Chapter 5

IMPACTS OF CURRENT AND FUTURE CLIMATE CHANGE

IMPACTS ON THE ENVIRONMENT:

Atmospheric Chemistry

Terrestrial Ecosystems

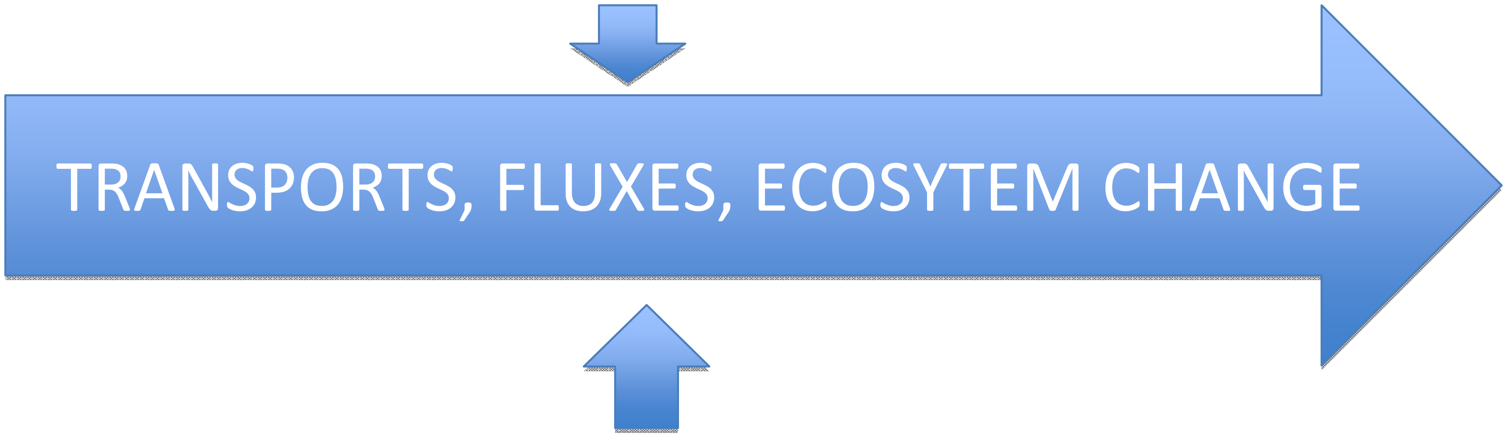
Freshwater Biogeochemistry

Marine Biogeochemistry

Marine Ecosystems

DRIVERS (compounding factors)

CLIMATE AND



CULTURAL EUTROPHICATION

URBAN/INDUSTRY/SHIP EMISSIONS

FORESTRY/WETLAND MANAGEMENT

HYDROLOGICAL ATERATIONS

LAND USE, FISHING ETC.

ATMOSPHERIC CHEMISTRY

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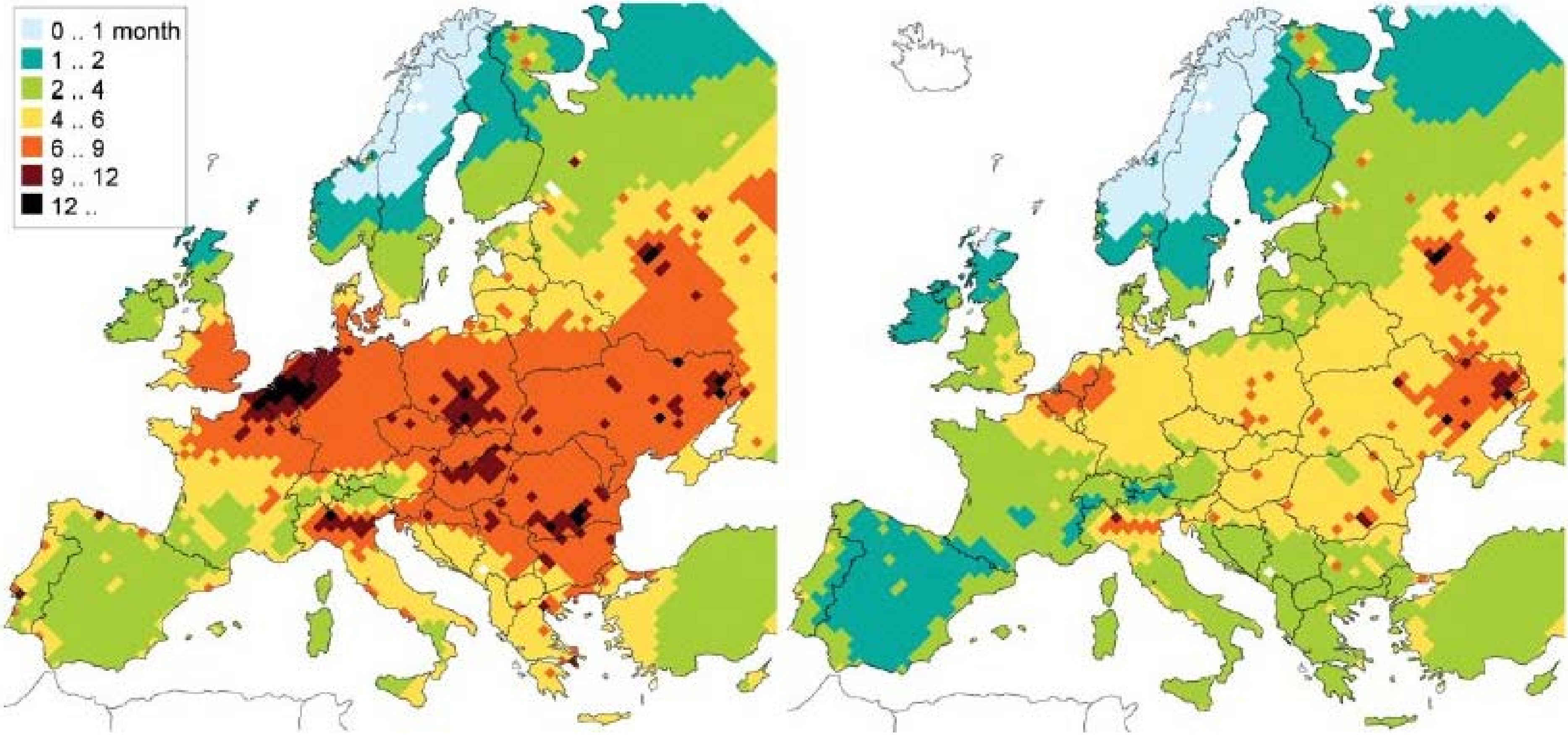
- Air pollution has important effects on the Baltic region, including:
  - ecosystem impacts due to deposition of acidifying and eutrophying pollutants
  - health impacts
  - climate impacts, including those of short-lived climate forcers such as sulphate and ozone (see chapter 6.2, Hansson et al.)

Health impacts, particularly of particulate matter (PM), but also of ozone and other pollutants.



Estimated loss in statistical life expectancy attributable to exposure to $PM_{2.5}$ from anthropogenic sources (in months). Left panel: 2005; right panel: baseline projection for 2020. From Amann et al. (2011)

- The main changes in air pollution in this region are due to changes in emissions rather than climate-change itself.
- Concentration and deposition changes of the acidifying components (SOx, NOx, NHx, PM) generally follow emission changes within the European area

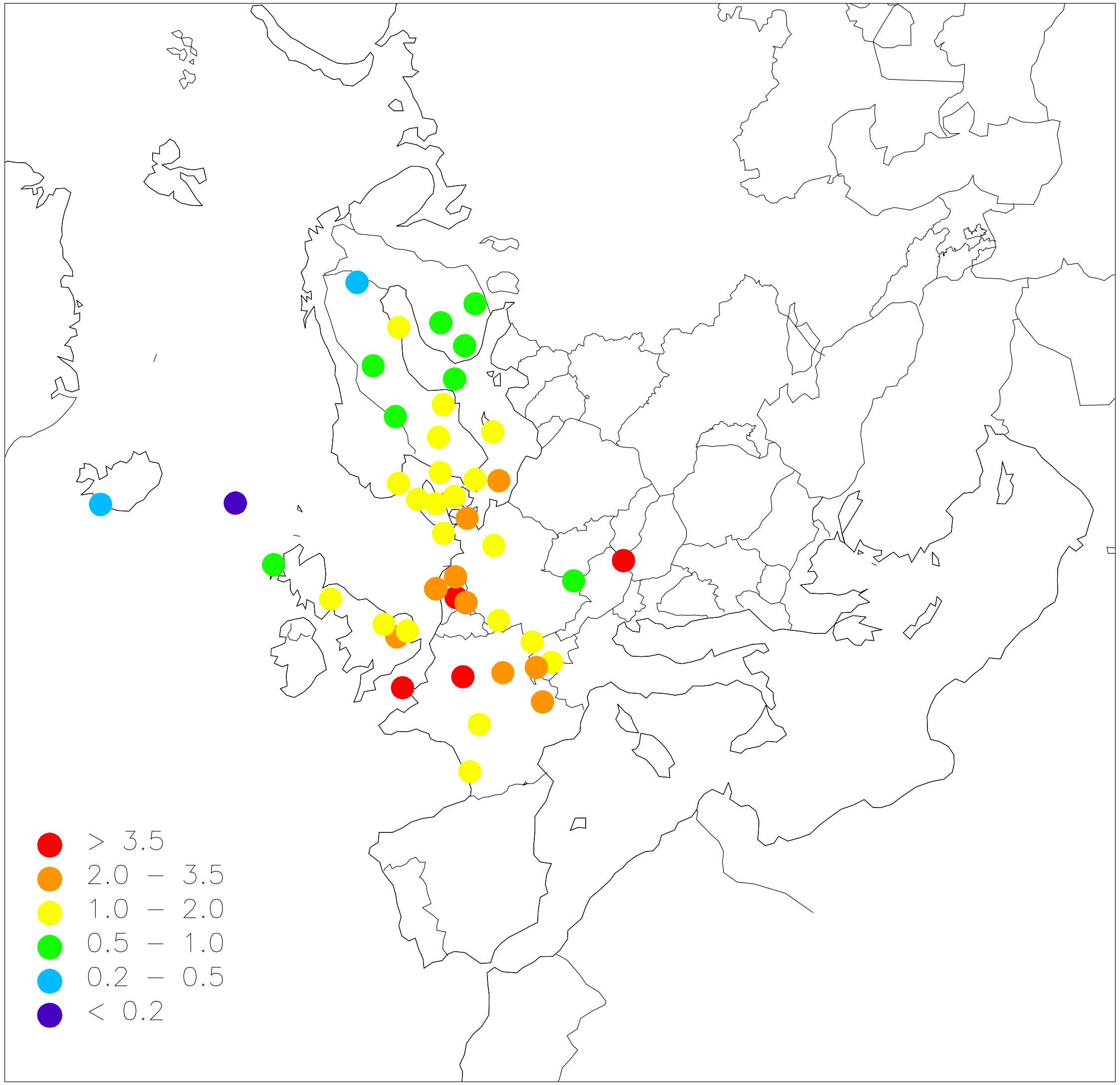
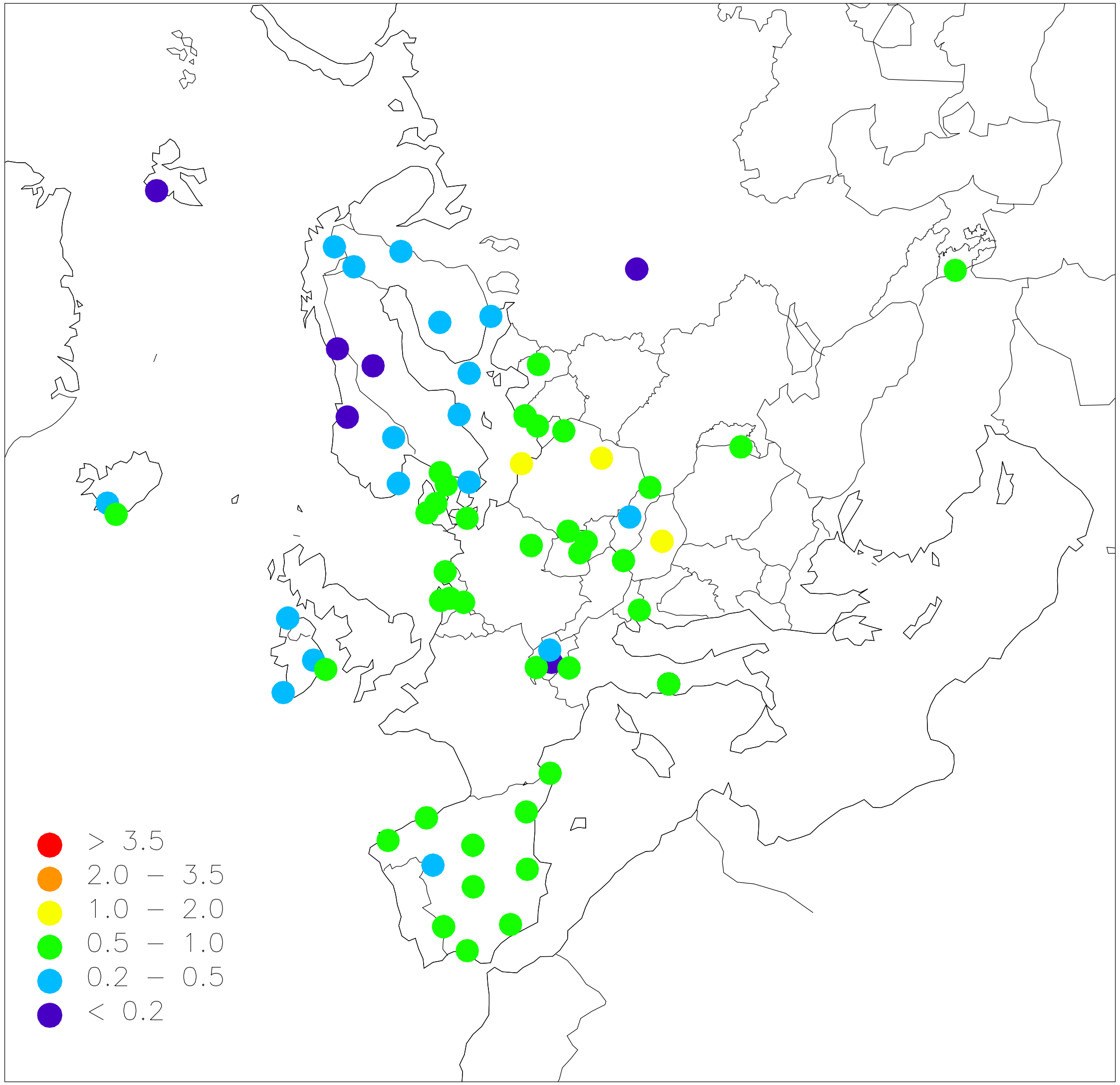


Fig. 2 **Annual mean concentrations of SO_4^{2-} in aerosols** for 1974 and 2009, estimated from the EMEP network for selected stations. Unit: ug S/m³. From Tørseth et al. (2012).



> 3.5
2.0 – 3.5
1.0 – 2.0
0.5 – 1.0
0.2 – 0.5
< 0.2

- Emission changes have been very significant over the last 100 years, although very different for land and sea-based sources:
  - Land-based emissions (industry, traffic, etc.) generally peaked around 1980-1990, and have since been reduced as a result of stringent emissions control measures
  - Emissions from shipping have been steadily increasing for decades, but the recent introduction of sulphur emission control areas (SECA) has reduced SOx emissions

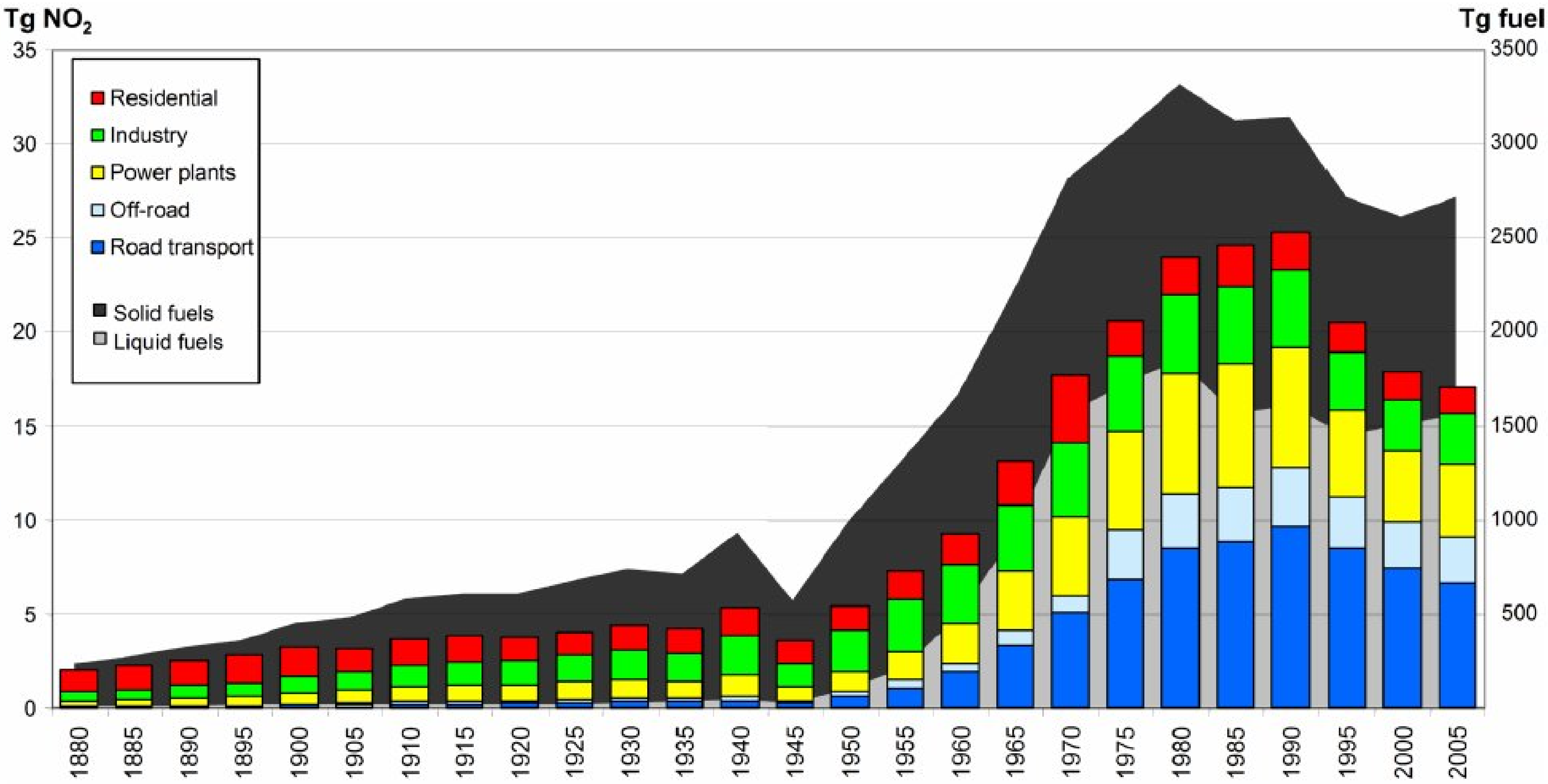
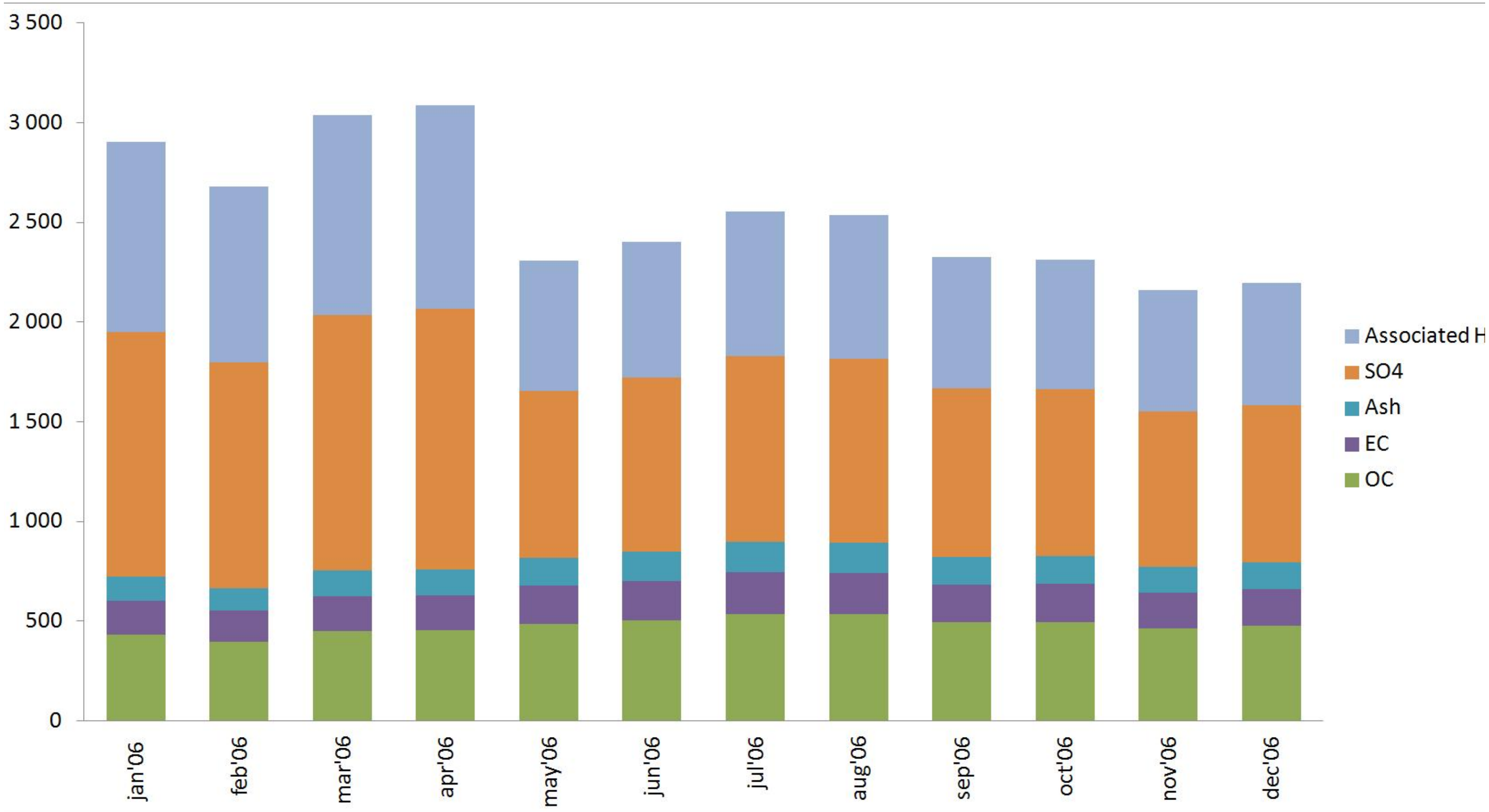


Fig. 3 European solid and liquid **fossil fuel consumption 1880-2005**. Data from the GAINS model 1990–2005 (Tg fuel/year, right axis). **Sector trends in European NO2** emissions 1880-2005 (Unit Tg(NO2)/yr, left axis). From Vestreng et al. (2009)



Emissions of particulate matter from Baltic Sea shipping during 2006. The reduction in emissions occurred as a result of tightened sulphur content requirements of the SOx Emission Control Area. (SECA) (Jalkanen et al. 2012).

IMPACTS OF CURRENT AND FUTURE CLIMATE CHANGE ON **TERRESTRIAL ECOSYSTEMS**

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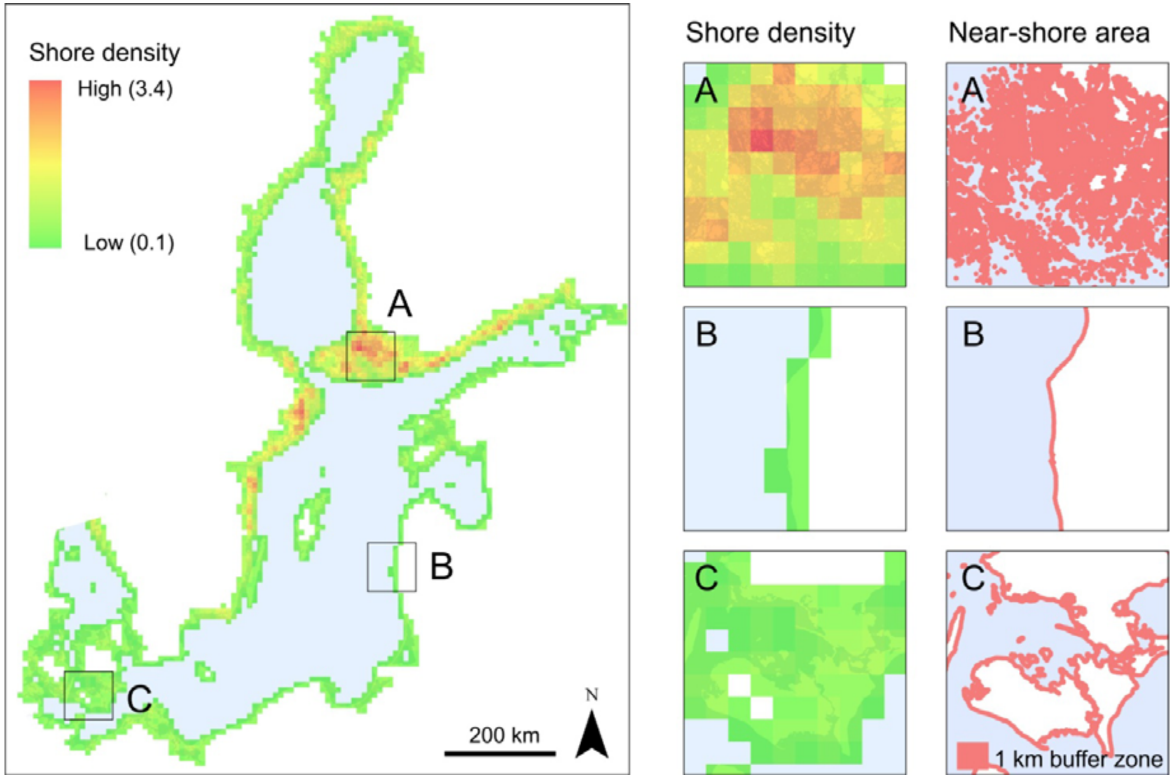
Coastal areas play a key role in the intreaction between the terrestrial and aquatic ecosystems.

Areas with high coastal area densities (for example A) represent high biodiversity of plant and animal communities and ecosystems.

Coastal and archipelago ecosystems are sensitive to environmental changes like climate or related changes (salainity etc).

Shore line density along the coasts of the Baltic Sea



Effects of the post-gacial land uplift on ecosystems

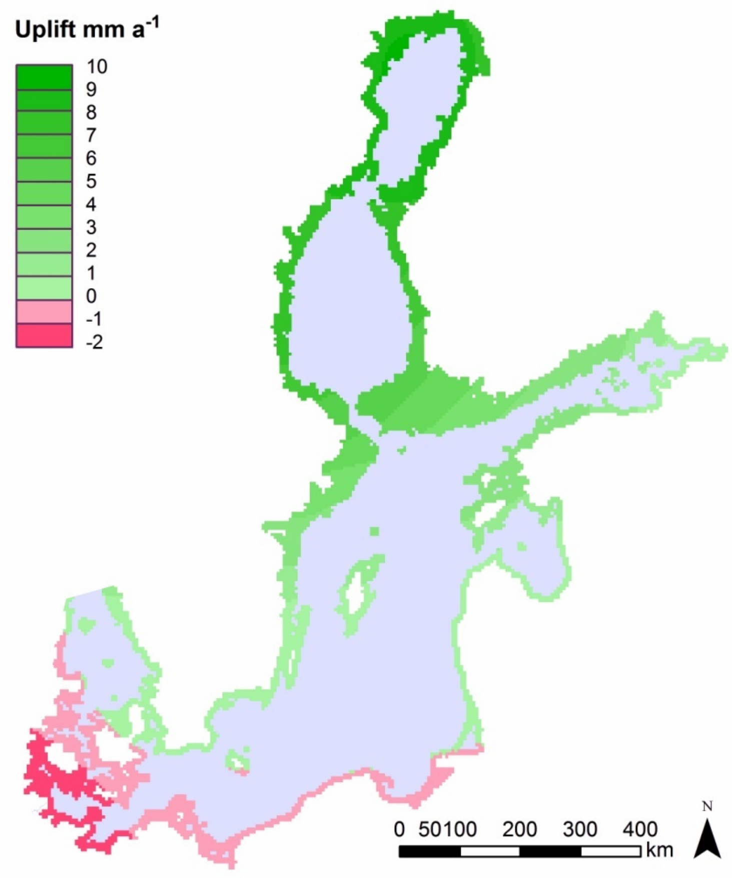
-The rate is highest in northern parts of Baltic Sea.

-Continous succession of coastal plant and animal communities.

-As a consequence of climatic change more southern species will invade into coastal terrestial and aquatic ecosystems.

-More southern invasive species will enter into coastal ecosystems

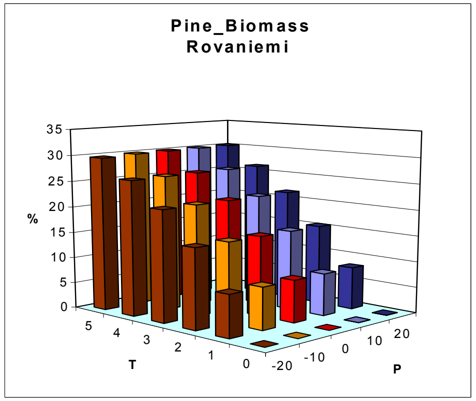
Rate of the post-glacial land uplilift

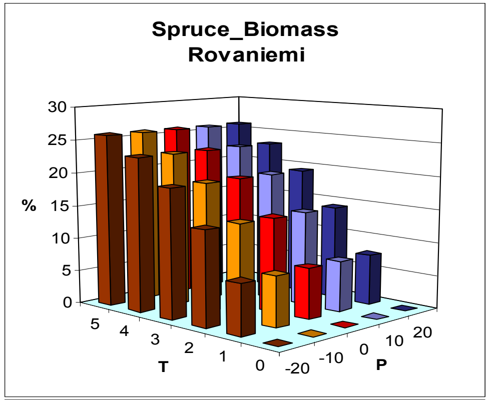


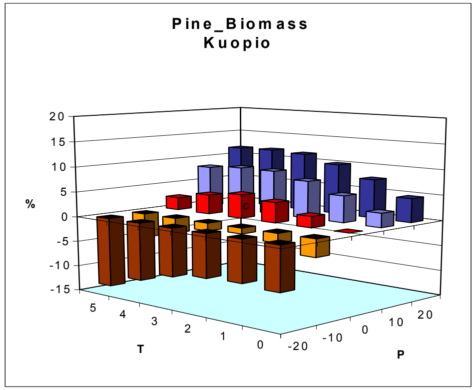
Sensitivity of forest to climate change (model study)

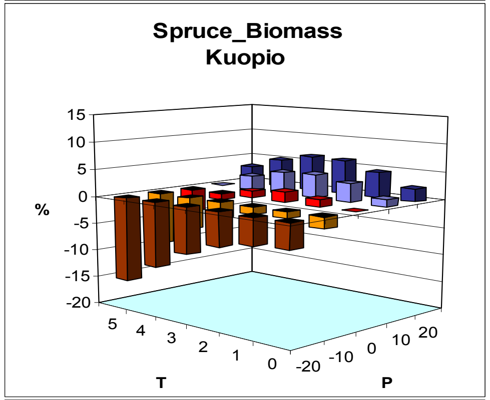
Sensitivity of growth of Scots pine and Norway spruce in different parts of the Baltic Sea Basin

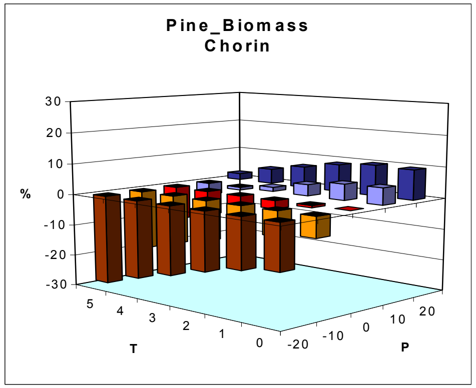
In the northern boreal forests, temperature is the only driving force in the climate response with generally positive effects on coniferous tree growth, whereas in the temperate forests in the southern part of the Baltic Sea Basin precipitation becomes more important

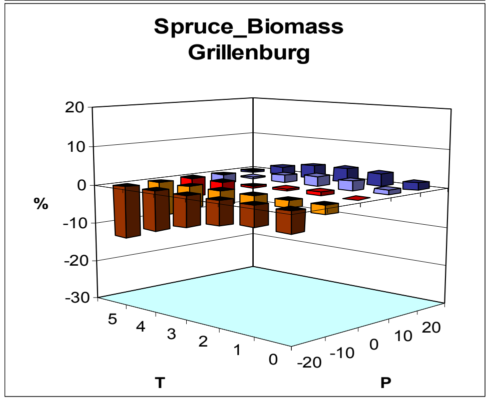












Average regional growing stock (m^3ha^{-1}) in 2000 (current climate) and in 2100 (current climate and two climate scenarios ECHAM4 and HadCM2).

Region and country group	2000	2100				
	Current Climate	Current Climate	ECHAM4		HadCM2	
Boreal	114	151	185	(+22%)	182	(+20%)
Baltic	197	208	239	(+15%)	240	(+15%)
Temperate-Atlantic	209	461	480	(+4%)	485	(+5%)
Temperate-continental	255	389	421	(+8%)	418	(+8%)

IMPACTS OF CURRENT AND FUTURE CLIMATE CHANGE ON **FRESHWATER BIOGEOCHEMISTRY**

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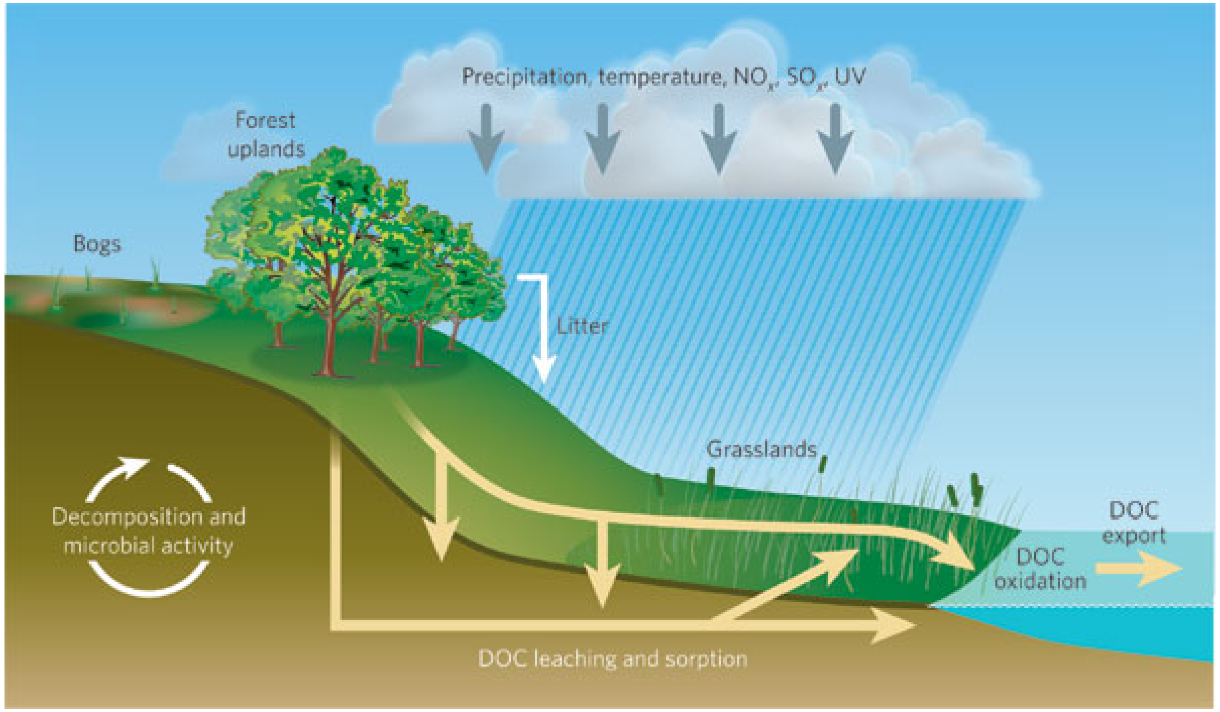
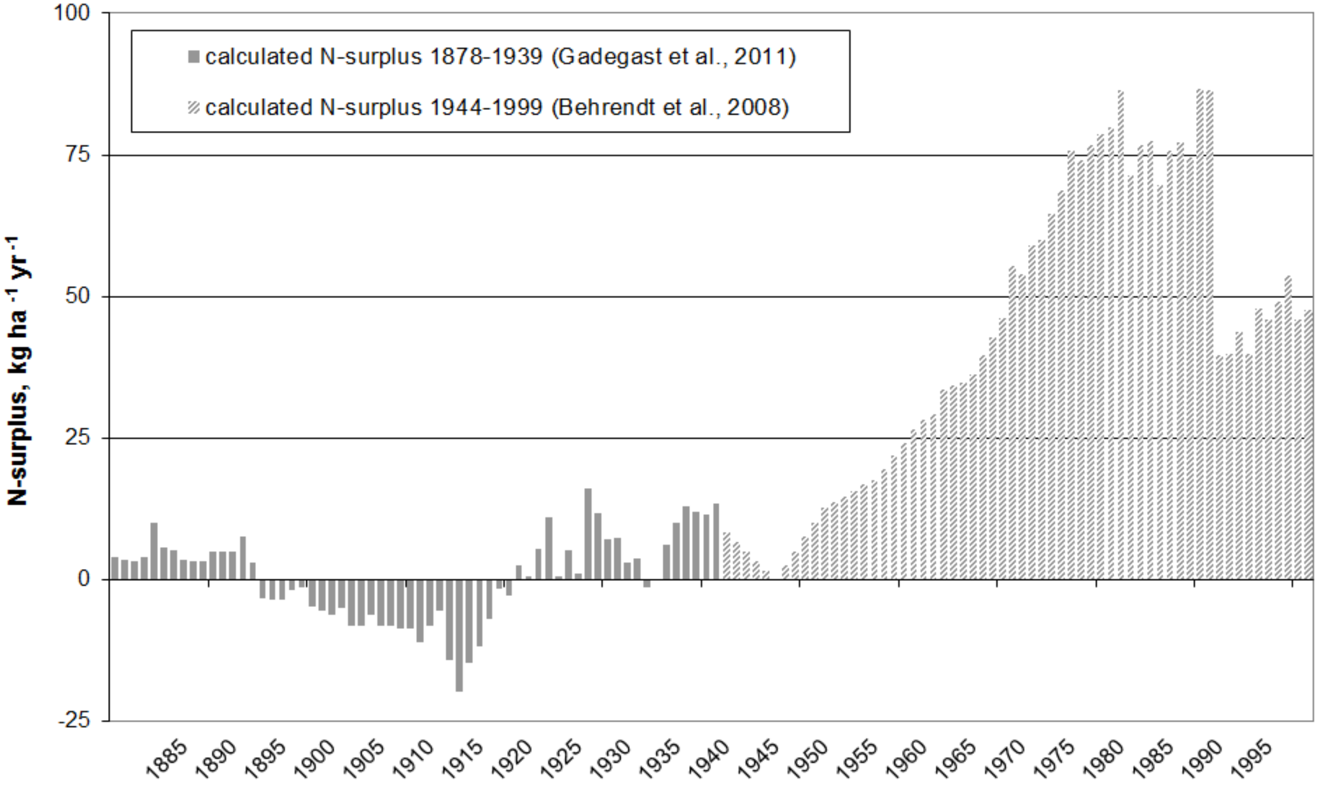
- More DOM export likely in boreal watersheds (small scale field studies)
  Higher runoff
  Recovery from acidification
  Higher biomass turnover

- On the short-term, climate change is unlikely to affect the spatial distribution of wetlands
- Forestry affects annually only small parts of the catchment



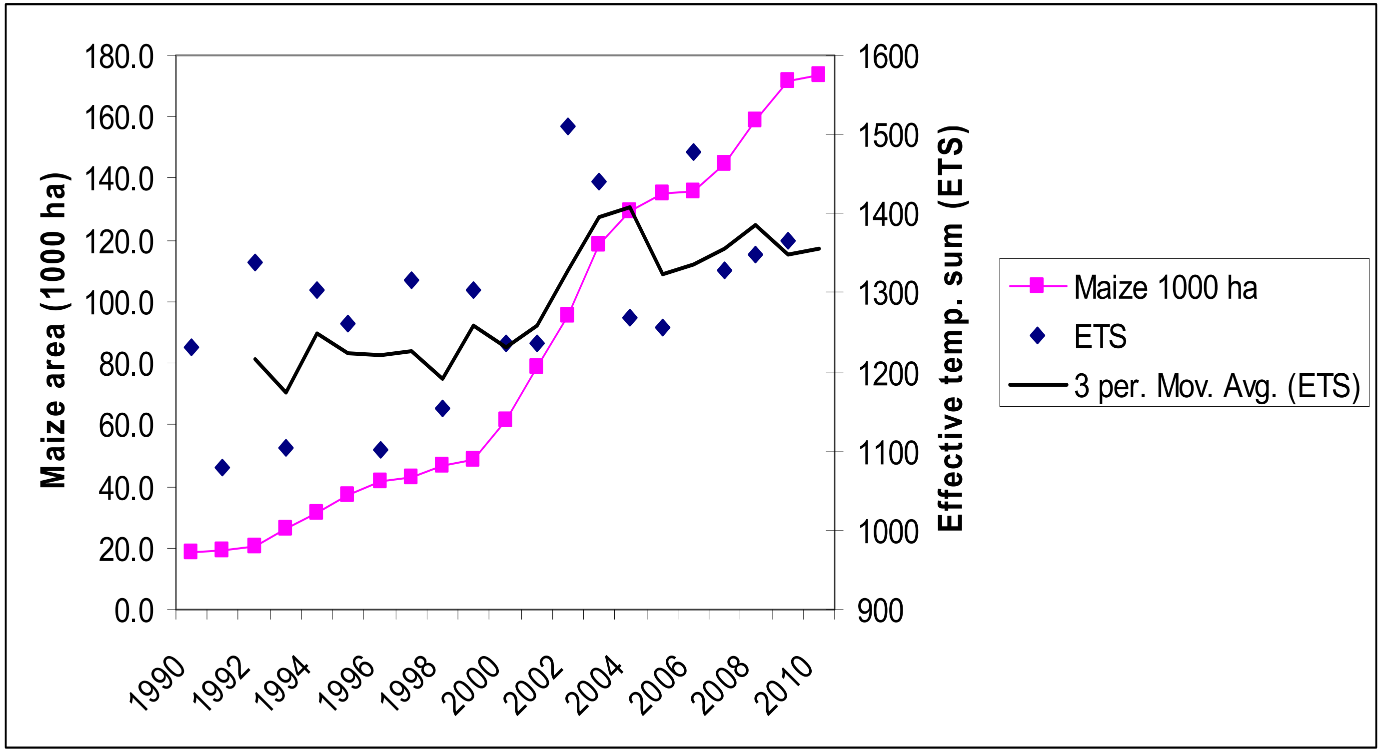
The decomposition and subsequent leaching of organic litter in bogs, forests and wetlands are the principal sources of DOC in the terrestrial landscape. *Production is mediated by atm. deposition, moisture and temperature. The rate of export of terrestrial DOC is determined by the rate of production combined with the rate of sorption by mineral soils, and the availability of pathways for water through the landscape (Roulet and Moore, 2006*

- Agricultural practices and urban sources significantly increased N and P concentrations in the rivers draining the cultivated watersheds of the southern Baltic Sea catchment.
- Nutrients loads from these rivers to the Baltic Sea increased by several times over the last 150 years peaking in the 1970s and 80s
- A slightly decrease only in P loads is visible in the recent years probably as a result of improved sewage treatment from urban areas.



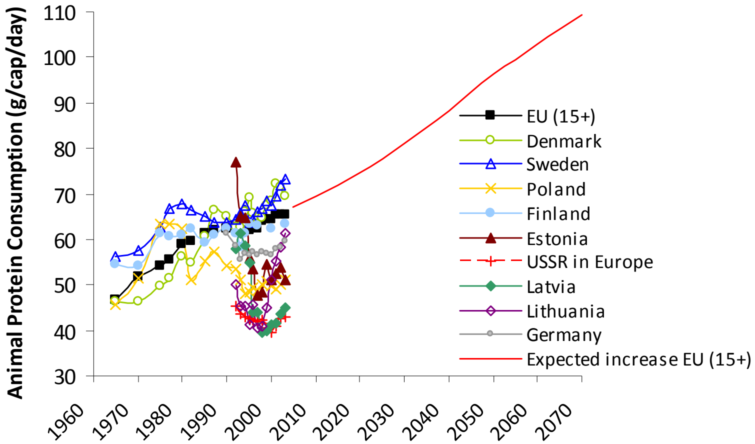
N surplus on agricultural areas in the Oder River catchment
1878 - 1939 and 1944 - 1999 ([Behrendt et al., 2008](), [Gadegast et al.]())

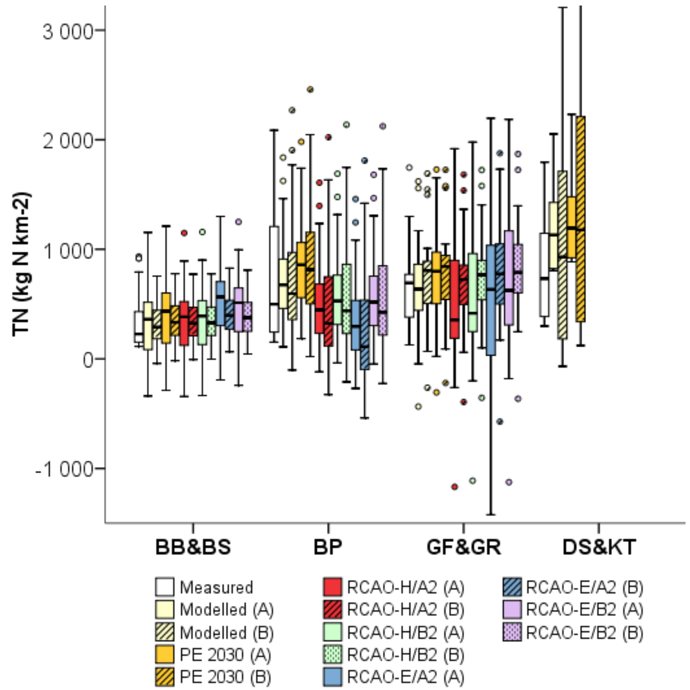
- Farmers currently adapt to a warmer and wetter climate by selecting heat-demanding and nutrient demanding crops like maize.



Area with maize in Denmark and effective temperature sum, ETS. ETS is calculated as the sum of daily mean temperatures above 6 °C from 15. April to 30. September. Maize demands ETS above 12 °C. (Olesen et al. 2011)

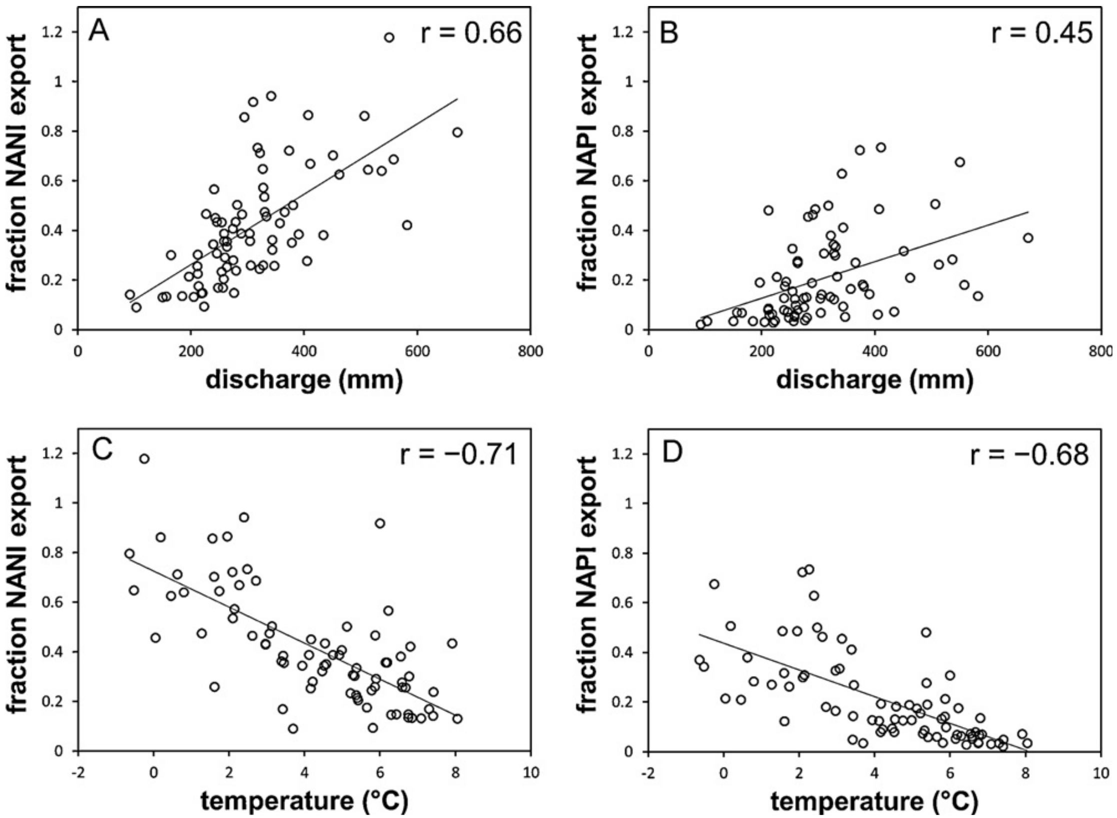
Changes in lifestyles in combination changes in runoff and may lead to an increased nutrient flux to the Baltic Sea by some 20%.





Boxplots with measured (mean 1992-1996), modeled (1992-1996), and future simulated TN fluxes (kg N km^{-2} y^{-1}) for the four sub-basins, Bothnian Bay and Bothnian Sea (BB and BS), Baltic Proper (BP), Gulf of Finland and Gulf of Riga (GF and GR), and Danish Straits and Kattegat (DS and KT) (Hägg et al. 2010)

- Runoff from the southeastern part of the catchment is foreseen to decrease
- The retention of nutrients may increase due to increased temperature
- The net result of a possible changes in agricultural policy is still unknown.



Fractions of Net Anthropogenic Nitrogen Inputs (NANI; A and C) and Net Anthropogenic Phosphorus Inputs (NAPI; B and D) exported as riverine fluxes controlled by discharge (A and B) and temperature. (Hong et al. 2012)

IMPACTS OF CURRENT AND FUTURE ANTHROPOGENIC CHANGES ON **MARINE BIOGEOCHEMISTRY**

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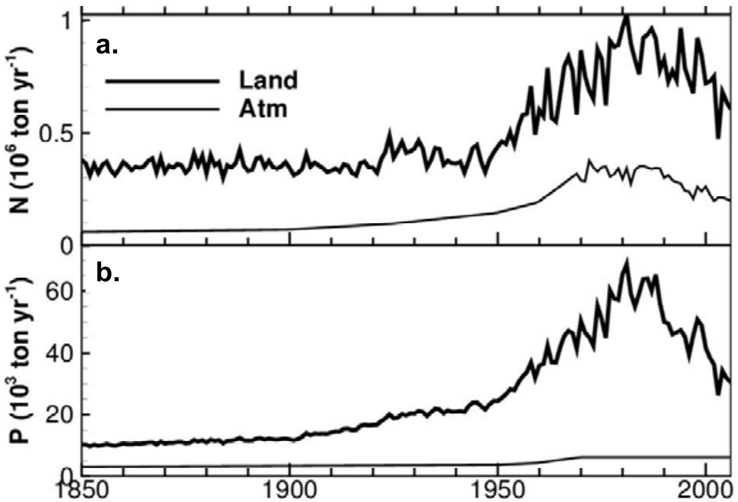
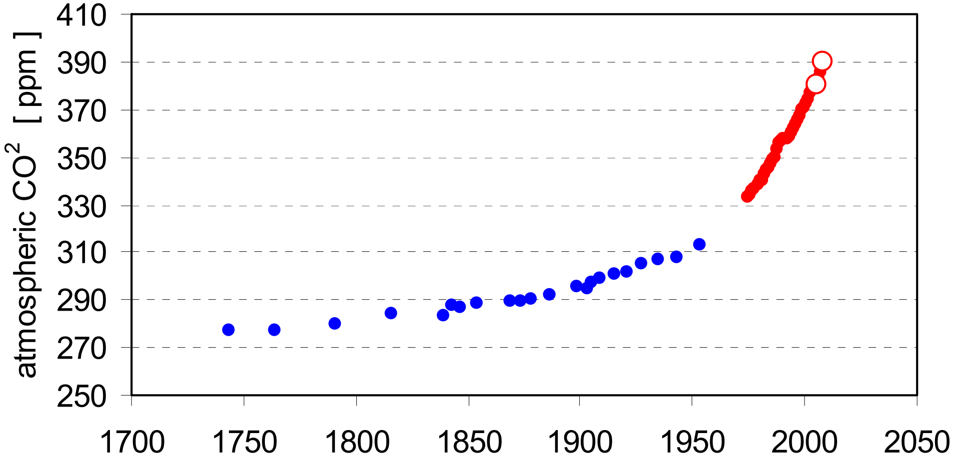
Changes in forcing

Increasing nutrient inputs



Increasing atmospheric CO_2

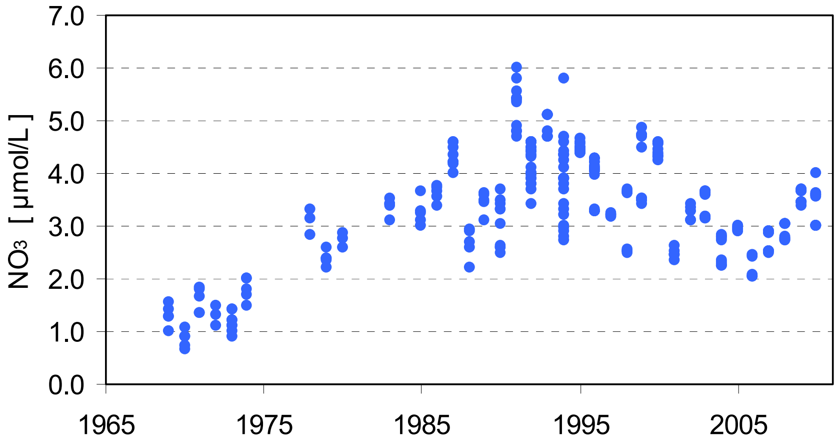


The inputs of nitrogen and phosphorus into the Baltic Sea have increased by a factor of 2 -3 and 5–6, respectively, during the last century (1).

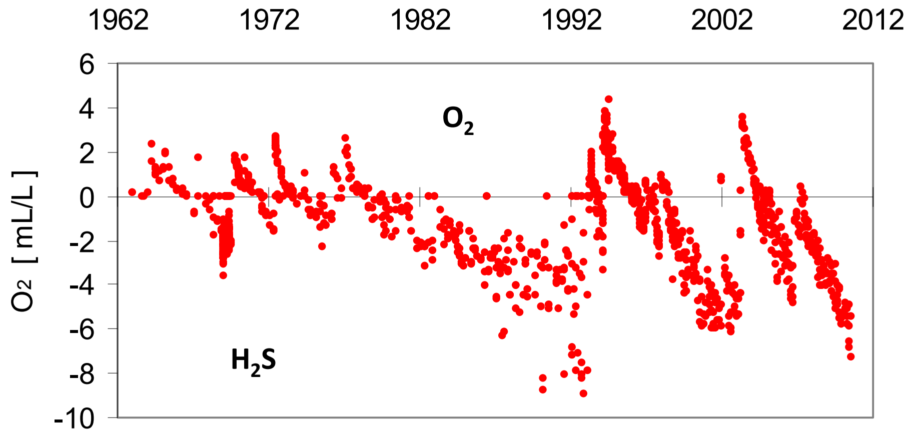
The concentrations of CO_2 in the atmosphere increased from the preindustrial level of 280 ppm to currently about 400 ppm (2, 3). Open circles represent data from the atmosphere over the Baltic Sea.

1.) Gustafsson et al., 2012. Reconstructing the development of Baltic Sea eutrophication 1850 – 2006. Ambio, accepted.
2.) Neftel et al, 1994. In Trends: A Compendium of Data on Global Change. CDIAC, ORNL, USA.
3.) Keeling et al., 2008. In Trends: A Compendium of Data on Global Change. CDIAC, ORNL, USA.

Impact: Eutrophication



Surface water nitrate concentrations in the central Baltic Sea during winter (4).

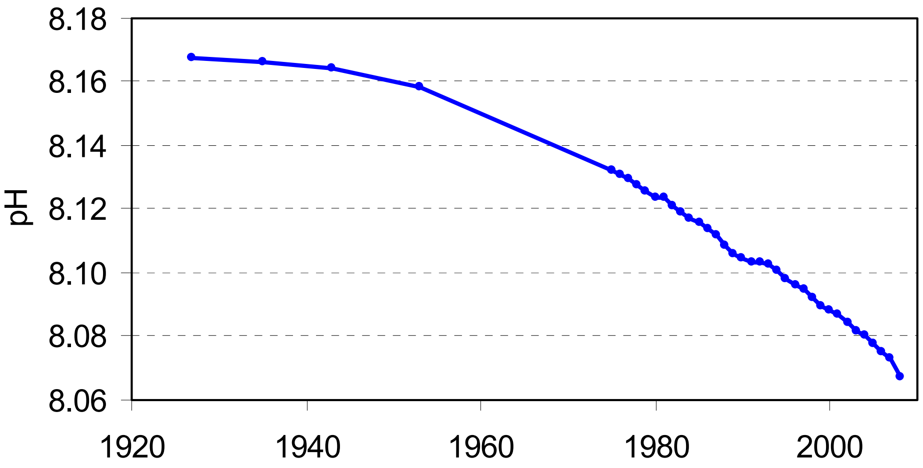


Oxygen and hydrogen sulphide (shown as negative oxygen equivalents) in the bottom water of the Gotland Sea (4).

Increasing nutrient inputs during the last century have caused rising nutrient concentrations and thus stimulated increasing plankton growth. Hence, more organic matter was sinking to the sea floor and has accelerated and intensified the oxygen consumption and the formation of toxic hydrogen sulphide.

4.) Swedish National Monitoring Programme, SMHI.

Impact: Acidification



Surface water pH decrease calculated on the basis of increasing atmospheric CO_2 and constant alkalinity.

Rising atmospheric CO_2 leads to increasing dissolution of CO_2 in seawater and thus to a pH decrease. Assuming constant alkalinity, a pH decrease by about 0.1 units is inferred from the CO_2 increase during the last 100 years. However, historic alkalinity data indicate an increase of the alkalinity that may have dampened the acidification.

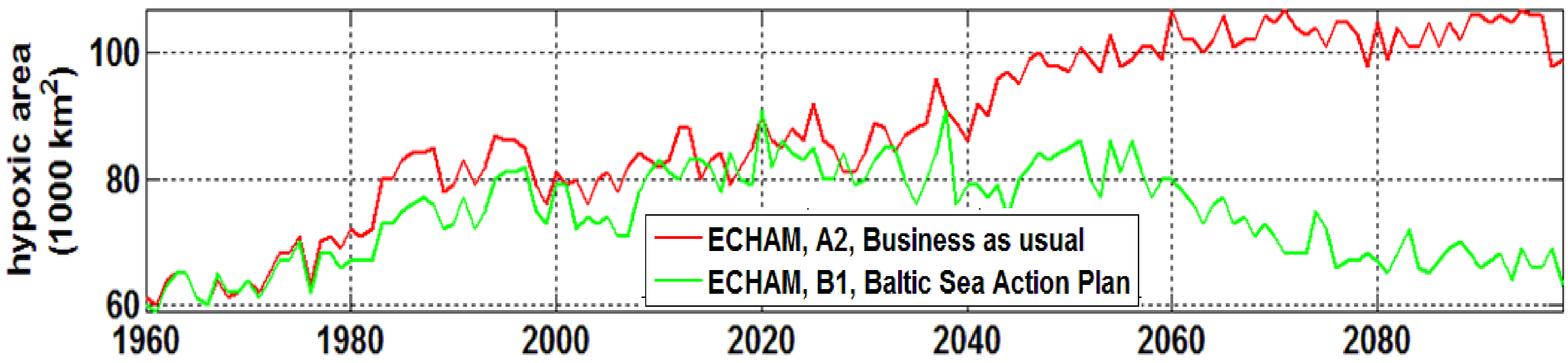
Scenarios

To simulate scenarios for the future development of oxygen depletion and pH on the basis of biogeochemical modelling (5) two combinations of forcing scenarios are used:

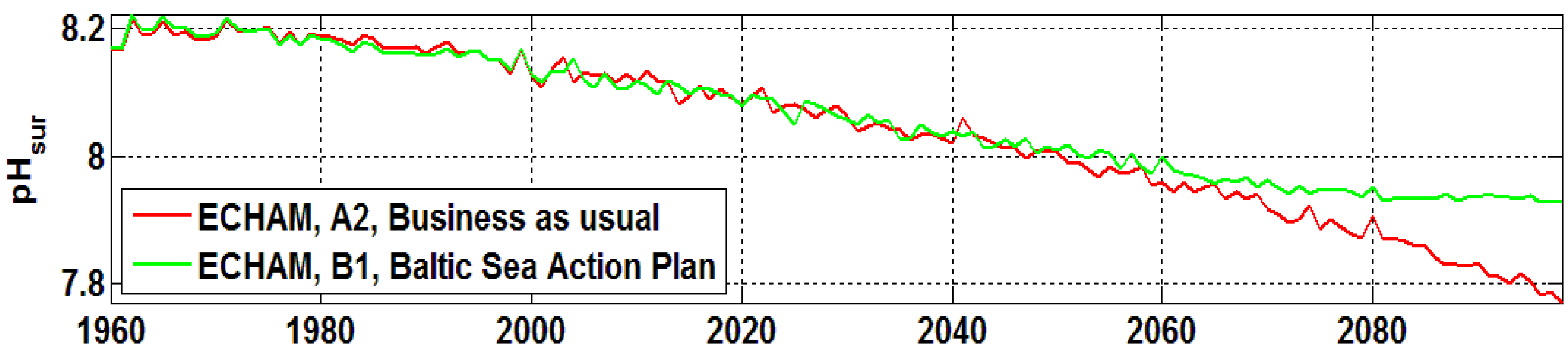
a. Climate model ECHAM with emission scenario A2 (CO_2 in 2100 = 840 ppm)
+
nutrient inputs according to „Business as usual“

b. Climate model ECHAM with emission scenario B1 (CO_2 in 2100 = 530 ppm)
+
nutrient inputs according to „Baltic Sea Action Plan“

5.) Omstedt et al., 2012. Future changes of the Baltic Sea acid-base (pH) and oxygen balances. Publication in preparation.



Mainly due to the Baltic Sea Action Plan the extent of the hypoxic areas (O_2 < 2 mL/L) will be reduced until 2100 whereas „business as usual“ will result in a continuous extension of hypoxia.



Despite the moderate B1 CO_2 emissions, the pH will continue to decrease but much slower than for A2 emission scenario.

IMPACTS OF CURRENT AND FUTURE CLIMATE CHANGE ON **MARINE ECOSYSTEMS**

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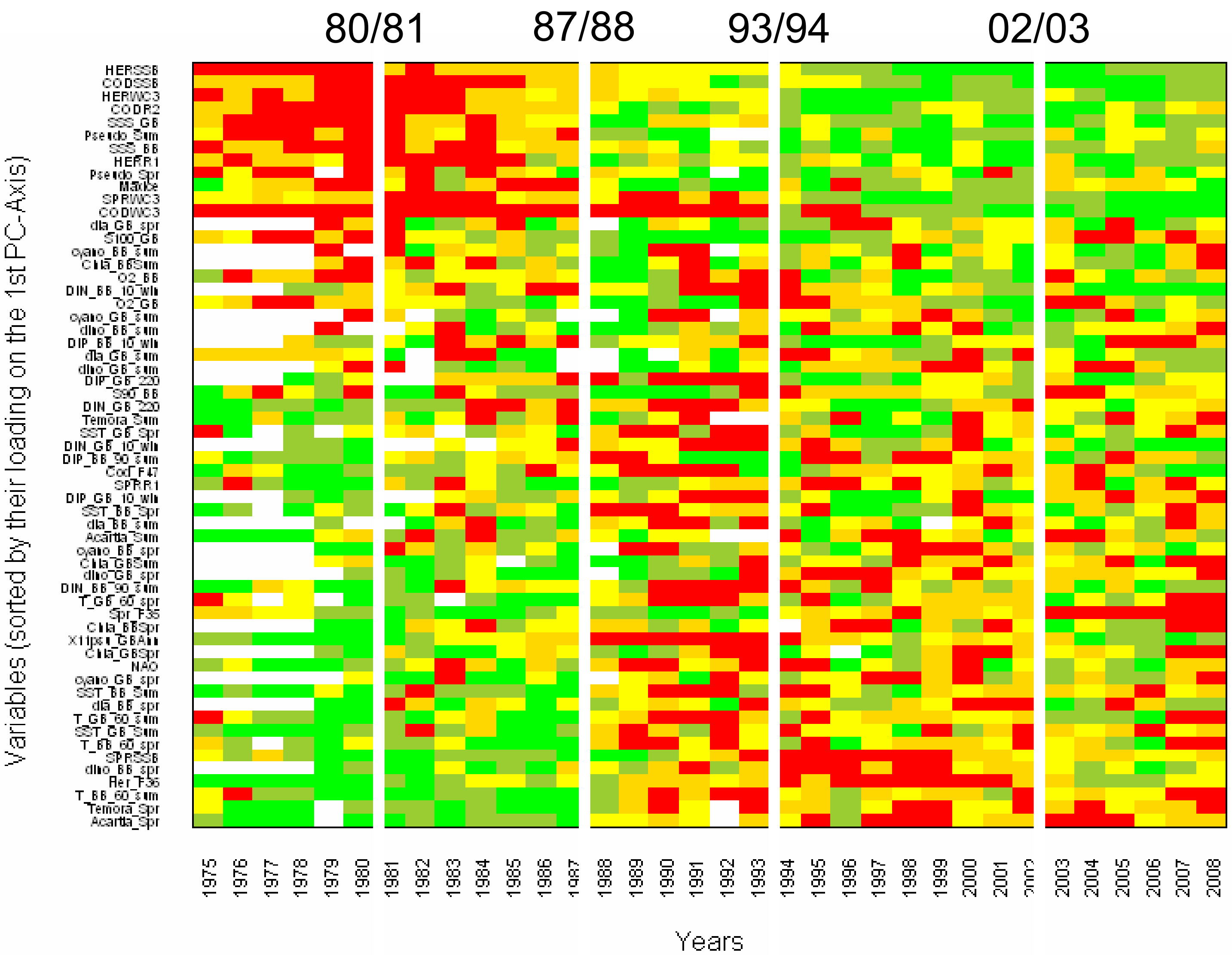
Regime shifts

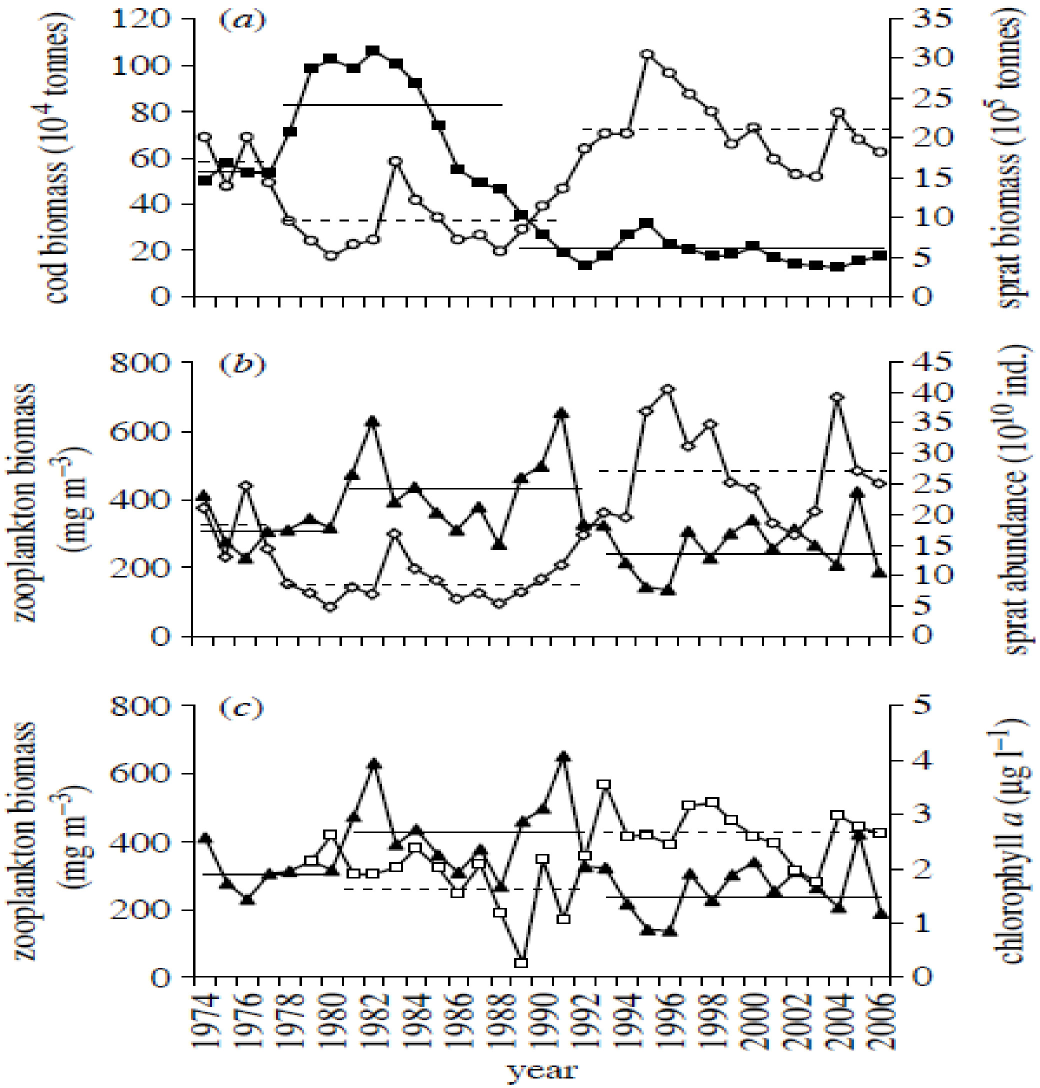
ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB)

April 2010



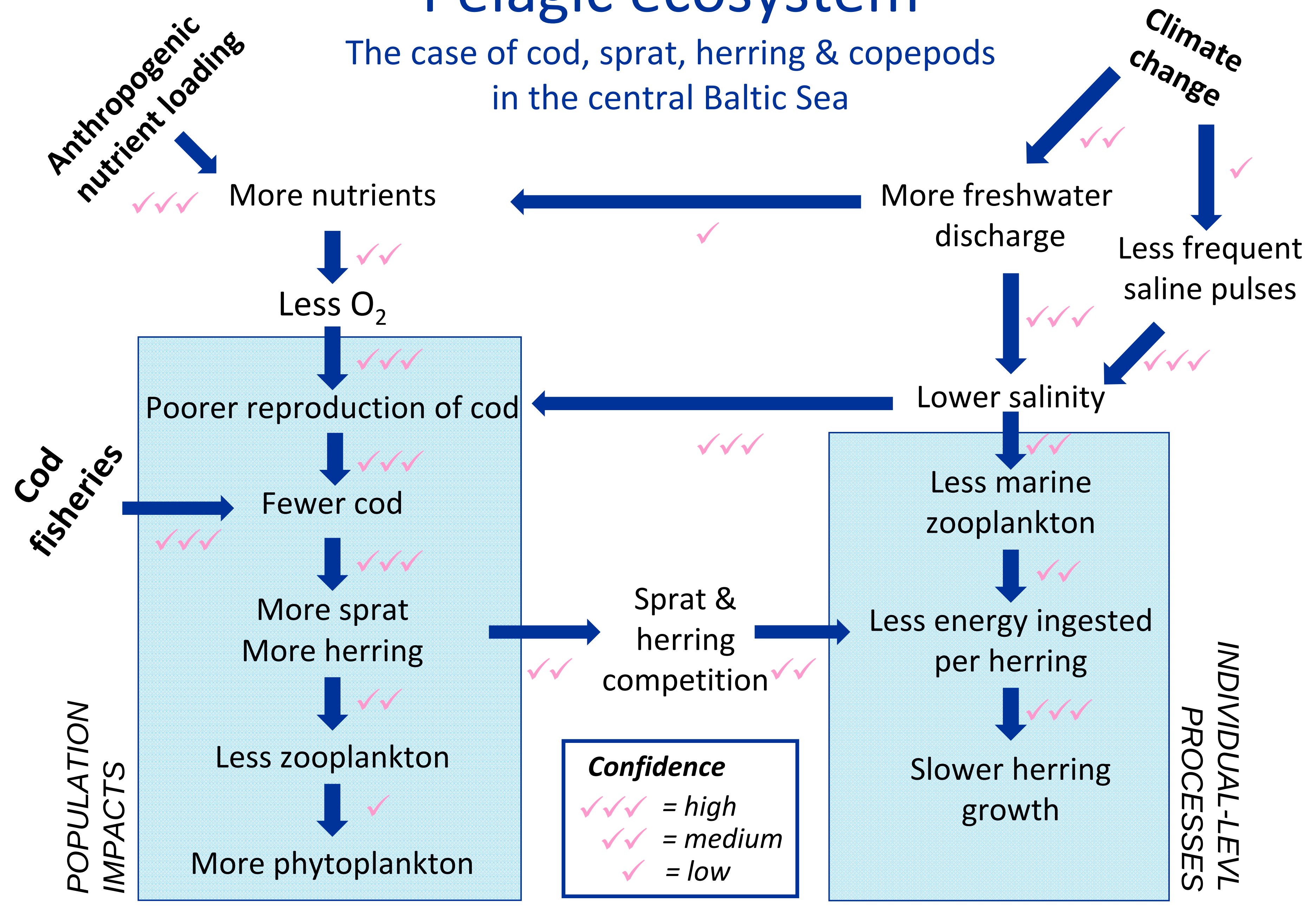
Cascading effects

Casini et al. 2008
Multi-level trophic cascades in a heavily exploited open marine ecosystem.
-Proc Royal Soc. B 275: 1793-1801

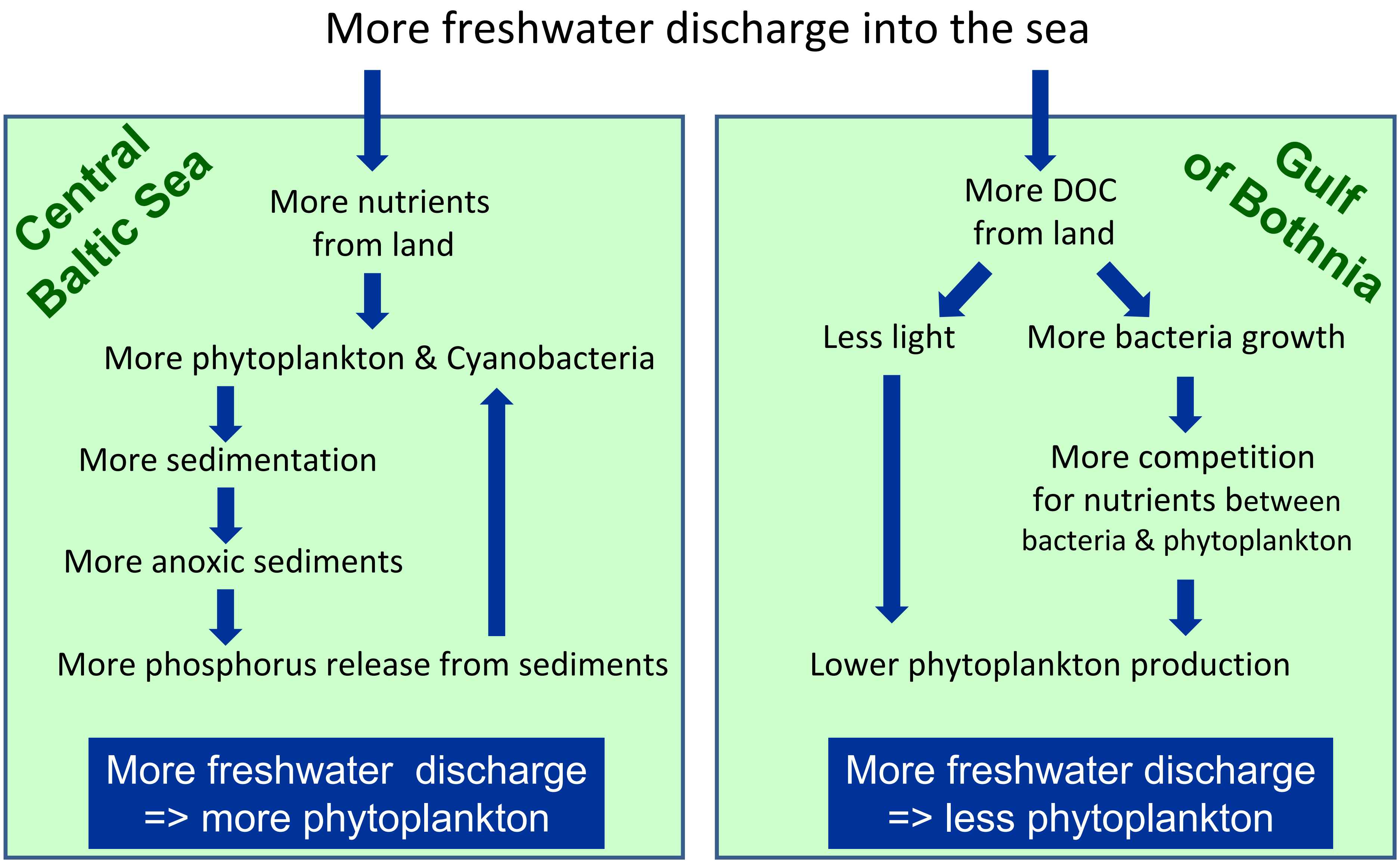


Pelagic ecosystem

The case of cod, sprat, herring & copepods in the central Baltic Sea



Eutrophication



Biodiversity

Salinity

- **macrobenthic** diversity in the open Baltic Sea
- **genetic diversity** in benthic marine species

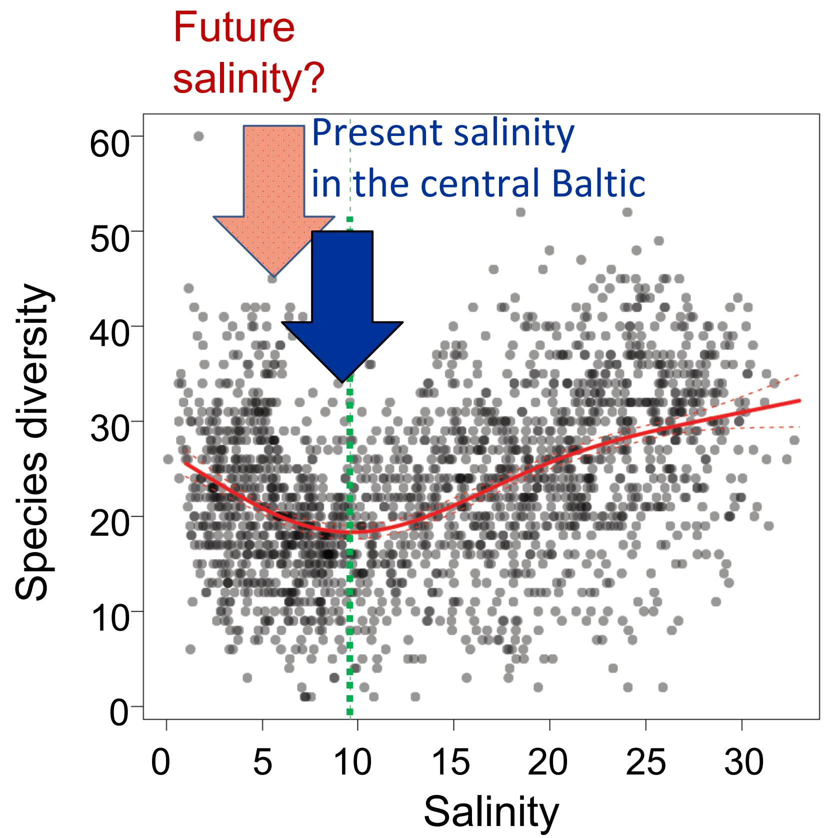
Unsure:

How salinity decline will affect diversity of plankton?

- **Protozoans**: diversity may decline (Telesh et al. 2011)

This was disputed by Ptacnik et al 2011:

- evidence from **Phytoplankton**: Gain of freshwater species may exceed the loss of marine species



Ptacnik et al., unpublished

Conclusions

- The main changes in air pollution in the Baltic Sea region are due to changes in emissions rather than climate-change itself
- More riverine DOM, effects of climate on cultivated watersheds unknown, both positive and negative feedbacks on nutrient fluxes, agricultural pratices will adopt fast
- Terrestrial ecosystems near the coast most prone to climate change; significant increase in spruce growth in the North
- Higher turnover of algal biomass may lead to larger anoxic areas; pH will decrease
- Climate change has led to regimes shifts in the Baltic Sea ecosystem; lower salinity will lead to less marine benthic species, unknown for pelagic groups (more nutrients and DOM may result in opposite effects)

- ***Very few evidence for impacts of climate change as such!***