hypoxia?

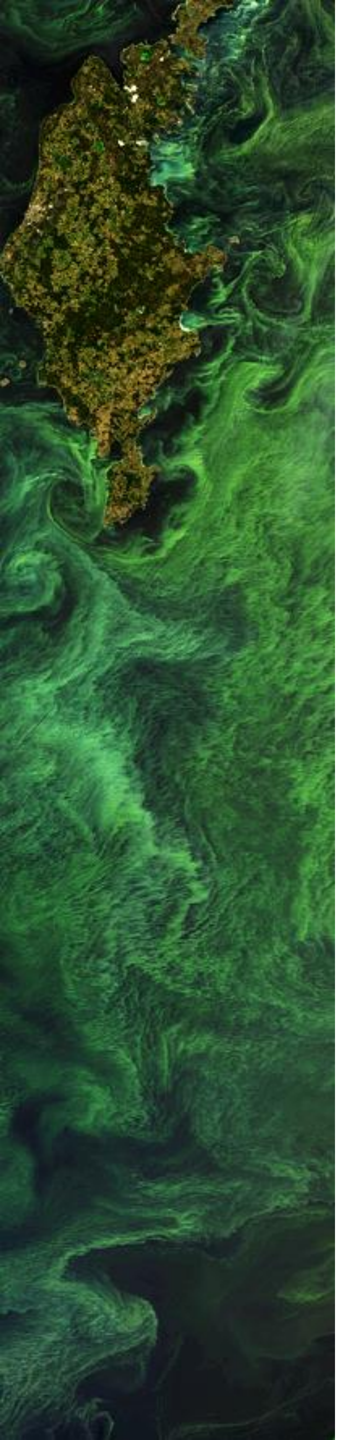


Conley et al. 2009

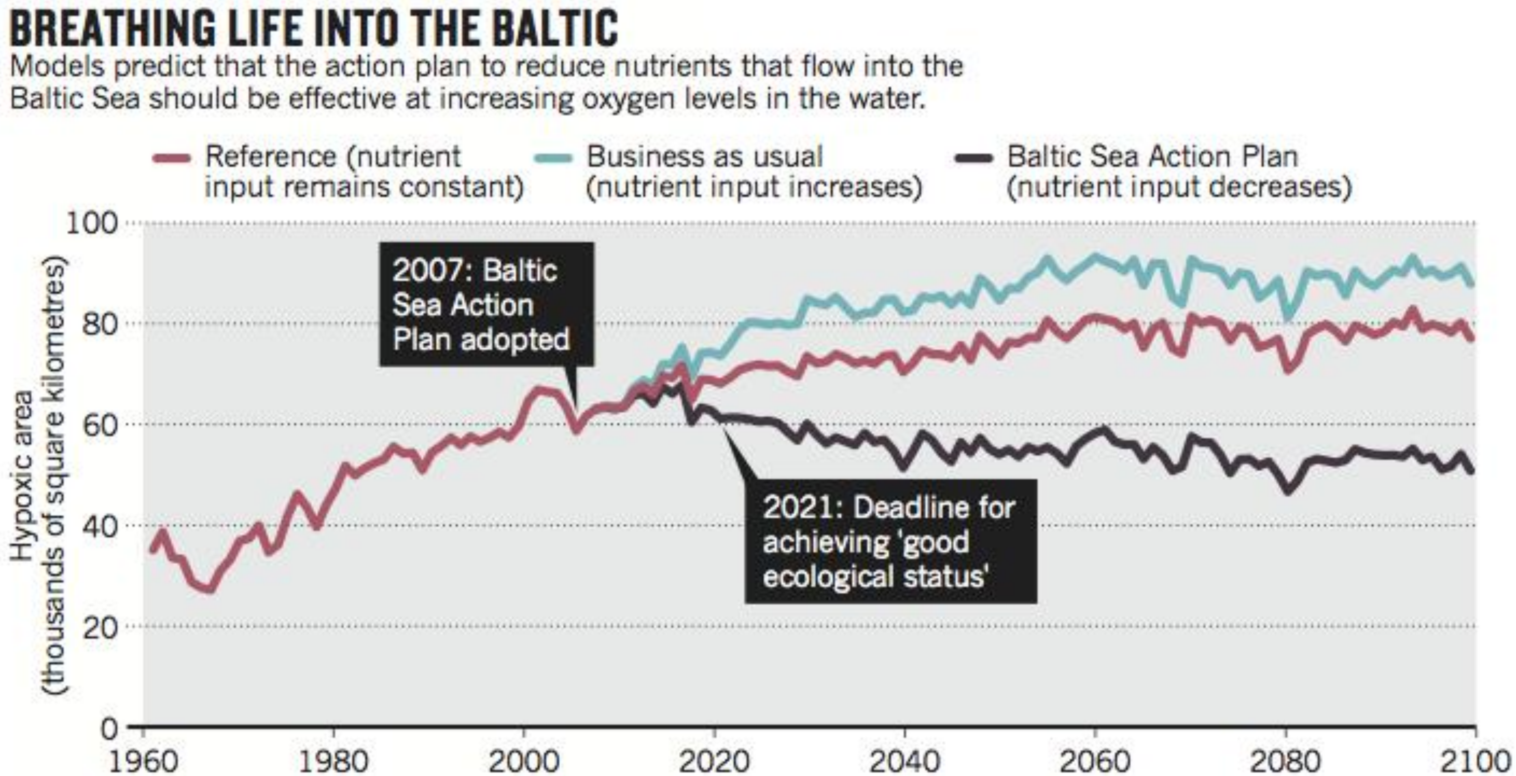
Going back is difficult…



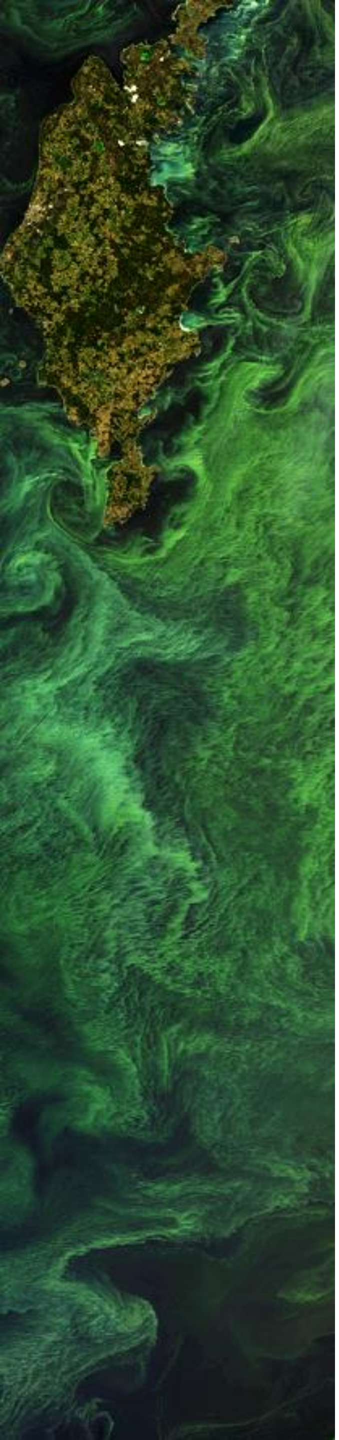
The future Baltic Sea?



The response of the Baltic Sea to *nutrient reductions* will take time



From Conley (2012) – redrawn from Meier et al. (2011)



But why?

Time scale of improvement is long (decades)

- Geoengineering provides rapid improvements

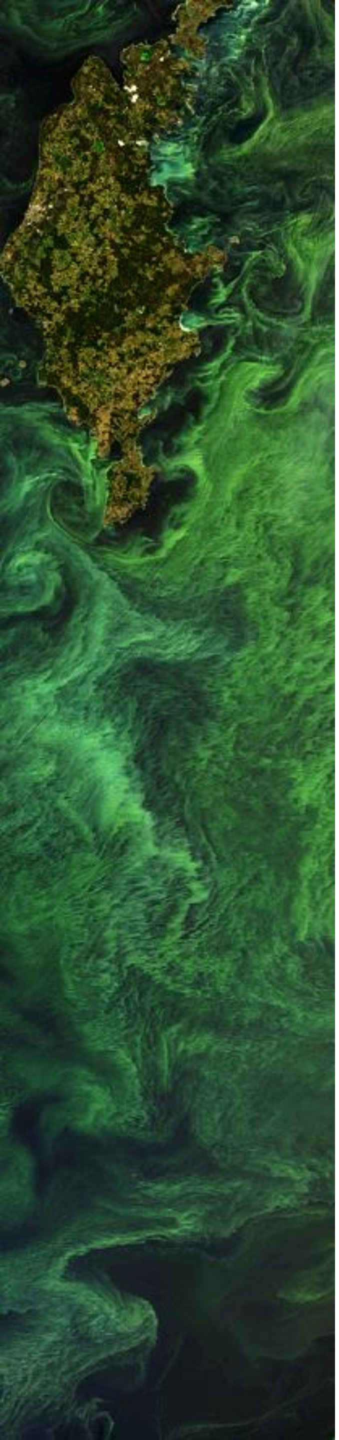
Costs of nutrient reductions to society are enormous

- Geoengineering is a cheaper alternative

Popular in the media and politically attractive

What are we going to geoengineer?

Baltic Sea eutrophication



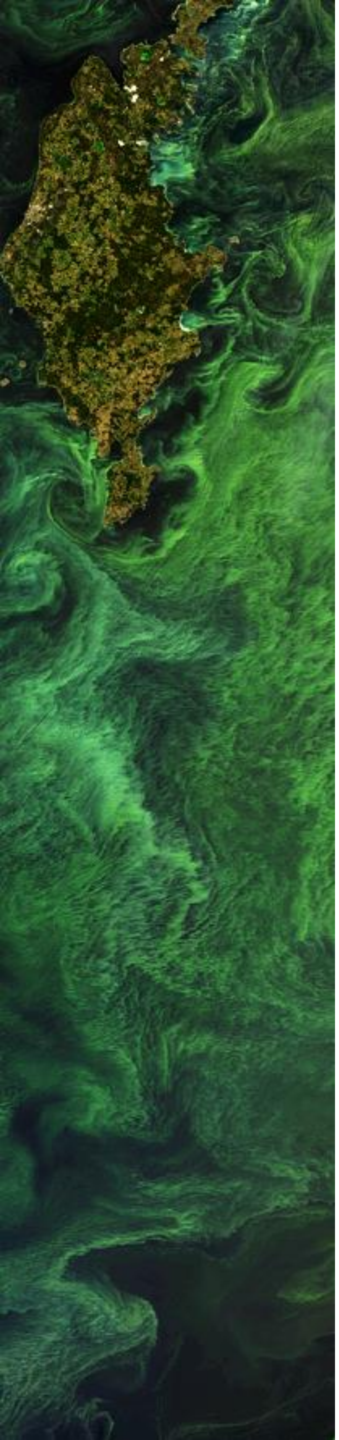
Can we add oxygen to the Baltic?

(Conley et al. 2009, *ES&T*)

The hypoxic area (oxygen < 2 mg/l) averages 49,000 km^2

Would require 2-6 million tons oxygen to be added each year

20,000-60,000 railway cars of liquid oxygen each year to keep bottom waters oxic



Model experiments

Four generalized “engineering” solutions considered:

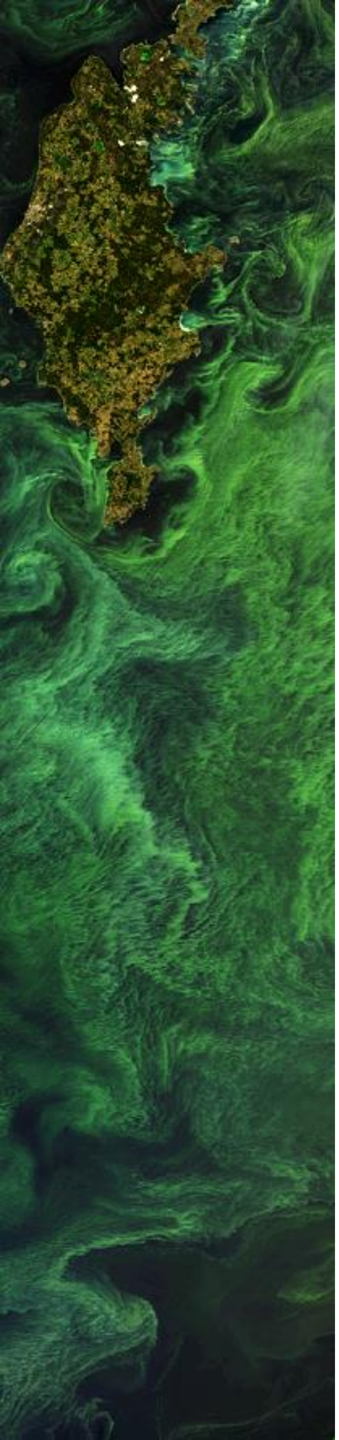
1) Deep water oxygenation
   2-6 million tons oxygen needed each year.

2) Increase exchange across the Drogden Sill
   More saltwater inflow creates more stratification and more hypoxia.

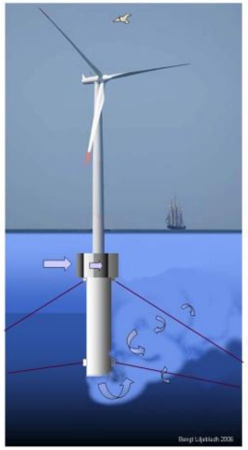
3) Closing the Drogden Sill
   Short term increase in hypoxia (10-15 years), but improved oxygen conditions after 30 years.

4) Halocline ventilation by mid-water mixing (80 m to 125 m)
   The only engineering solution that improves conditions, but has potentially serious ecological effects.

Conley et al. 2009, *ES&T*



Baltic Deepwater Oxygen (BOX)

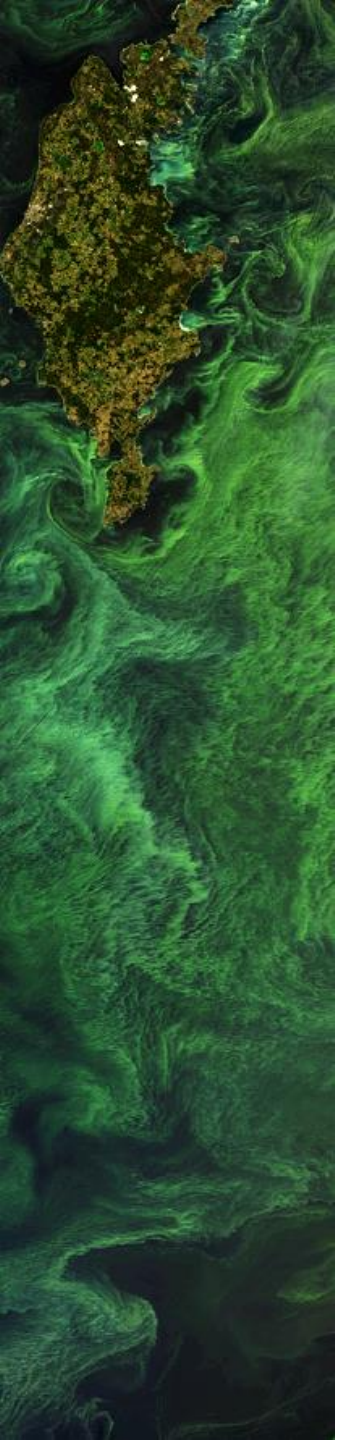


Mechanically pump oxygenated water below
the halocline to oxygenate deep water.
The Box Project and models (Stigebrandt &
Kalen 2013) showed a reduction in vertical
stratification and increase in inflows from the adjacent basin.

PROPPEN Project

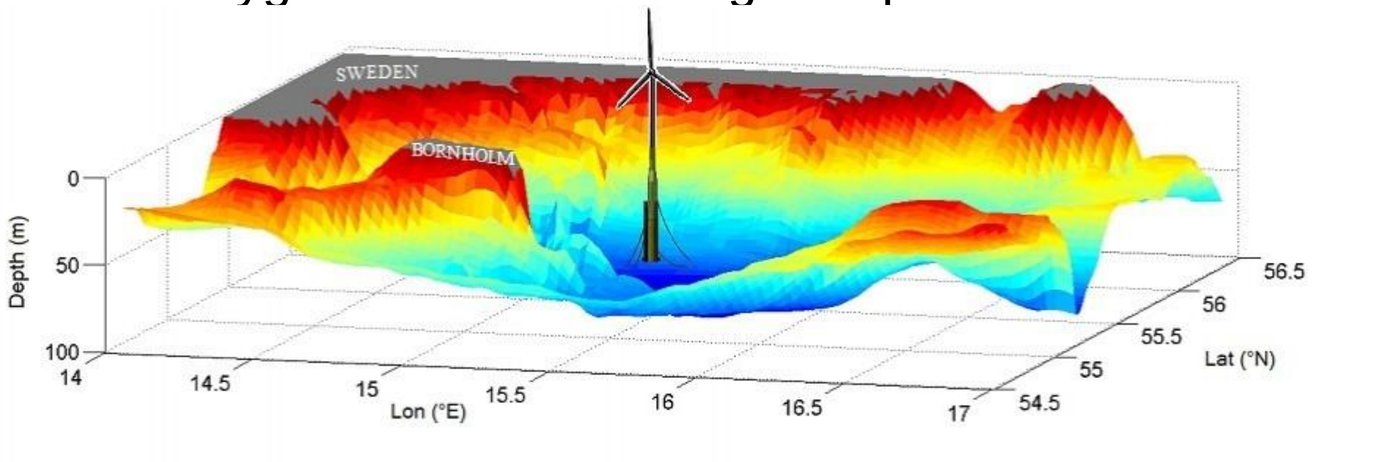
At Sandöfjärden, Finland pumping proved insufficient to keep
keep the area oxygenated.

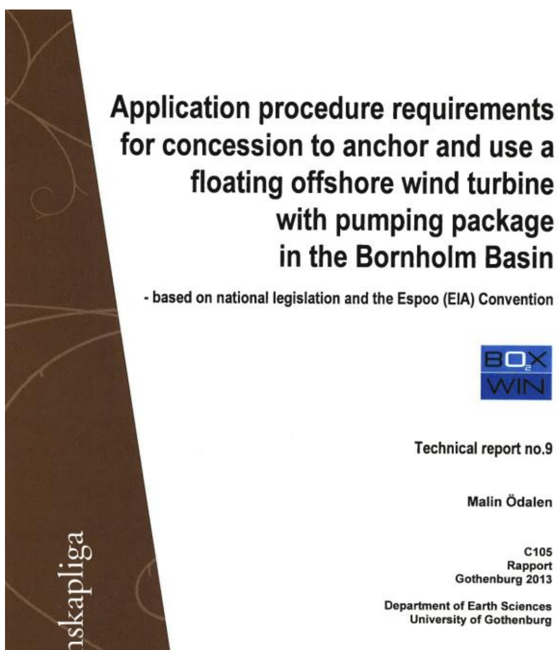
But, mixing warmed bottom waters increased bottom water
oxygen demand!



BOX-WIN (http://BOX-WIN.se)

Baltic Sea oxygenation and floating windpower demonstrator





Application procedure requirements for concession to anchor and use a floating offshore wind turbine with pumping package in the Bornholm Basin

- based on national legislation and the Espoo (EIA) Convention

Technical report no.9

Malin Ödalen

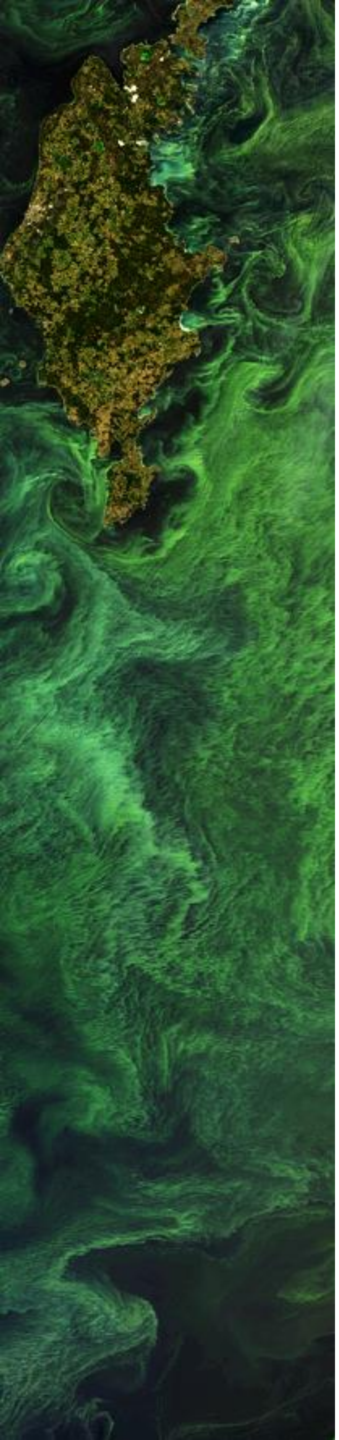
C105
Rapport
Gothenburg 2013

Department of Earth Sciences
University of Gothenburg

Who decides?

Danish Energy Agency

HELCOM has said no – Sept 2014
but the saga continues



Scientific questions:

How much would phosphorus be reduced?

How would the Baltic react to more inflow events?

Would destabilization of the water column allow winter mixing to break through the halocline?

What would happen to phytoplankton, zooplankton and larve?

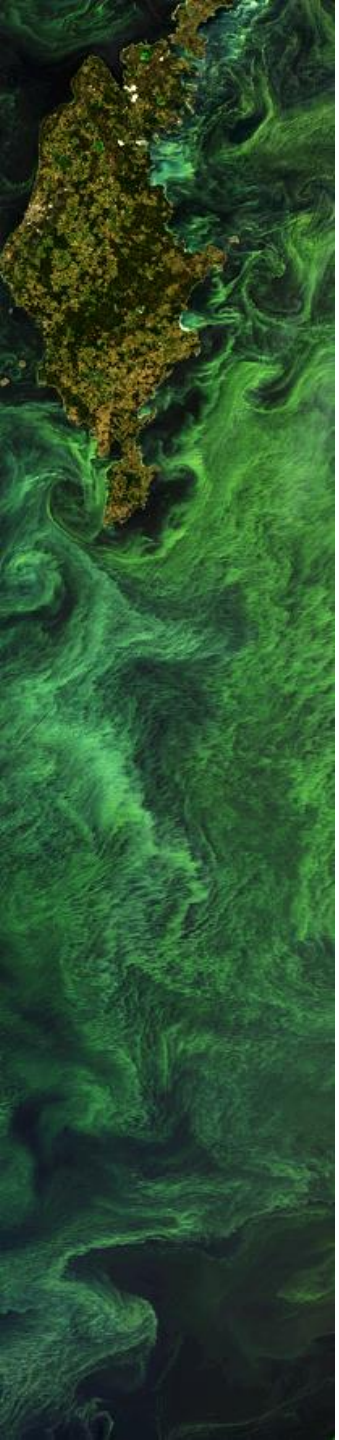
Consumer questions:

Cost are enormous to set up the system; installation and maintenance costs should also be included.

Effect on shipping lanes?

Management concerns:

Would this reduce efforts and money for nutrient reductions?



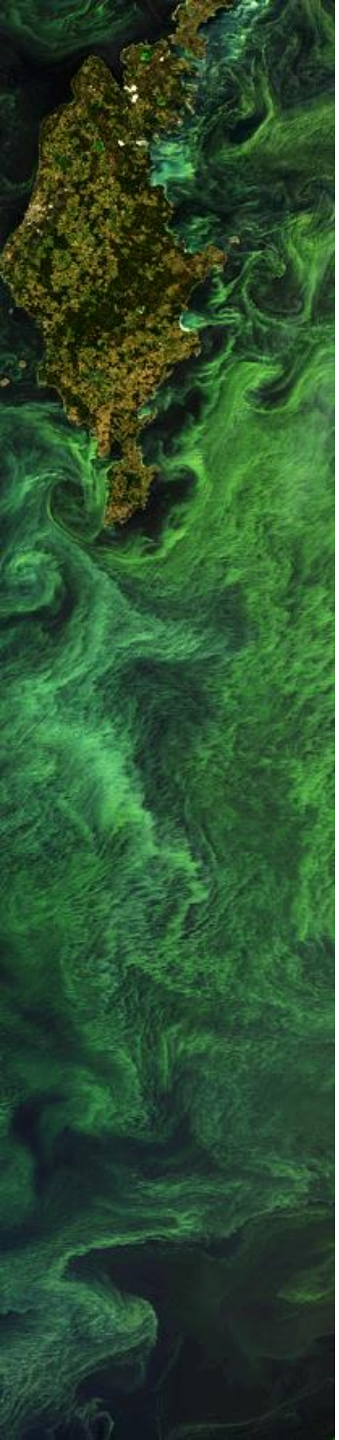
Phosphorus Sequestration

Can we enhance the permanent burial of phosphorus in sediments by precipitation?

Energy and CO_2 considerations with alum

Ethical (reversibility)

Legal considerations (London Convention)



Change trophic interactions

Let's fish out the intermediate predators (sprat) in the Baltic Sea (PLANFISH)

Oops, the cod are starving…

Science News

Recovering Baltic Cod Is Lacking Food

Aug. 20, 2012 — The eastern Baltic cod stock has recently started to recover, after two decades of severe depletion, however with unexpected side-effects.

Pathway to a healthier marine ecosystem based on

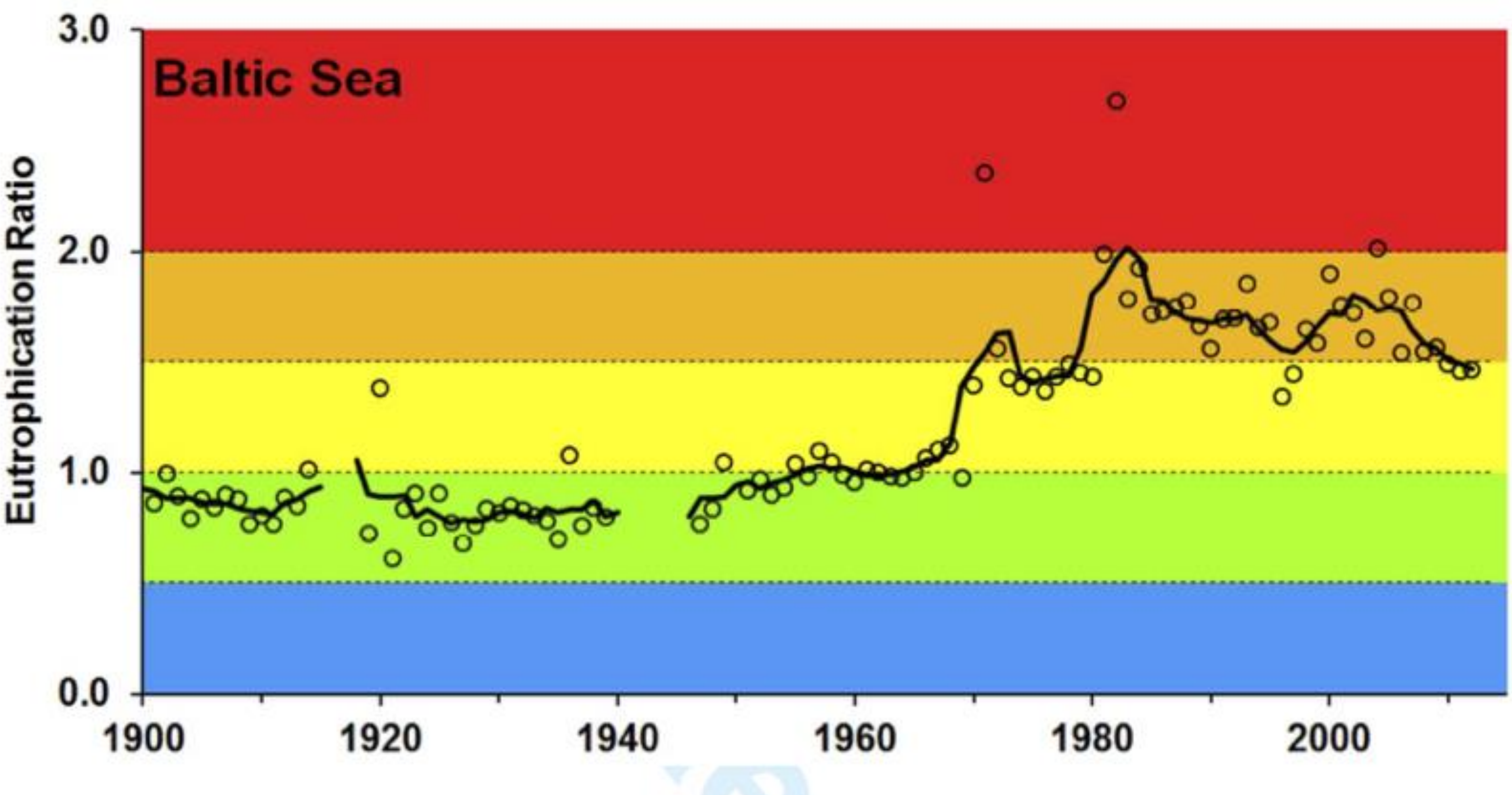
- Basic knowledge
- Monitoring & Assessment
- Governance & Management
- Action

In all of the excitement of SEKs, DKKs & €€€s

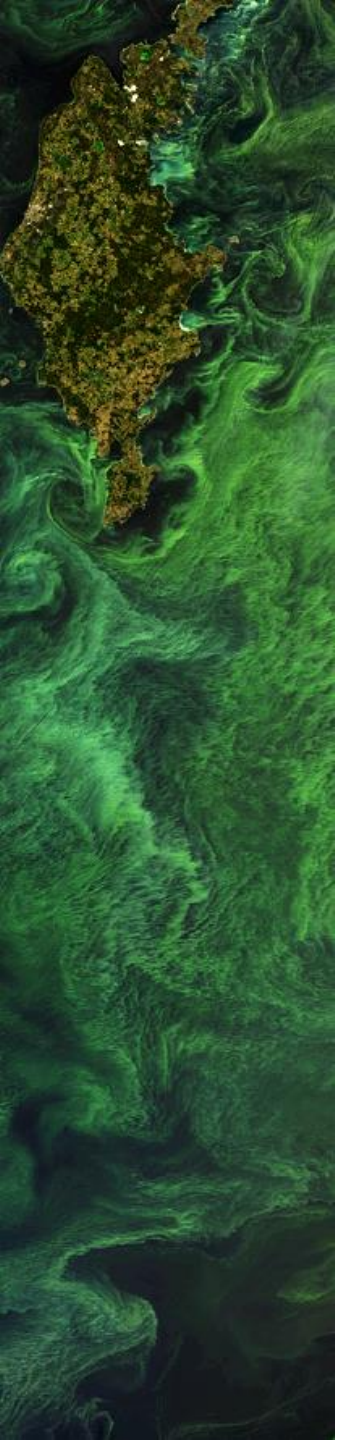
We must reduce nutrients for mitigation to be effective.

The Baltic Sea is getting better!

HELCOM Eutrophication Assessment Tool (HEAT 3.0)
(Based on Chl, DO, benthic biomass, winter DIN/DIP, secchi depth, CDOM)



Andersen et al. 2015 Biological Reviews



Perspectives

Model predictions are for a warmer, wetter climate

More nutrient runoff counteracts reductions, but a fresher Baltic allows for more mixing across the halocline

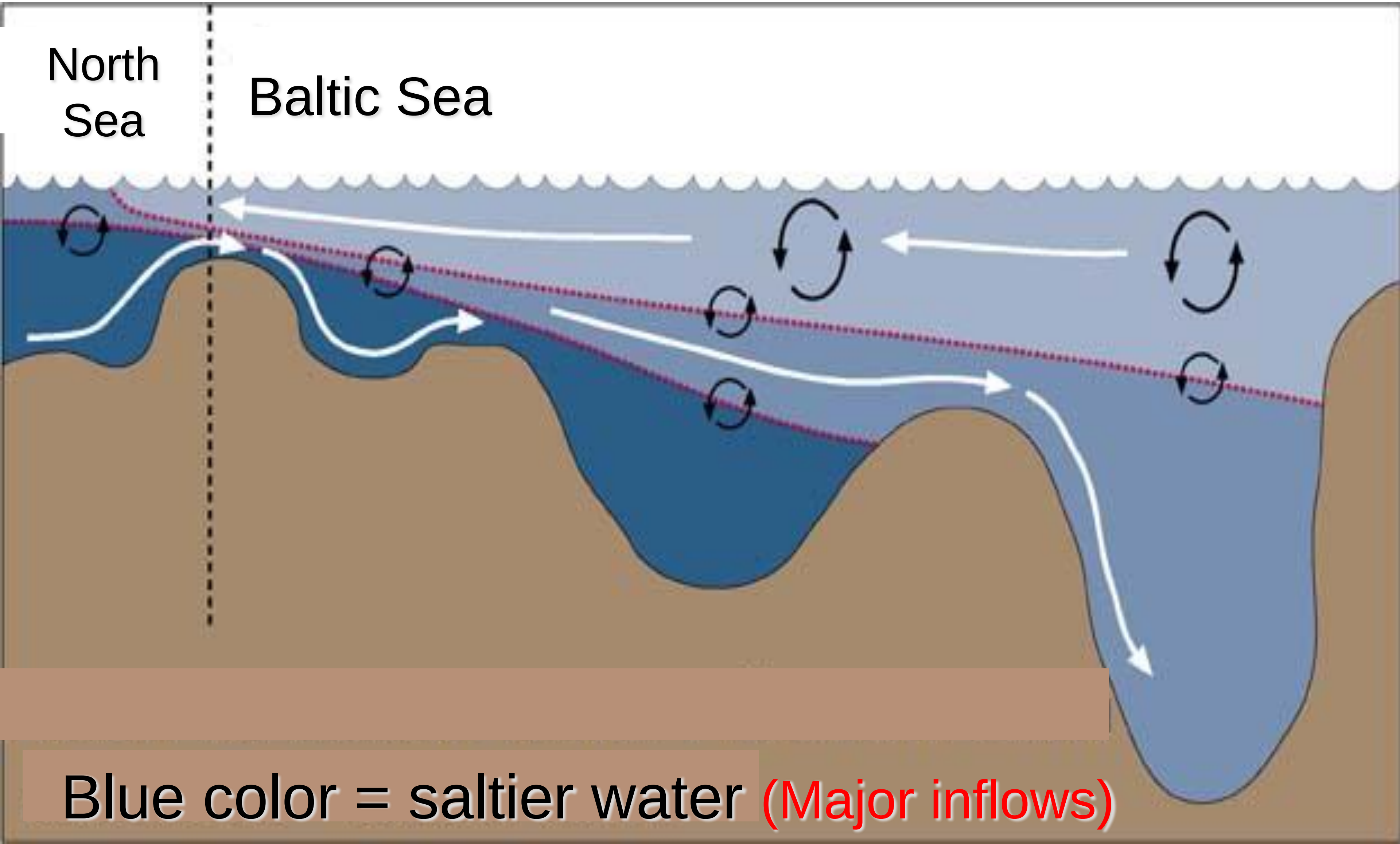
Cyanobacteria blooms are likely to increase

“Geoengineering” promises rapid improvements, but there are significant potential ecological effects

We must focus on the prescribed nutrient reductions


Thanks for listening!
QUESTIONS???

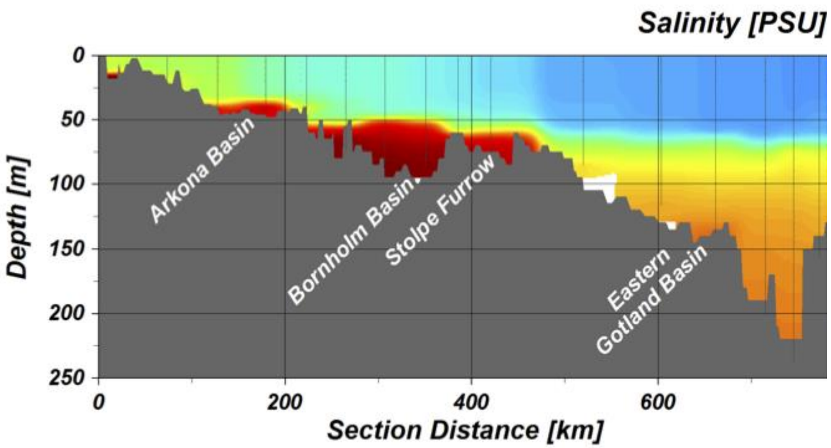
Saltwater inputs into the Baltic Sea

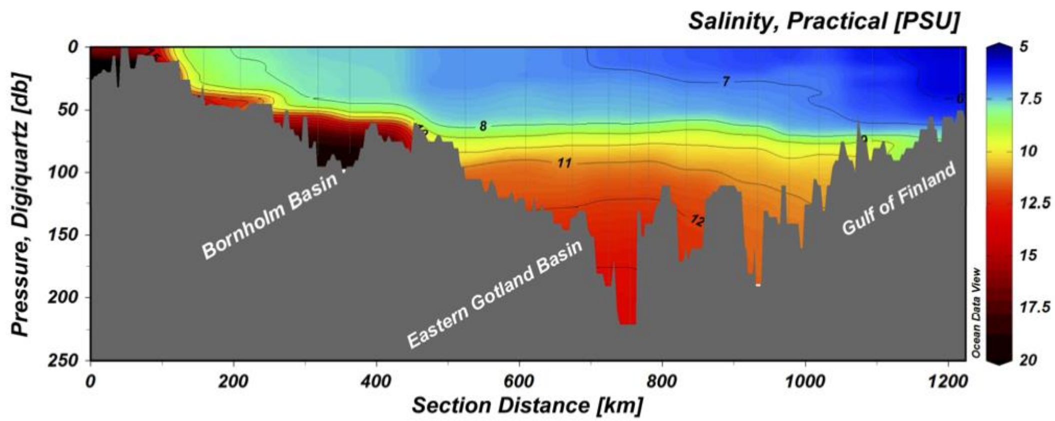


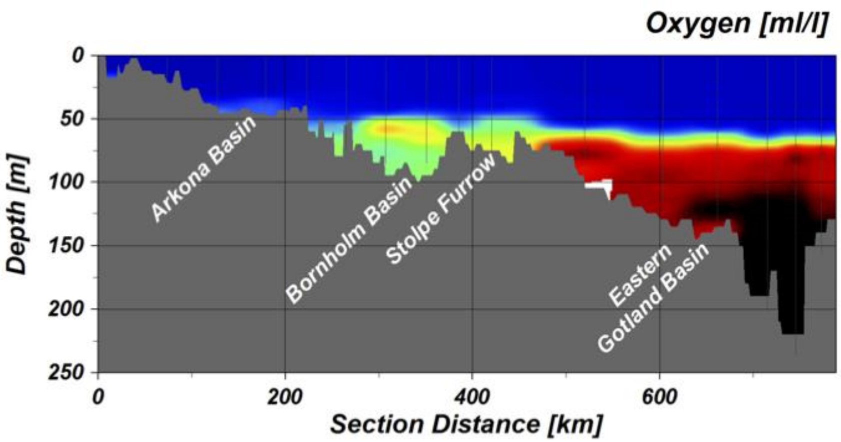
Blue color = saltier water (Major inflows)

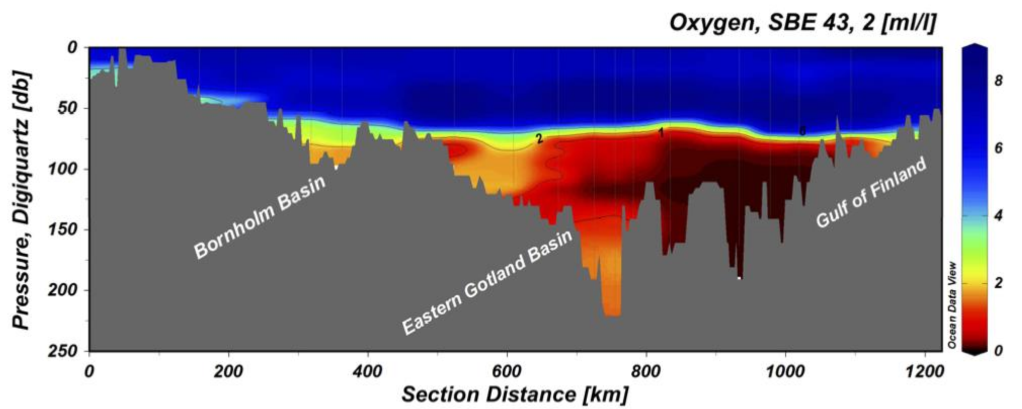
February 2015

July 2015









Data from SMHI

Blooms Like It Hot

A link exists between global warming and the worldwide proliferation of harmful cyanobacterial blooms.

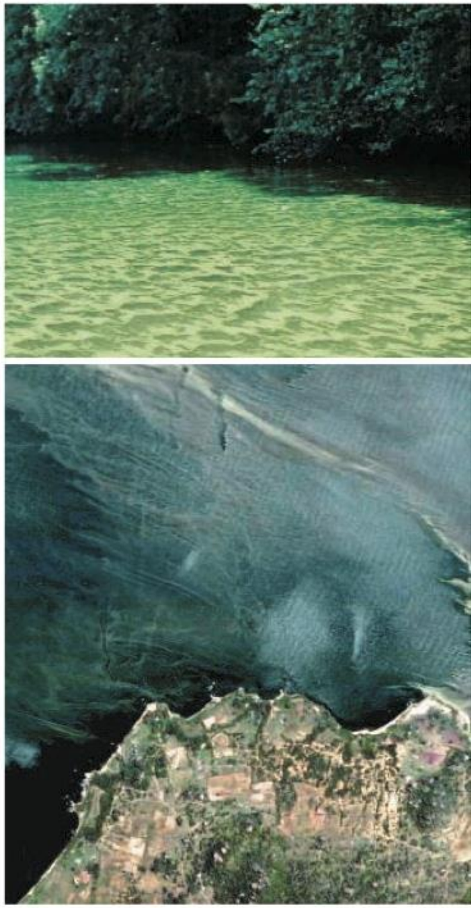
Hans W. Paerl[1] and Jef Huisman[2]

Nutrient overenrichment of waters by urban, agricultural, and industrial development has promoted the growth of cyanobacteria as harmful algal blooms (see the figure) (*1*, *2*). These blooms increase the turbidity of aquatic ecosystems, smothering aquatic plants and thereby suppressing important invertebrate and fish habitats. Die-off of blooms may deplete oxygen, killing fish. Some cyanobacteria produce toxins, which can cause serious and occasionally fatal human liver, digestive, neurological, and skin diseases (*1*–*4*). Cyanobacterial blooms thus threaten many aquatic ecosystems, including Lake Victoria in Africa, Lake Erie in North America, Lake Taihu in China, and the Baltic Sea in Europe (*3*–*6*). Climate change is a potent catalyst for the further expansion of these blooms.

Rising temperatures favor cyanobacteria in several ways. Cyanobacteria generally grow better at higher temperatures (often above 25°C) than do other phytoplankton species such as diatoms and green algae (*7*, *8*). This gives cyanobacteria a competitive advantage at elevated temperatures (*8*, *9*). Warming of surface waters also strengthens the vertical stratification of lakes, reducing vertical mixing. Furthermore, global warming causes lakes to stratify earlier in spring and destratify later in autumn, which lengthens optimal growth periods. Many cyanobacteria exploit these stratified conditions by forming intracellular gas vesicles, which make the cells buoyant. Buoyant cyanobacteria float upward when mixing is weak and accumulate in dense surface blooms (*1*, *2*, *7*) (see the figure). These surface blooms shade underlying nonbuoyant phytoplankton, thus suppressing their opponents through competition for light (*8*).

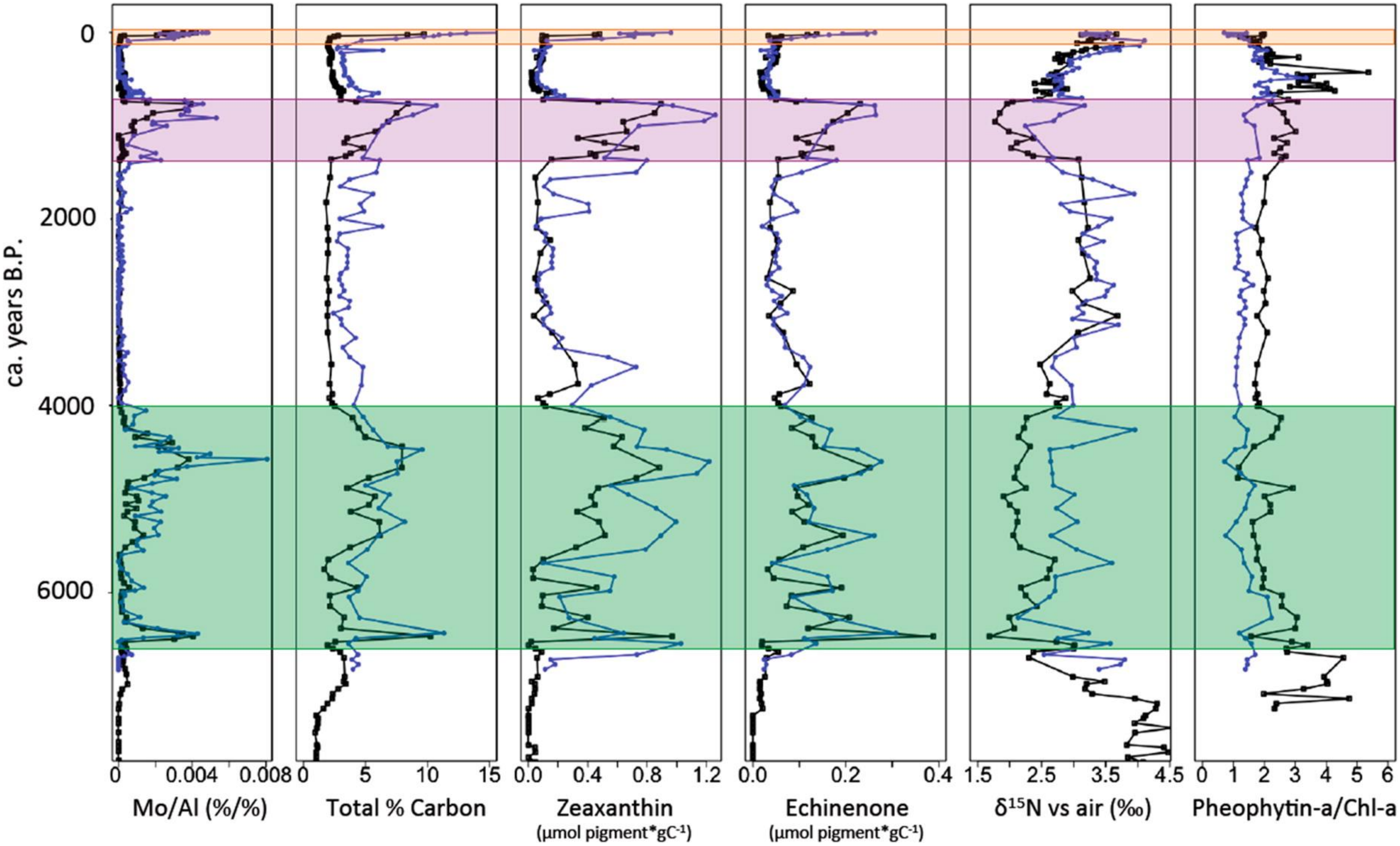
Cyanobacterial blooms may even locally increase water temperatures through the intense absorption of light. The temperatures of surface blooms in the Baltic Sea and in Lake IJsselmeer, Netherlands, can be at least 1.5°C above those of ambient waters (*10*, *11*). This positive feedback provides additional competitive dominance of buoyant cyanobacteria over nonbuoyant phytoplankton.

Global warming also affects patterns of precipitation and drought. These changes in the hydrological cycle could further enhance cyanobacterial dominance. For example, more intense precipitation will increase surface and groundwater nutrient discharge into water bodies. In the short term, freshwater discharge may prevent blooms by flushing. However, as the discharge subsides and water residence time increases as a result of drought, nutrient loads will be captured, eventually promoting blooms. This scenario takes place when elevated winter-spring rainfall and flushing events are followed by protracted periods of summer drought. This sequence of



Undesired blooms. Examples of large water bodies covered by cyanobacterial blooms include the Neuse River Estuary, North Carolina, USA (**top**) and Lake Victoria, Africa (**bottom**).

[1]Institute of Marine Sciences, University of North Carolina at Chapel Hill, Morehead City, NC 28557, USA. E-mail: hpaerl@email.unc.edu [2]Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, 1018 WS Amsterdam, Netherlands. E-mail: jef.huisman@science.uva.nl



Published in: Carolina P. Funkey; Daniel J. Conley; Nina S. Reuss; Christoph Humborg; Tom Jilbert; Caroline P. Slomp; *Environ. Sci. Technol.* **2014,** 48, 2598-2602. DOI: 10.1021/es404395a