Aquatic Ecosystems

23.02.-03.03.2016

Nitrogen and eutrophication
- Lecture 2 -

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Overview of this teaching unit

- **Lecture 1**
  - Nitrogen (Importance, sources, transformations and recent trends)
  - Environmental Quality Criteria
- **Exercise 1**
  - Application of the Environmental Quality Criteria and mapping using R
- **Lecture 2** on Thursday – 10.15 – 12.00
  - Feedbacks, interactions, stable states
  - Eutrophication Management (Directives, examples)

Overview of this teaching unit

- **Lecture 2** on Thursday – 13.15 – 15.00
  - ‚Brownification‘ in inland waters
  - Time series analysis using linear mixed effects models
- **Exercises 2 to 5** – Fr 26/02 to Tue 01/03
  - Case studies brownification in lakes, rivers and estuaries
  - Time series analyses, mixed effects modeling, R
- **Final seminar** – Thursday 03/03 – 10.15 – 12.00
  - Presentation of case study results and group discussion

Learning goals

1. Reduction of just one nutrient in eutrophication management may have side-effects
2. Eutrophication management plans are long-term projects
3. Sediment-nutrient interactions need to be considered (e.g. ‚internal loading‘)
4. Different stable ecosystem states may exist, non-linear dynamics
5. Directives examples, management plan example

Questions welcome at all times!!

Nutrient limitation characteristics in freshwaters

- **Phosphorus** often limits upstream **freshwater** productivity because:
- generally large watersheds which mobilize large amounts of reactive nitrogen relative to phosphorus
- cyanobacteria commonly bloom and fix nitrogen at low availability
- **But:** Lakes with small watersheds more often nitrogen-limited, or N and P co-limited
- **Also:** Different community members can be limited by different nutrients, and may also change in time (e.g. seasons)
- **Current discussion:** Phosphorus limitation in unproductive lakes may be induced by **atmospheric nitrogen deposition** - i.e. ‚naturally' N limitation or co-limitation by N and P

Bergström and Jansson 2006; Elser et al. 2009 ; Paerl, 2009; Howarth et al., 2011; European Nitrogen Assessment, 2011

Nutrient limitation characteristics in estuaries and oceans

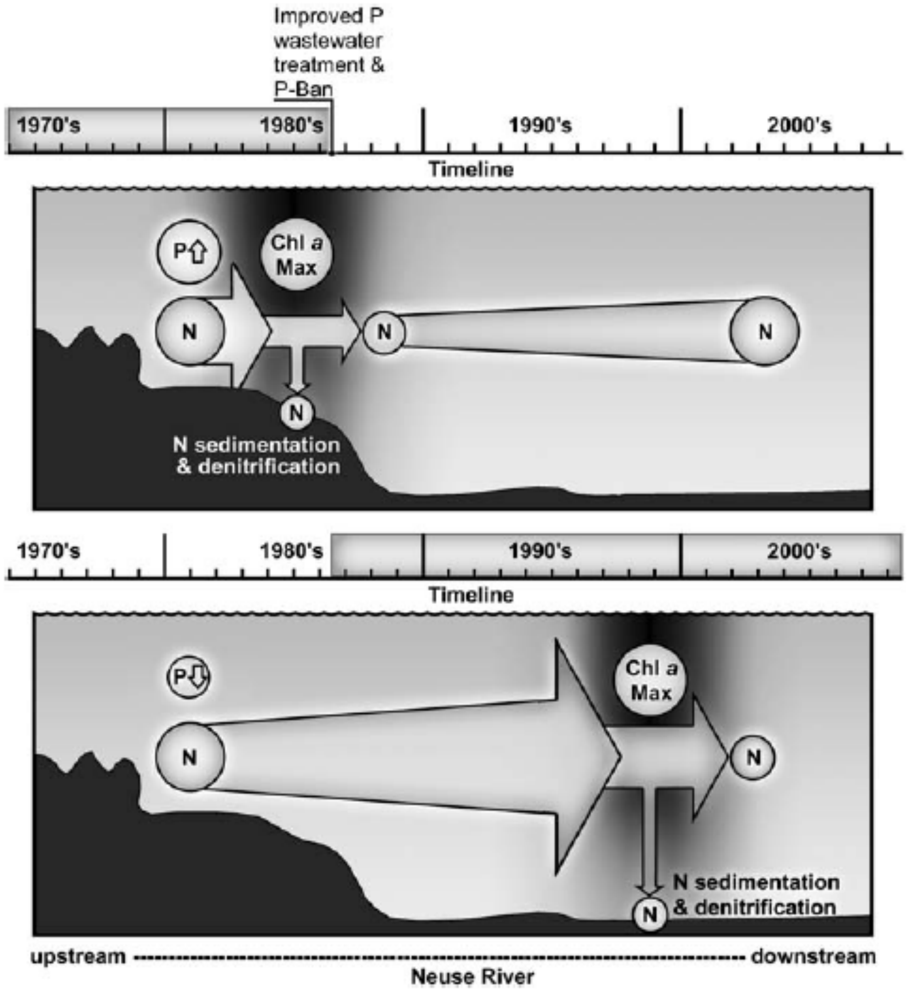
➢ Historically, **coastal** productivity was **nitrogen**-limited because:

- clay- and silt-bound phosphorus is released as salinity increases
- nitrogen fixation rates are immeasurably low in most estuaries with salinities >8-10 ppt
- fractions of the nitrogen pool can exchange with and escape to the atmosphere (e.g. denitrification) while phosphorus is essentially ‚trapped‘ in receiving marine waters

Paerl, 2009; Howarth et al. 2011

Need to consider the freshwater-marine-continuum

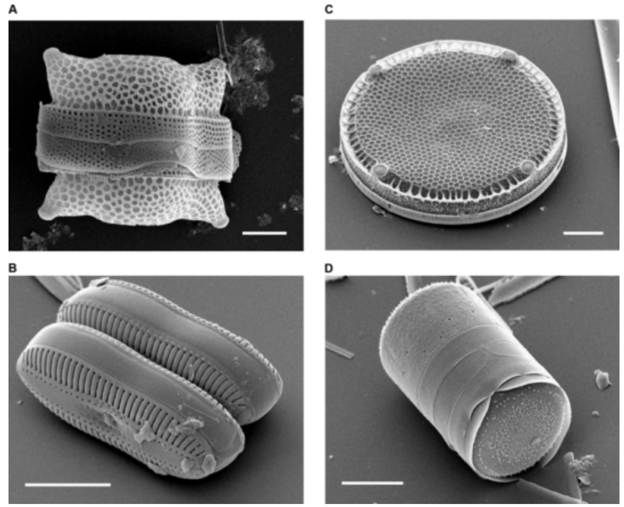
- Exclusive phosphorus reductions upstream (without accompanying nitrogen reductions) can cause increased nitrogen loading further downstreams on the **‚freshwater-marine-continuum**‘, or vice versa
- Call for carefully designed **dual nutrient reduction strategies**



Paerl, 2009

Other nutrients matter as well...for example Silica

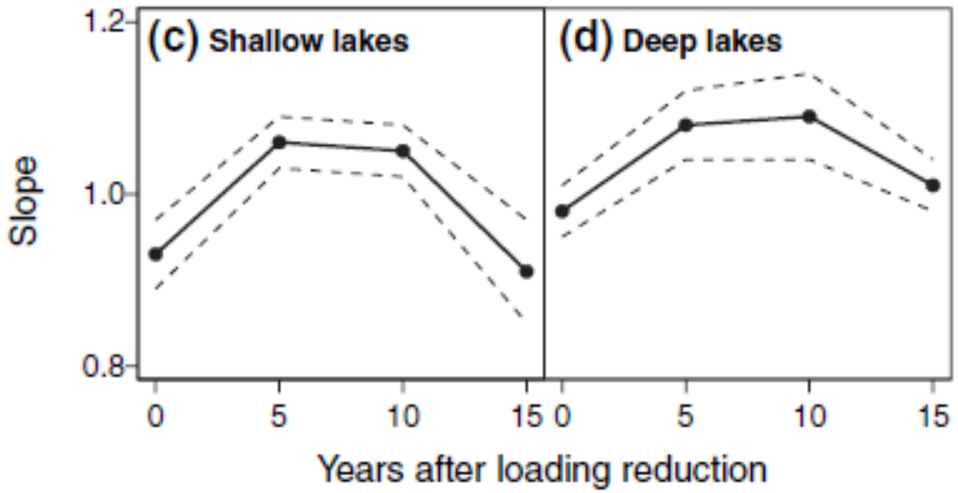
- Originates from rock weathering
- Si fluxes remained constant or decreased due to eutrophication and/or trapping in reservoirs
- Si has become limiting for river **diatoms** in the main branch of large rivers, changing Si-P and Si-N input ratios to the coastal areas
- Shifts in phytoplankton communities, especially from diatoms to non-diatoms



European Nitrogen Assessment 2011

Time scales of recovery

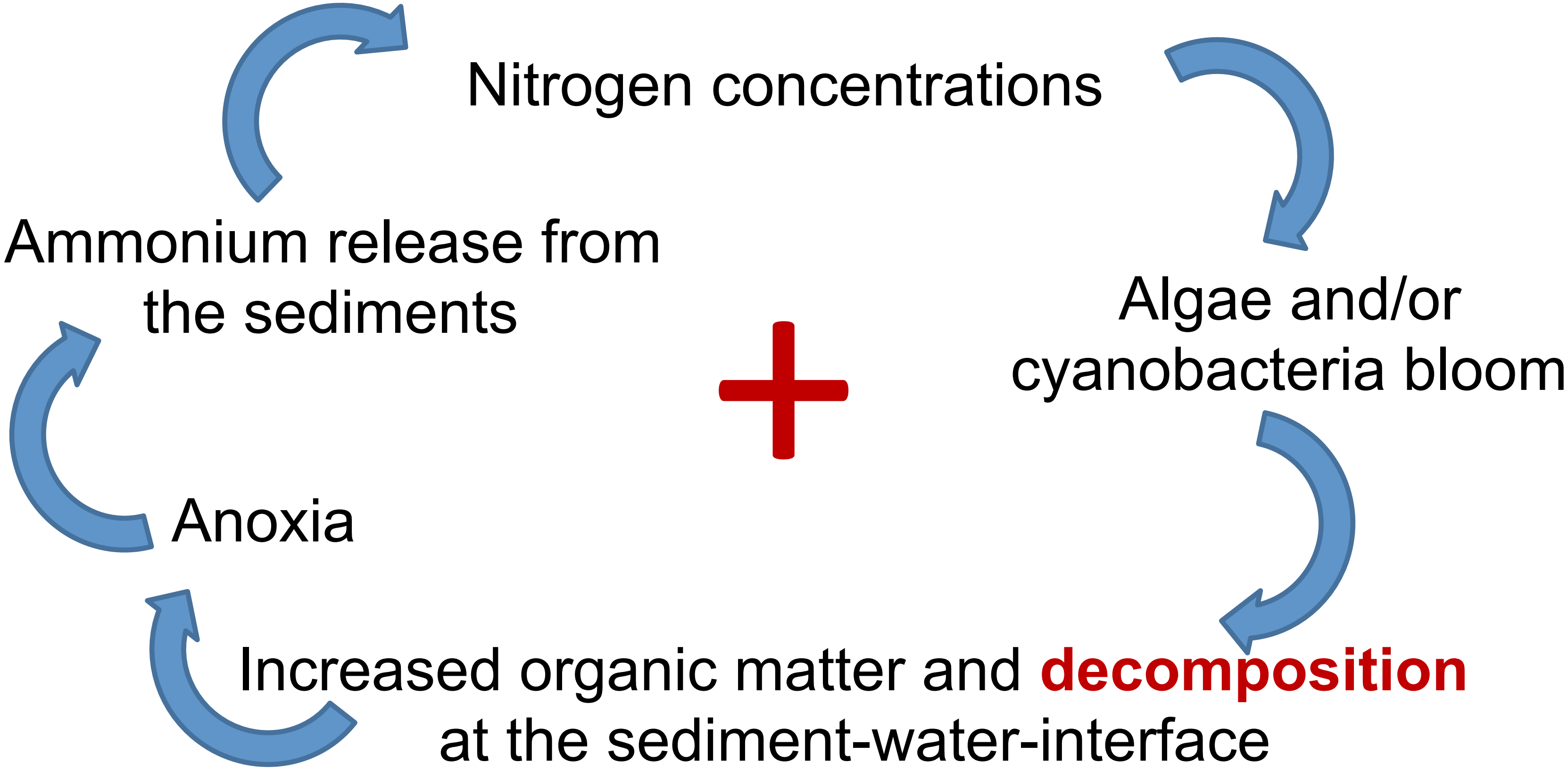
- Meta-analysis of 35 lake re-oligotrophication studies:
- 10-15 years until phosphorus levels had declined **...why?**
- largely due to internal loading from the sediments



- No prolonged delay for nitrogen levels in these lakes, typically <5 years and only in a few cases >10 years
- But: In some aquifers (groundwater), nitrogen concentrations will continue to increase for decades after implementation of efficient mitigation measures!

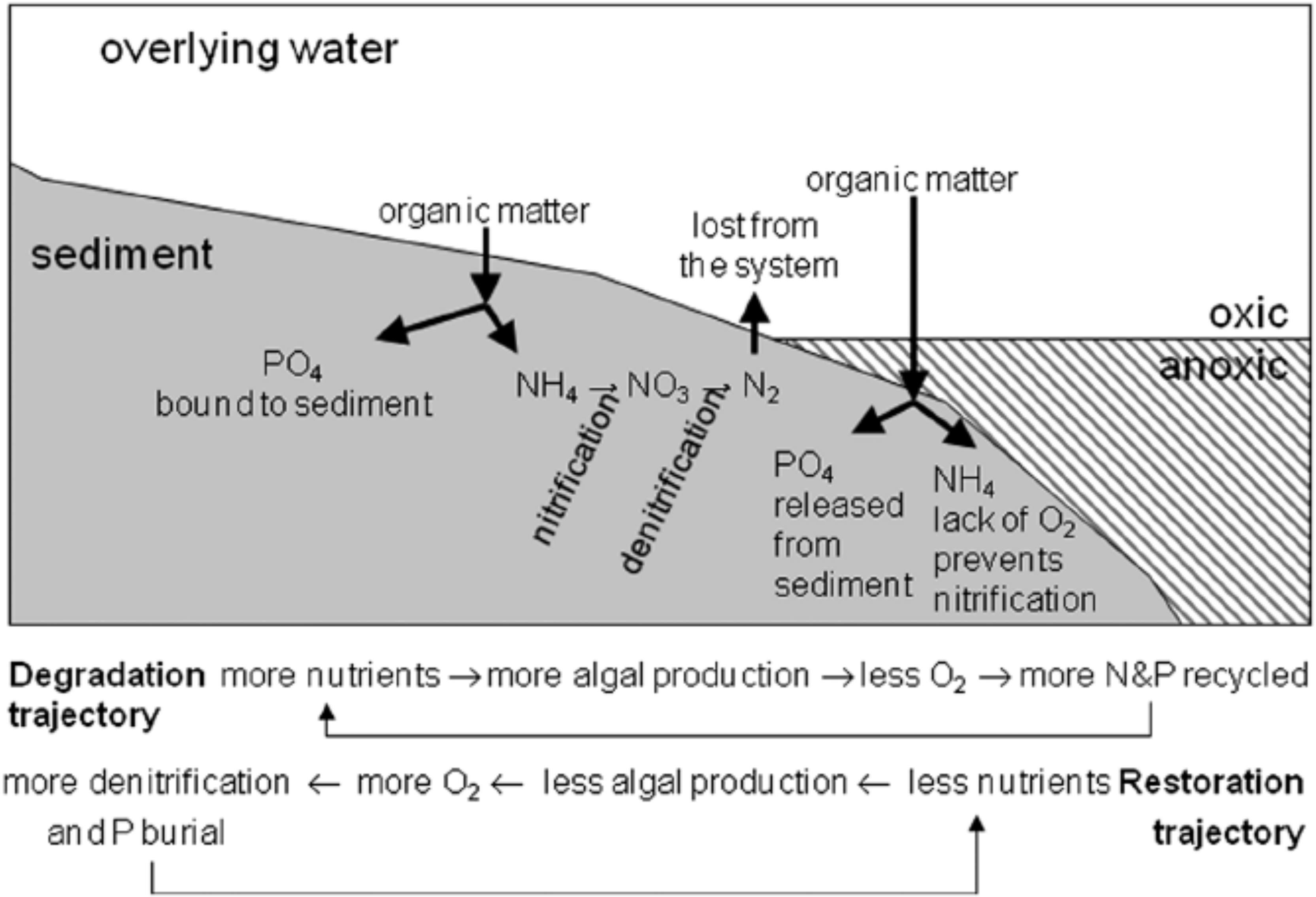
Jeppesen et al., 2005; European Nitrogen Assessment 2011

Feedback by internal nutrient recycling



- **Internal loading** delays the recovery once external nutrient input is reduced

Sediments, oxygen and nutrients

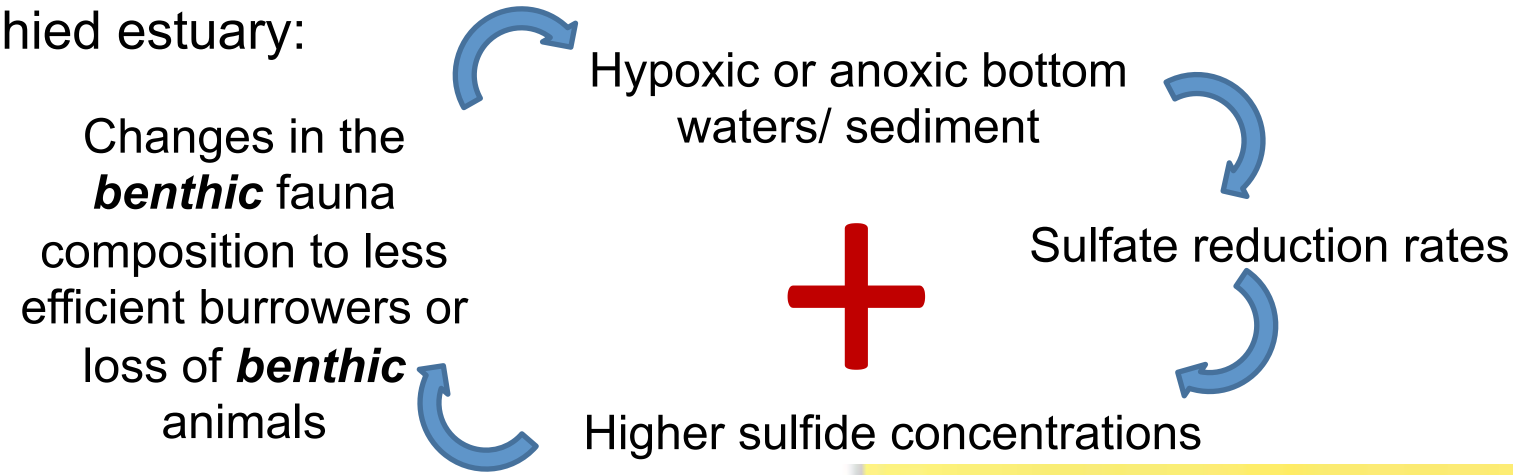


European Nitrogen Assessment 2011

Another sediment-nutrient interaction

- Non-eutrophied estuary: ***Benthic*** (bottom-living) animal burrows increase oxygen penetration into the sediment
- Substantial nitrogen removal by both nitrification and denitrification

- Eutrophied estuary:

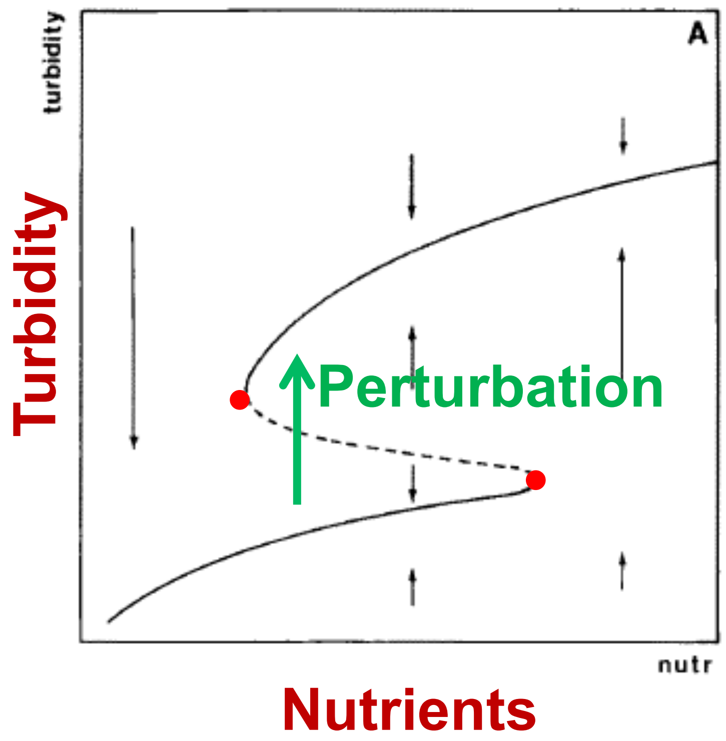


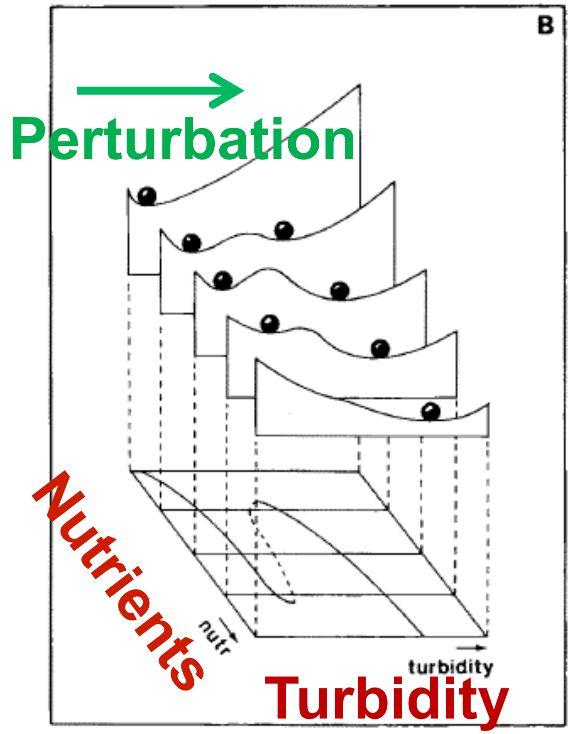
- Oxygen concentrations decrease further due to **changes in the benthic fauna**. What is the consequence of this?

3. Sediment-nutrient interactions need to be considered (e.g. ‚internal loading‘)

Model: Alternative stable ecosystem states

- Abrupt changes of ecosystem ‚behaviour' at bifurcation points (•), or by perturbations
- Restoring to previous environmental conditions is insufficient because of the ‚hysteresis effect'
- ‚Size of the valleys' defines ‚resilience' of the system





Scheffer 1990; Scheffer et al. 2001

An alternative stable state system in lakes

- Sudden loss of transparency and vegetation following eutrophication
- Pristine state: Clear water & rich ***submerged*** (underwater) vegetation
- Alternative state: Turbid water with little or no submerged vegetation

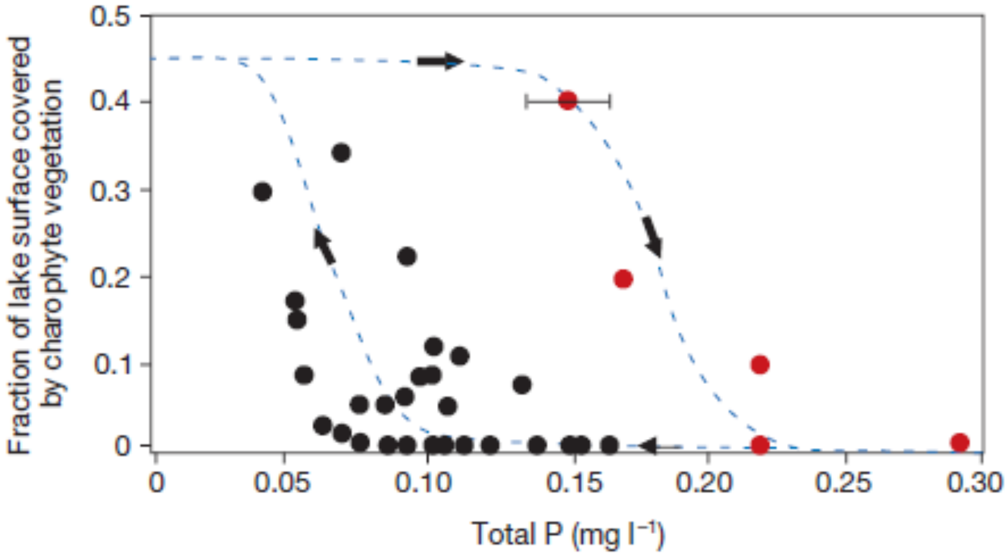


Figure 4 Hysteresis in the response of charophyte vegetation in the shallow Lake Veluwe to increase and subsequent decrease of the phosphorus concentration. Red dots represent years of the forward switch in the late 1960s and early 1970s. Black dots show the effect of gradual reduction of the nutrient loading leading eventually to the backward switch in the 1990s. From ref. 59.

Implications for management/ restoration!

4. Different stable ecosystem states may exist, non-linear dynamics

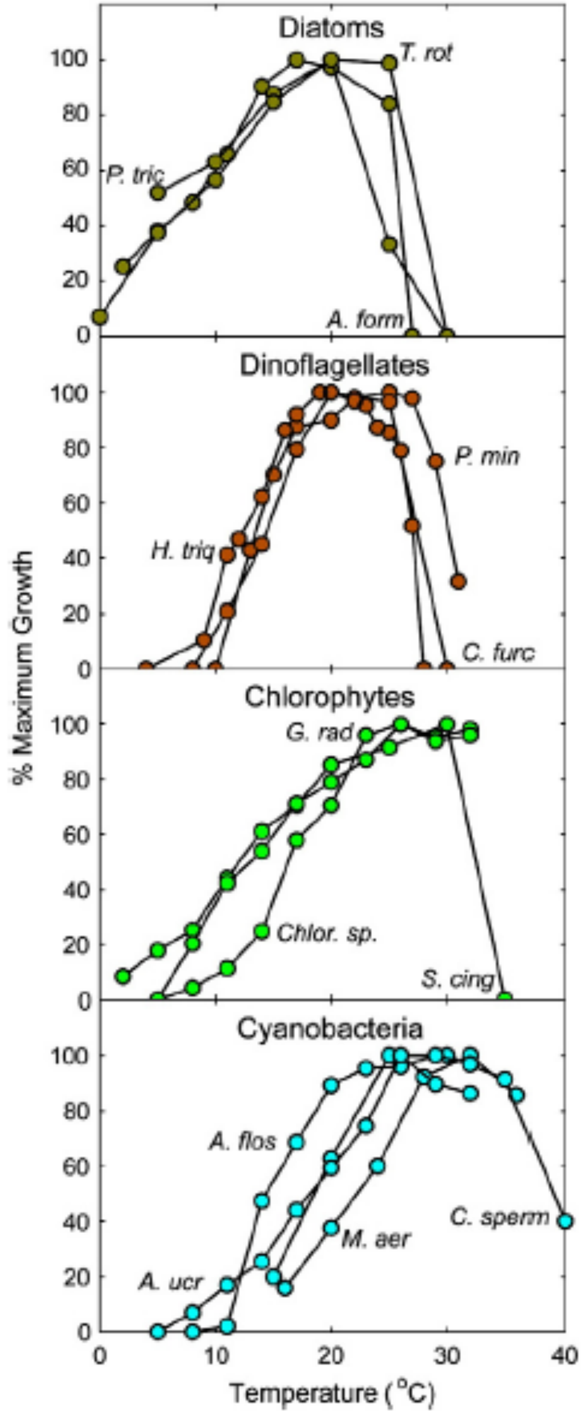
Scheffer 1990; Scheffer et al. 2001

Interactions between climate change and CyanoHABs

- ➢ Reduced **ice-covered periods** expand the seasonal duration of CyanoHABs
- ➢ Warmer surface water intensifies thermal ***stratification*** (layering):
- • favours cyanobacteria which obtain buoyancy by gas vehicles – they float
- • worsenes hypoxia/anoxia at the lake bottom and internal nutrient loading
- ➢ Longer and more intense summer **droughts** intensify salinity stratification -> see above
- ➢ Floating cyanobacteria are favoured when carbon becomes limiting (access carbon dioxide from the atmosphere)
- ➢ High optimal growth rate **temperatures** of cyanobacteria

Paerl et al., 2011

High optimal growth rate temperatures of cyanobacteria



Paerl et al., 2011

Managing hydrodynamic or sediment processes to reduce CyanoHABs?

- **Remember? When nutrient inputs are decreased, how long about does it take until nutrient concentrations in the water actually decrease?**
- **Why is that?**
- **If ‚technical' management, then only in parallel with long-term nutrient reduction strategies!**

- Enhance ***hypolimnion*** (bottom layer of a stratified lake) oxygenation by artificial vertical mixing, e.g. air-bubbling -> expensive and restricted to small lakes
- Reduce water residence times by water flushing -> expensive and freshwater supplies may be limited
- Reduce internal loading by removing or capping sediments -> expensive and extensive bottom disturbance
- Reduce water column phosphorus by chemical precipitation that also forms a barrier to sediment nutrient release -> irreversible!!

Paerl et al., 2011

FIKA!

Questions about part 1?

Commonly, primary production is...

1. limited by phosphorus in freshwaters, and limited by nitrogen in coastal waters.
2. limited by nitrogen in freshwaters, and limited by nitrogen in coastal waters.
3. co-limited by phosphorus and nitrogen in both fresh- and coastal waters.
4. unlimited in both fresh- and coastal waters.
5. limited by iron and silica.

2 times 2 minutes ’speed dating’ with your neighbour

a) What was unclear for you so far?
   2 minuter

b) What was the most interesting for you so far?
   2 minuter

Questions to the big group?

What are consequences of low/no oxygen (hypoxia/anoxia) over and in the sediment?

Which central concepts/mechanisms need to be kept in mind when planning nutrient management programs?

- Which actions concerning eutrophication management are required by EU law?
- How do eutrophication management plans look like in practise?

Main EU Directives related to nitrogen

Directive	Description / objectives
2000/60/EC **2000**	**Water Framework Directive (WFD):** to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater from pollution and depletion
91/271/EEC **1991**	**Urban Waste Water Treatment Directive (UWWD):** to protect the environment from the adverse effects of waste water discharges from urban areas and certain industrial sectors
91/676/EEC **1991**	**Nitrates Directive (ND):** concerning the protection of waters against pollution caused by nitrates from agricultural sources

- Requires to reach ‚good ecological status‘ by 2015

- Requires collection systems and standardized sewage treatment
- Treatment system needs to remove 70-80% of the initial reactive nitrogen

- Requires:
  - Monitoring
  - Identification of polluted waters and of those at risk
  - Designation of areas draining into these
  - Establishment of ‚good agricultural practises‘ and of action programmes
  - Review at least every 4 years

Main EU Directives related to nitrogen

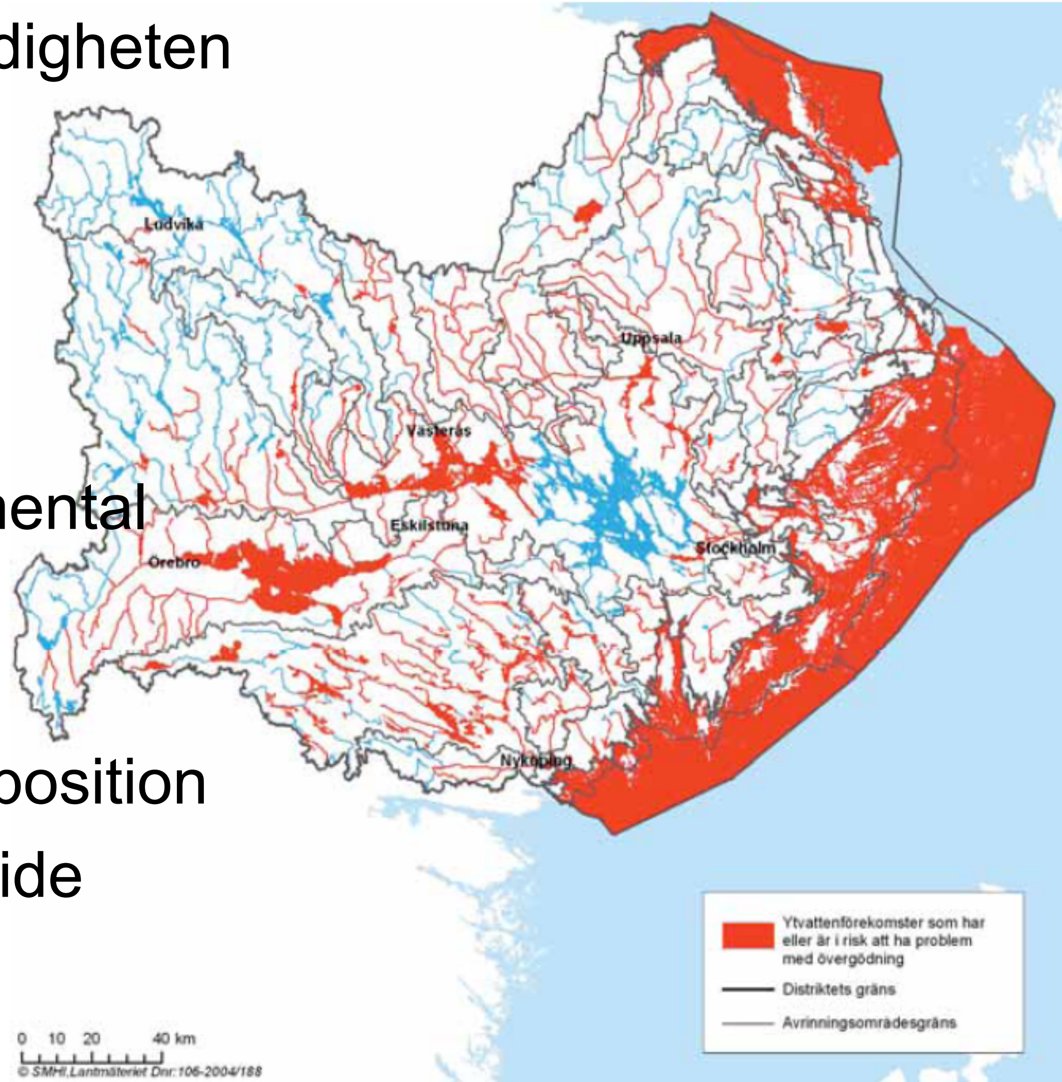
2008/56/EC **2008**	**Marine Strategy Framework Directive:** establishes a framework to take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 at the latest	
2006/118/EC **2006**	**Groundwater Directive:** establishes a regime which sets underground water quality standards and introduces measures to prevent or limit inputs of pollutants into groundwater	

- Establish good environmental status of the marine waters by 2020
- Requires regular monitoring and assessments

- Requires to:
  - Carry out pollution trend studies
  - Reverse pollution trends till 2015
  - Review in 2013 and every 6 years thereafter
  - Comply with ‚good chemical status' criteria

Example: Åtgärdsprogram för Norra Östersjöns vattendistrikt 2009 - 2015

- Published by Vattenmyndigheten Norra Östersjön and Länsstyrelsen Västmanländs lan
- Eutrophication is the most extensive environmental problem in the district
- About 85% of the atmospheric nitrogen deposition stems from sources outside Sweden



Figur 2. Vattenförekomster som bedömts ha miljöproblemet övergödning är markerade med rött.

Six main sources evaluated and analysed

Agriculture

Forests/Silviculture

Industry

Sewage treatment plants

Atmospheric deposition

Household wastewater

Agriculture

- Status:
- ~5% reduction in P between 1995-2005
- ~5% increase in N between 1995-2000 and another 15% between 2000-2005

- Analysed as promising management options:
- Ponds for phosphorus elimination
- Buffer zones
- Wetlands

- Can be conducted in big areas, without much time delay, will cause a significant effect, and it‘s possible to estimate the costs and the reduction effects

Forests/Silviculture

- No changes in nutrient losses

- Analysed as promising management options:
  - Buffer zones
  - Reduce damages during harvest and management

Sewage treatment plants

- Status between 1995-2006:
- ~20% reduction in P and ~35% reduction in N
- Projected population increase of ~5% from 2008-2015 will cause an increase in nutrient inputs if treatment is not improved

- The treatment plants need to reduce the losses of P by 35-50%, and the losses of N by 50-70%
- Higher doses of precipitation chemicals
- Installation of final filters
- Post-incubation in wetlands
- Improved microbial processing

Industry

- ➢ Status between 2000-2006:
- • ~30% reduction in P and ~40% reduction in N

- ➢ Until 2015 a projected 5-40% increase in industrial activities, needs to be met with increased effectivities or improved cleaning

- ➢ Hard to make generalized statements
- ➢ Assumed similar techniques and consequences as for water treatment plants

Atmospheric deposition

- Status between 1995-2006:
  - Increased by ~4% for P and by ~3% for N
  - N deposition is expected to increase

- No further statement - main sources are outside of Sweden, political decisions and actions needed!

- See e.g. INI (International Nitrogen Initiative)

  http://initrogen.org/

  International Nitrogen Initiative

- N*in*E (Nitrogen in Europe)

  http://www.nine-esf.org/node/204

Wastewater from households

- Wastewater from households between 2000-2006:
- Increased by ~5% for both P and N
- Can increase parallel to the increasing population, trying to counteract by ban of P in detergents
- The losses need to be reduced by 25-40%

- Analysed as promising management options:
- Installation of sand beds/sand filters and/or P-filter behind the existing silt/mud filters

All in all

- Phosphorus input to the aquatic systems in Norra Östersjöns vattendistrikt not expected to be significantly reduced until 2015, N input expected to increase somewhat

Tabell 19. Kostnader och nyttor av minskad tillförsel av fosfor och kväve

Åtgärd / kostnadspost		**Direkta kostnader (tkr/år)**	
Jordbruk		175 000	(120 000 – 230 000)
Kommunala ARV		255 000	(200 000 – 310 000)
Industri		21 000	(18 000 – 26 000)
Enskilda avlopp		119 000	(84 000 – 140 000)
Administrativa kostn.		154 000	(120 000 – 189 000)
Summa kostnader		724 000	(545 000 – 896 000)
	Direkta nyttor	**Effekt (kg/år)**	
		Fosfor	**Kväve**
Jordbruk	Rening av fosfor och kväve	45 000	107 000
Kommunala ARV	Rening av fosfor och kväve	34 000	2 500 000
Industri	Rening av fosfor och kväve	3 900	150 000
Enskilda avlopp	Rening av fosfor och kväve	17 000	90 000
Summa	Rening av fosfor och kväve	100 000	2 800 000
	Indirekta kostnader och nyttor	**Effekt**	
	Biologisk mångfald	++	
	Rekreation och friluftsliv	++	
	Minskning av miljögifter	++	
	Minskad smittspridning	++	
	Minskad variation i närsaltflöde	+	
	Minskad rening vid vattenverk	+	
	Minskad luktolägenhet	+	
	Ökade transporter	-	
	Ökad energianvändning	-	
	Brukningshinder	-	
	Metangasutsläpp	--	

Movie ‚A fragile sea', HELCOM

The Baltic Sea

- Shallow *brackish* water sea
- Average depth 52.3 m
- Limited water exchange through the Danish sounds -> average water residence time 30 years
- Surrounded by heavily industrialized countries and a population of ~85 million people
- Eutrophication is the major problem of the Baltic Sea
- Since the early 1900 the N loading from rivers has increased ~7 times, the P loading ~4 times

European Nitrogen Assessment 2011

In front of our door step

- The Baltic Sea contains the largest anthropogenic dead zone (hypoxia/anoxia) in the world!

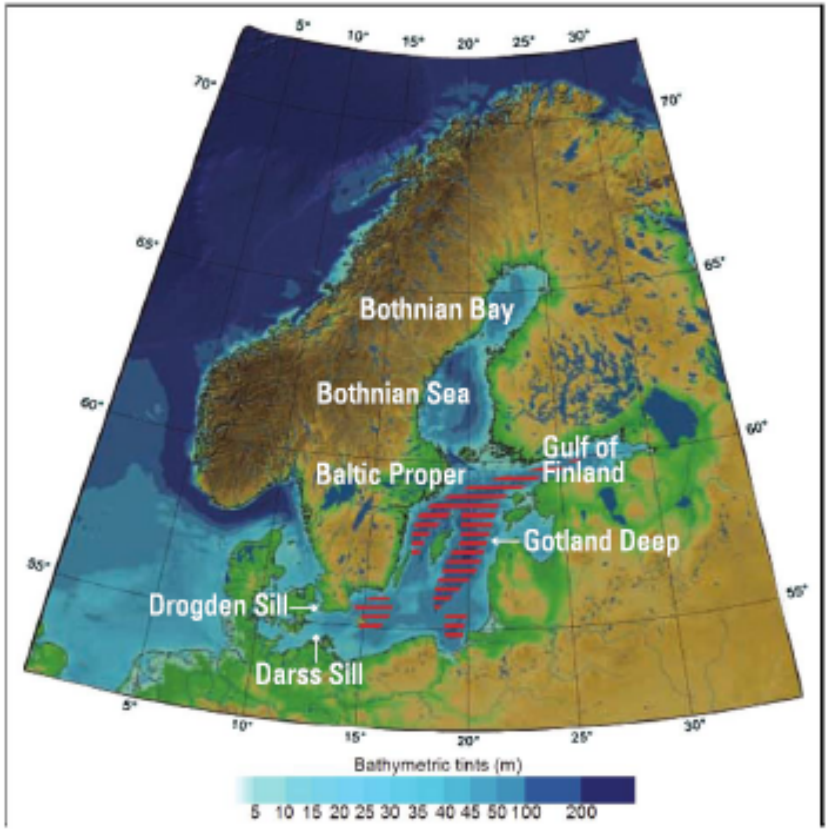
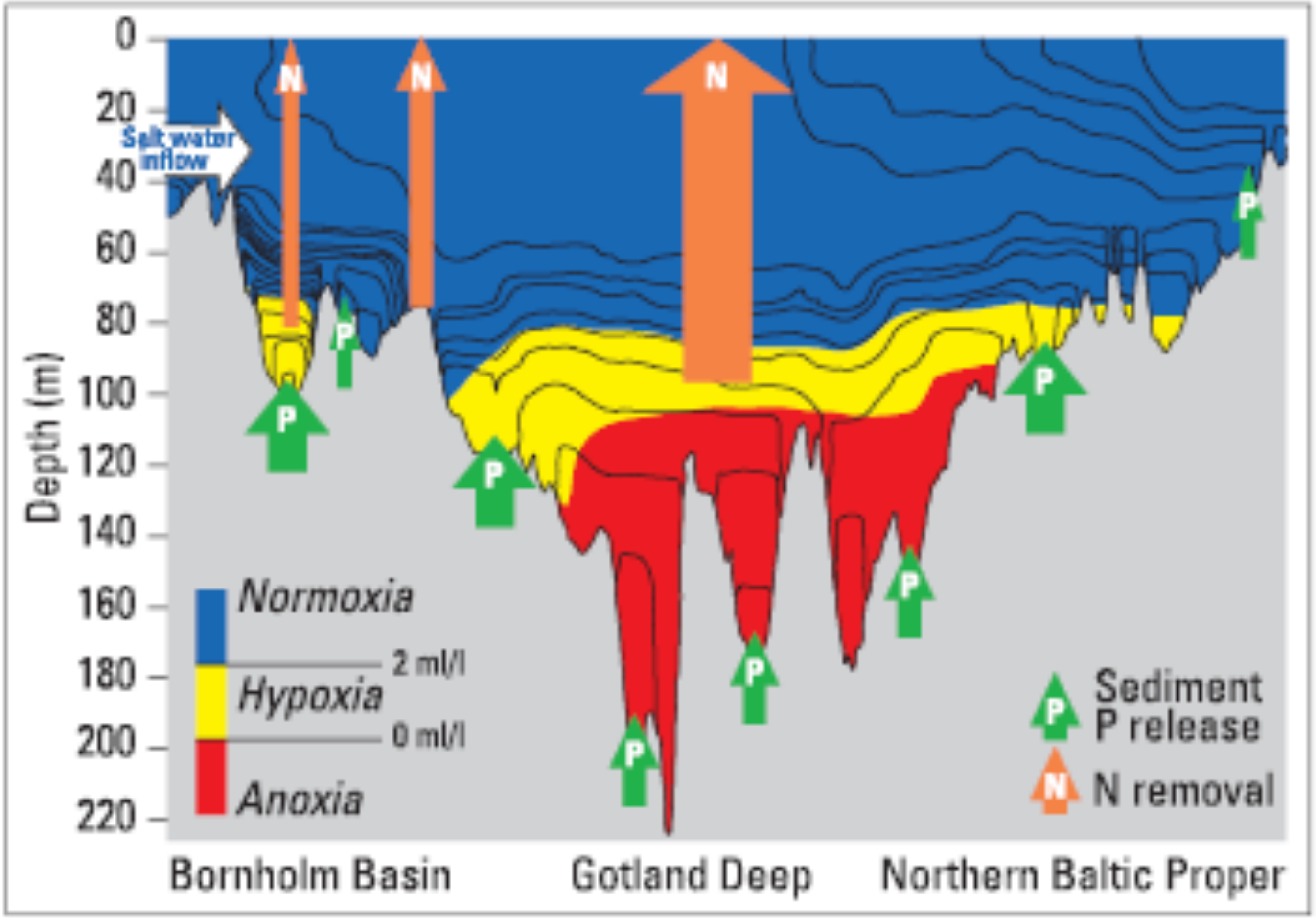


FIGURE 1. Map of the Baltic Sea identifying its major basins and sills governing the inflow of saltwater. The red lines designate the maximum hypoxic area that occurs in the Baltic Sea.

Díaz and Rosenberg, 2008; Conley et al., 2009

Oxygen conditions in the Baltic Sea



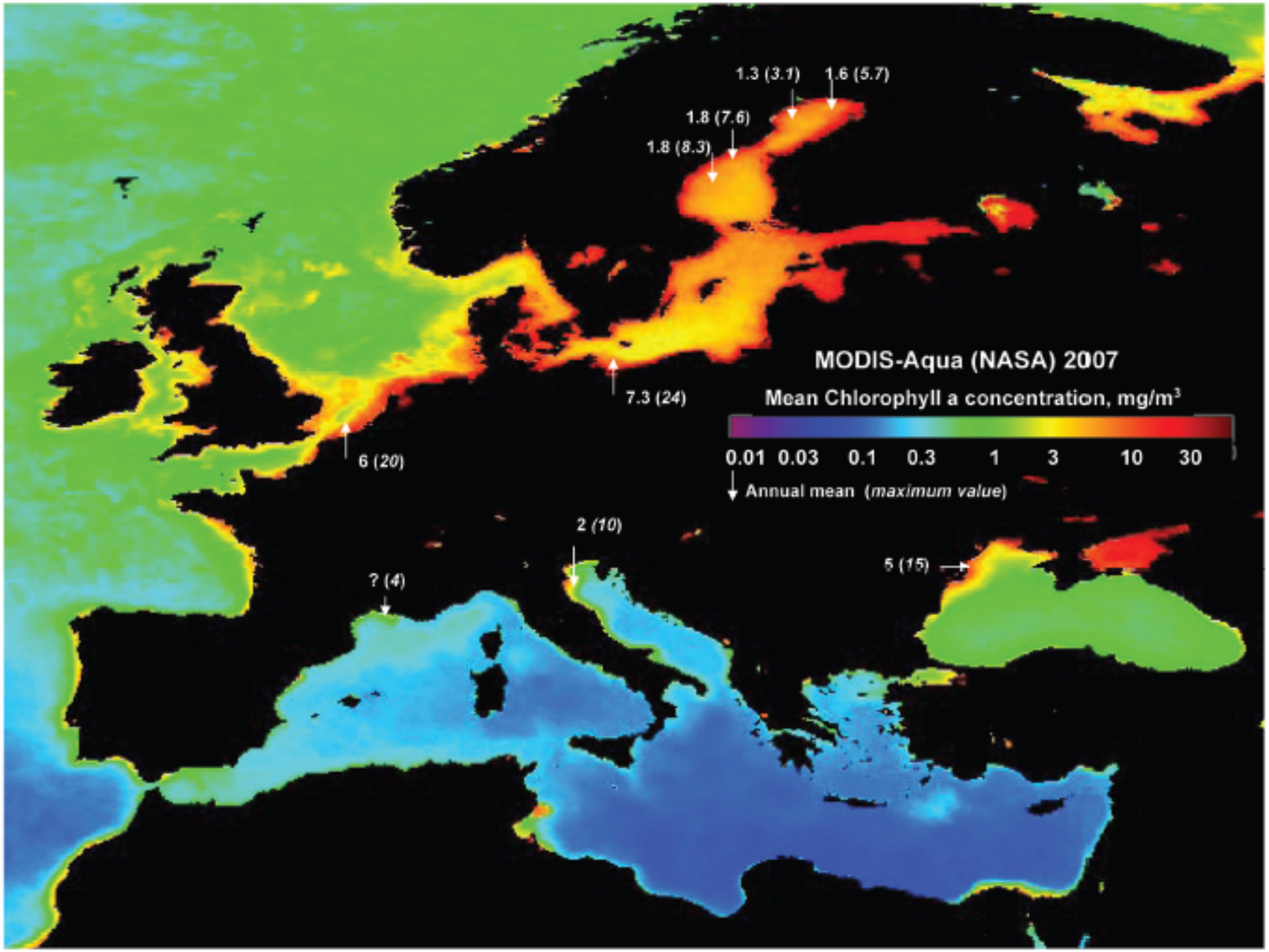


Figure 13.17 Composite satellite image of mean chlorophyll concentration along the European coasts in 2007 (from MODIS-Aqua satellite data, source: JRC, http://marine.jrc.ec.europa.eu/). Annual mean and maximum values in brackets of direct measurements at selected stations are also shown to provide an absolute reference (Lancelot *et al.*, 2005; Solidoro *et al.*, 2009; M. Voss, personal communication).

European Nitrogen Assessment 2011

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