Responses of organic contaminant cycling to multiple drivers in the Baltic Sea

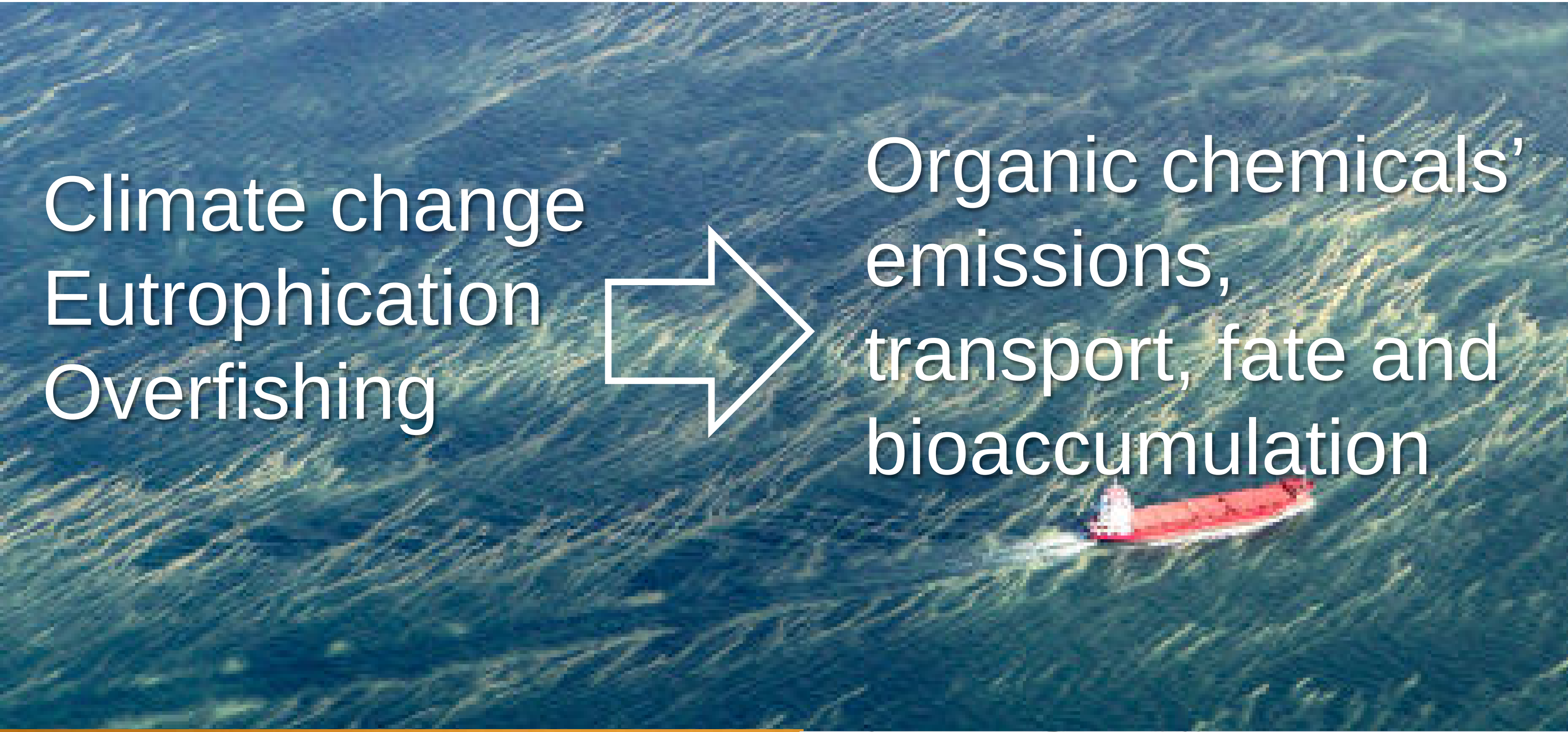
Emma Undeman

emma.undeman@su.se

Tallinn Nov 2018

Stockholm University

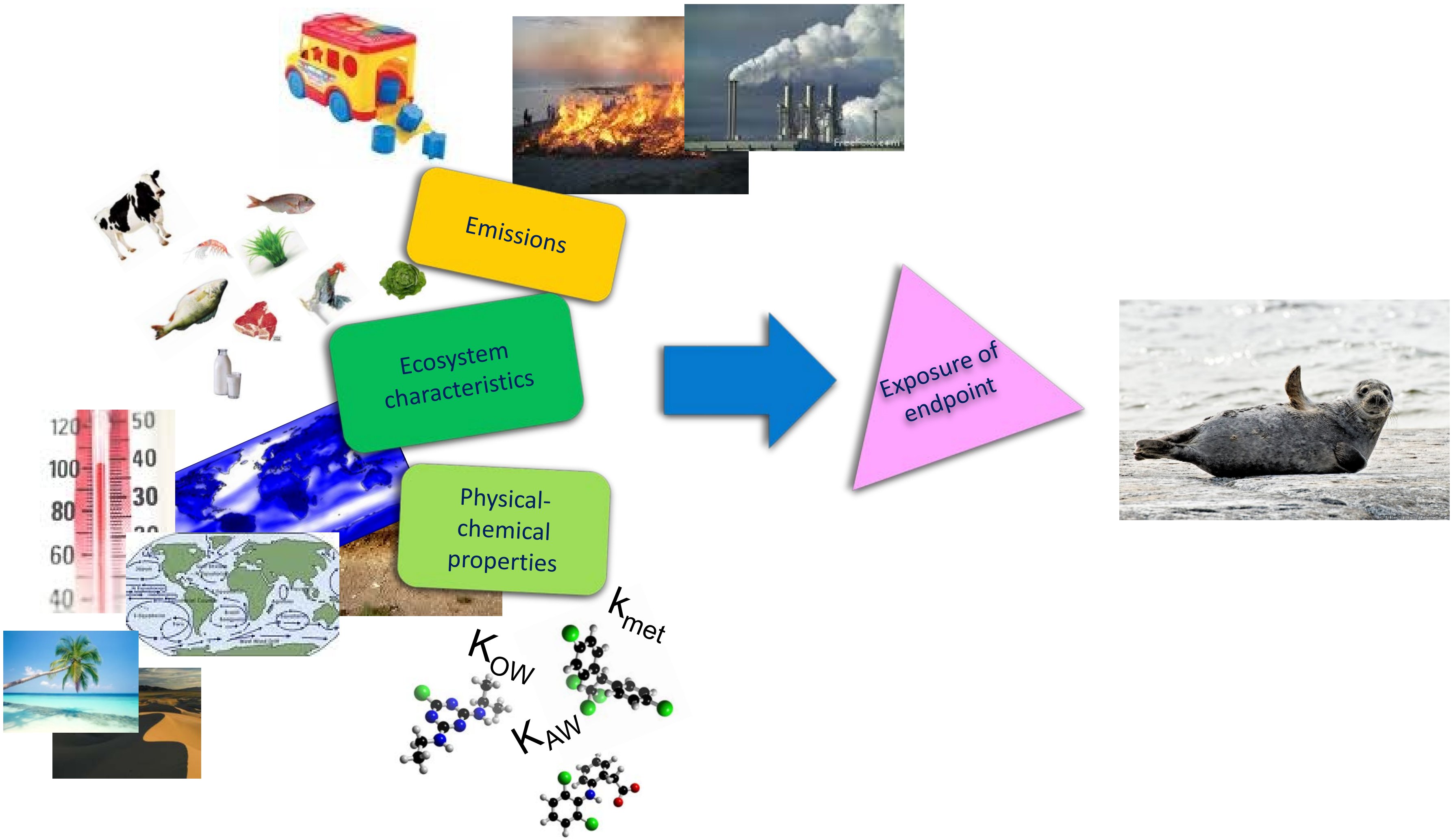
Stockholm University Baltic Sea Centre



Climate change
Eutrophication
Overfishing

Organic chemicals' emissions, transport, fate and bioaccumulation

Distribution in environment and biota depends on:



Eutrophication

Organic contaminants – many sorb to organic carbon

primary production →

- air-sea gaseous exchange
- downward transport via sedimentation
- bioavailability

hypoxia/anoxia →

- reduced bioturbation

- food web structure→ bioaccumulation

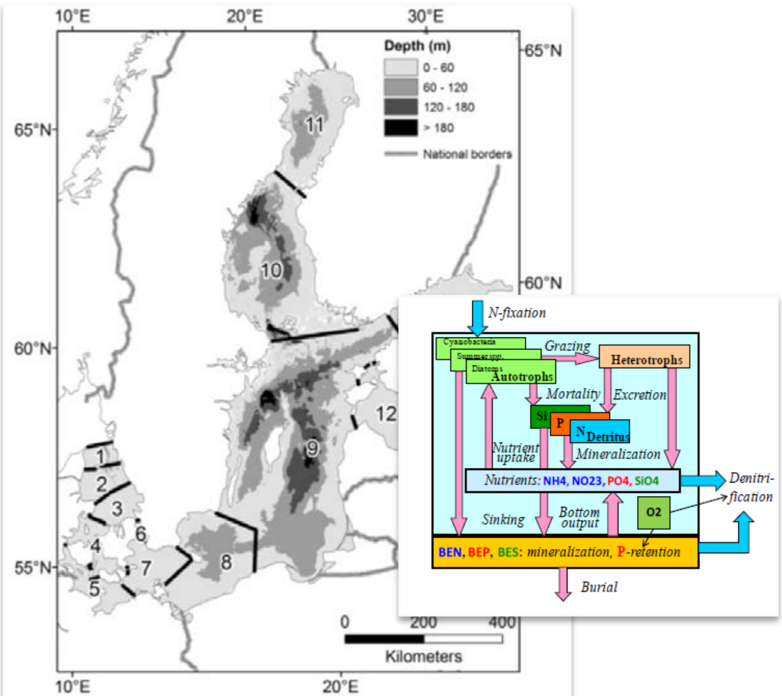
light penetration →

- reduced photolysis

Case study for real environment: the Baltic Sea

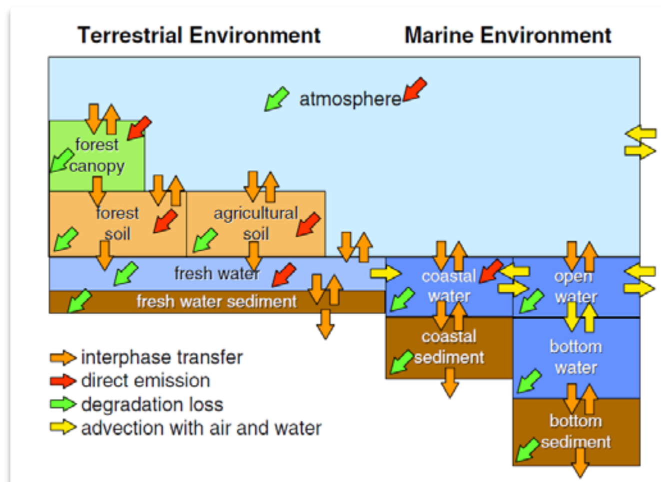
Stockholm University

BALTSEM = hydrodynamic model with biogeochemistry → "eutrophication model"



+

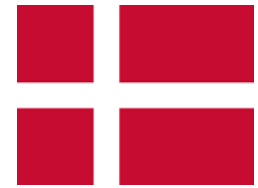
Contaminant transport and transformation model POPCYCLING (the marine part only)

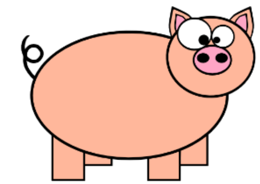


=

BALTSEM-POP =
hydrodynamics + biogeochemistry + organic contaminants

Case study for real environment: the Baltic Sea





Nutrients (N and P):

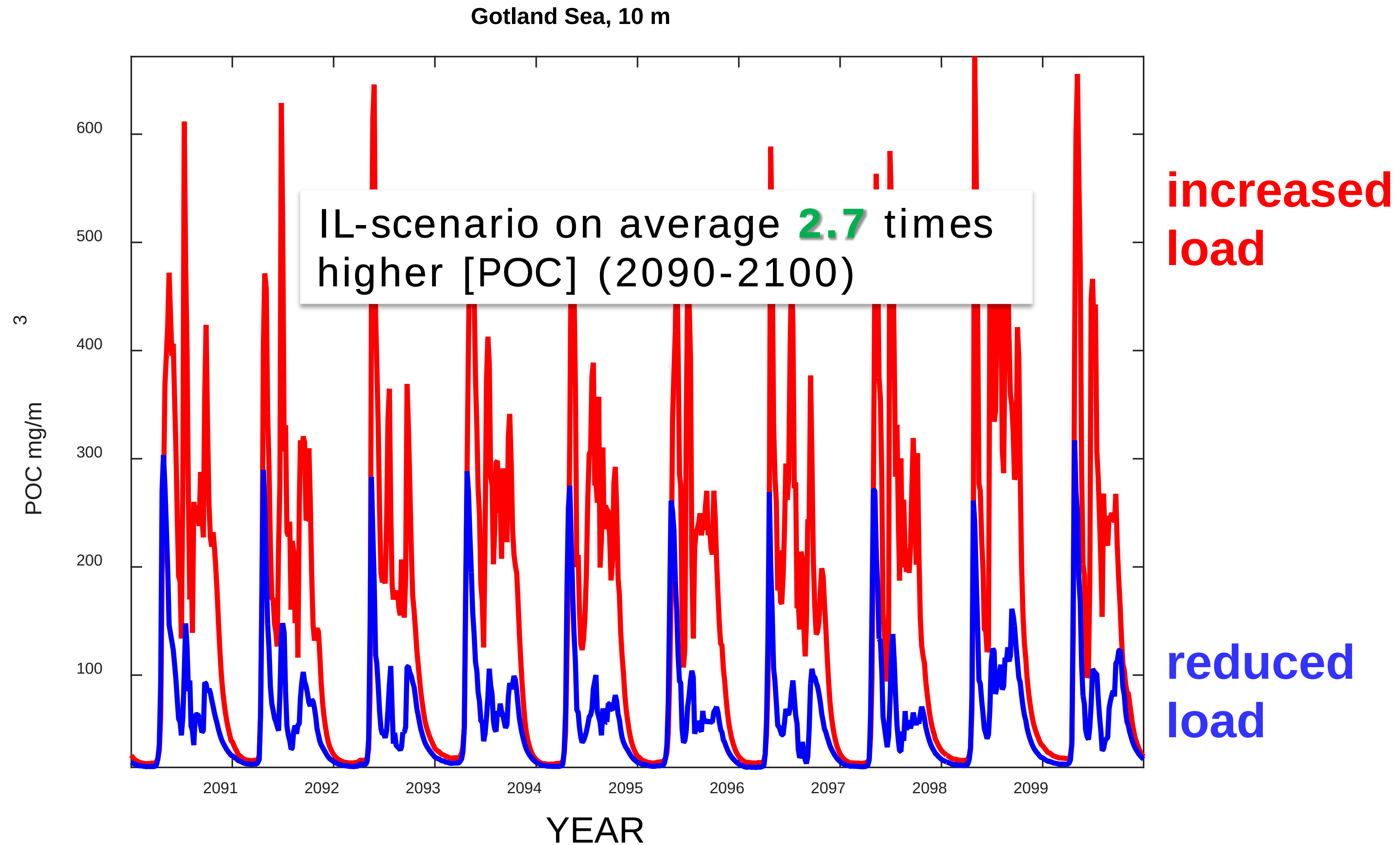
1. ”Increased load (IL)” = denser livestock, ca 50% increase in TP and TN river loads

2. ”Reduced load (RL)” = HELCOM Baltic Sea Action Plan successfully implemented (reduced nutrient emissions)

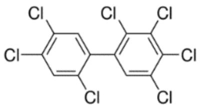
Compared average chemical concentration for last 10 years (years 2090-2100) in surface water simulated with IL and RL scenarios

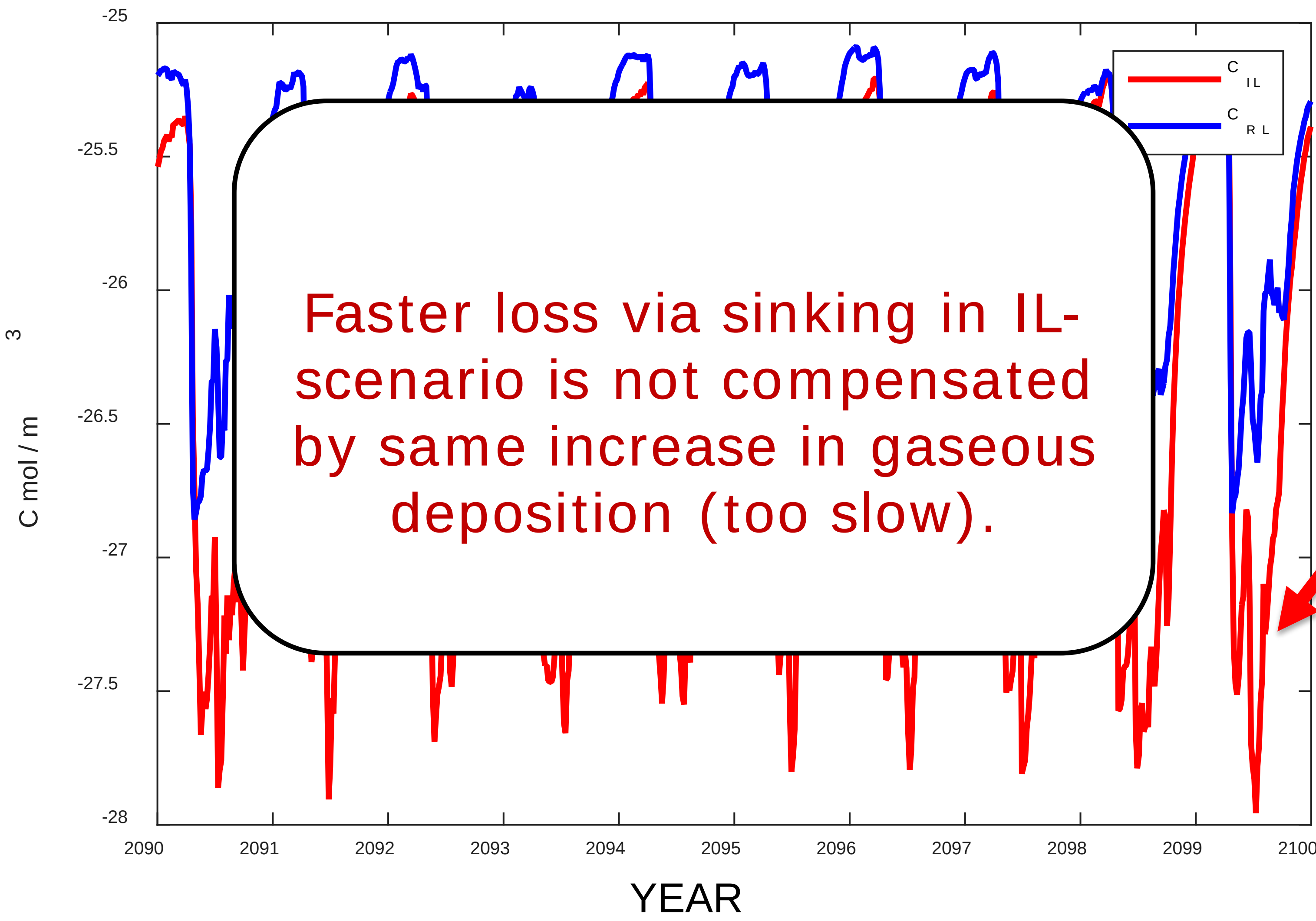
Particulate Organic Carbon POC (plankton, zooplankton and detritus) last 10 years of simulation:

Stockholm University



Predicted concentrations of "PCB180" in surface water





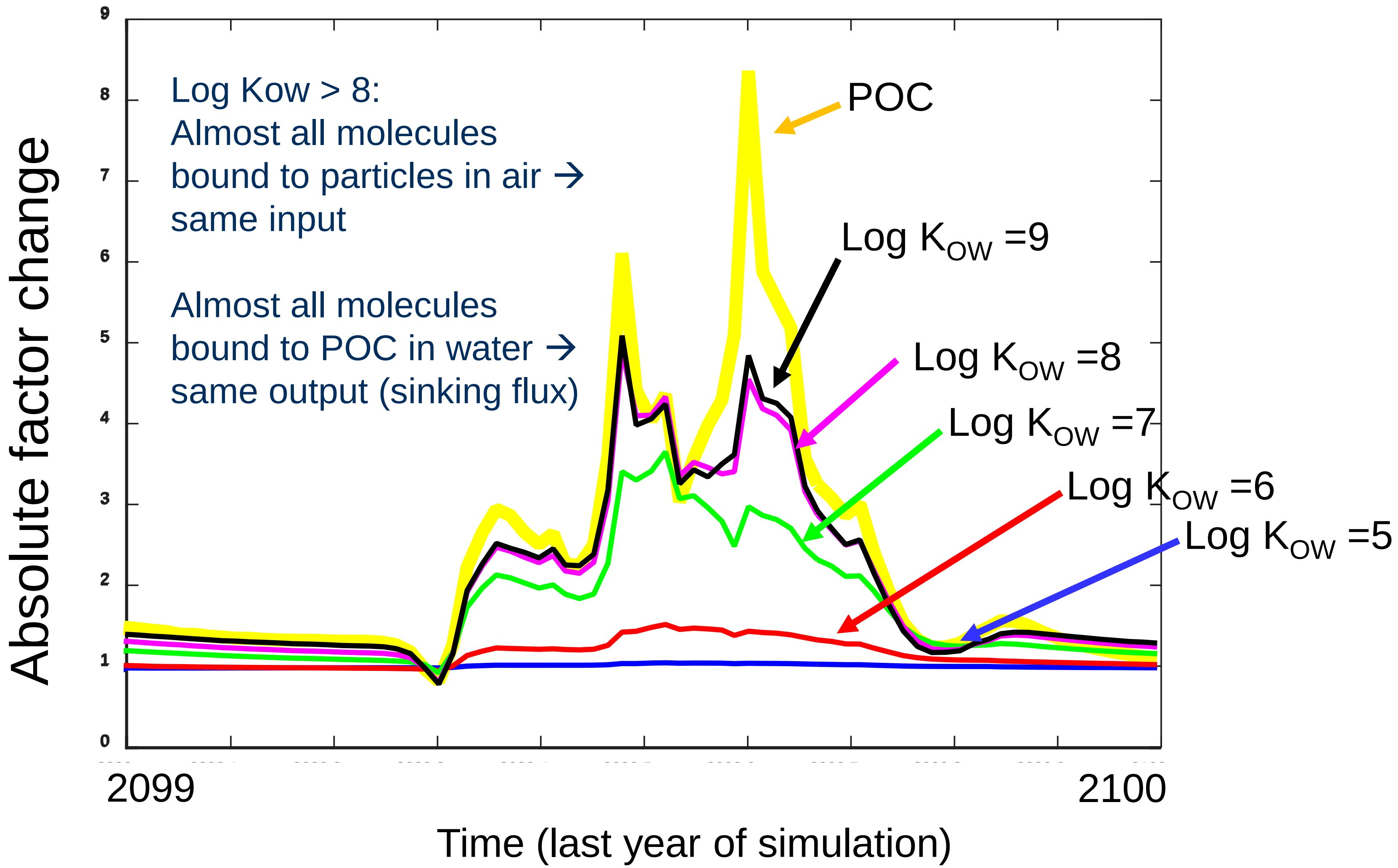
reduced load

On average 45% lower concentrations in the eutrophied system

increased load

Sensitivity to change in trophic status linked to hydrophobicity of the compound

Stockholm University



Climate change

Stockholm University

Precipitation →
- transport via runoff
- erosion + OC transport
- wet deposition (atm)

Temperatures →
- partitioning between air-water, air-soil, air-vegetation etc.,
- reaction rates

Ice cover →
- volatilization from sea
- re-mobilization of archived contaminants

Windspeed and frequency of extreme events →
- air-water exchange
- resuspension

- food web structure→ bioaccumulation

Land use → emissions
Vector control → emissions
Forest fires → formation

Table 2. Summary of recent multimedia fate and bioaccumulation model output incorporating long-term GCC scenarios[a]

Study	Scale scope	Chemical compound	Changes	Results
McKone et al. [12]	Regional (W. USA),	HCB	T↑ (mean 2.5°C)	Mean cancer risk ↓ (22%)
Macleod et al. [13]				C_{AIR}↑ by max 2-fold with high NAO index under current extent of variability
Valle et al. [14]	Lo			C_{AIR} ↑~10% C_{SED} ↓ 20–45% C_{WAT} ↓ 2–10% C_{SPM} ↓ 20–50% vs control at the end of 50-year simulation (i.e., ↑dissipation)
Lamon et al. [15]	G			(1) C_{AIR} in Arctic ↑ by ~2.0- to 2.5-fold; ↑emissions is the main factor (2) P_{OV} ↓
Ma and Cao [19]	Clo p			4–50% increase in air concentration compared to mean ±4 and ±53% change from mean air concentration for α- and γ-HCH, respectively
Borgå et al. [16]	S			C_{FISH} ↓ vs control γ-HCH: F_{MAX} = 0.78–0.93 PCB-52: F_{MAX} = 0.44–0.62 PCB-153: F_{MAX} = 0.33–0.44
Ng and Grey [17]	Regional (Great Lakes), D coupled bioenergetics/ bioaccumulation model	PCB-77	T↑ (5–6°C) based on 100-year projections for Lake Superior surface water temperatures	C_{FISH} ↑ vs control species-specific and confounded by predator–prey dynamics F_{MAX} = approx 3

Summary of summary:

Impact **usually max factor 2 difference** in env. Concentrations

Parameter changed:

Temperature ↑
Precipitation Δ or ↓
Wind speed Δ
Emissions ↑
Degradation ↑
Ocean currents Δ
POC,DOC ↑

Result compared to baseline:

Cair ↑
Csed, Cwat, Csusp part mtrl ↓
Cfish ↑ or ↓

Gouin et al 2013

Climate change in the Baltic Sea

Modeling study applying the POPCYCLING-Baltic model yrs. 2071-2100, downscaling of IPCC scenarios

Temperature+, Precipitation+, Wind speed+, POC+

Depending on mode of emission, chemical and scenario →

Concentration ratios (scenario/reference) ca **0.5 to 3**

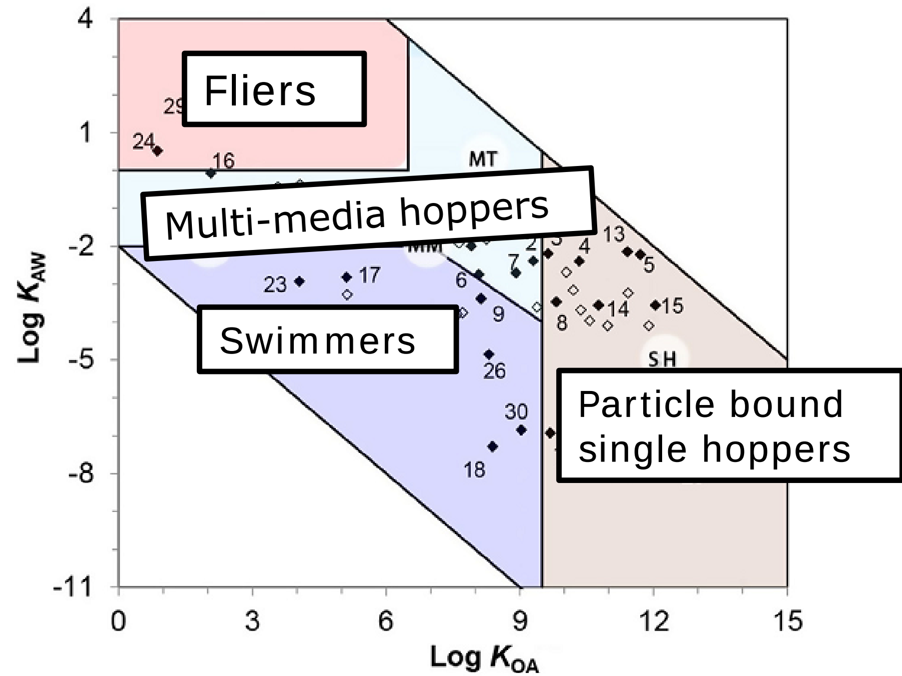


Table 1
Summary of the modelled climate change-induced impacts on the concentrations of hypothetical perfectly-persistent organic chemicals (considering all four studied climate variables).

	Air	Forest canopy	Forest soil	Agricultural soil	Fresh water	Fresh water sediment	Coastal and open ocean water	Coastal and open ocean sediment
Volatile fliers	+/+/+	+/+/+	±/±/–	±/±/–	+/–/±	+/–/±	+/±/+	+/–/±
Water soluble and relatively volatile multiple hoppers	+/+/+	+/+/+	±/+/–	+/+/–	+/±/+	+/±/+	+/±/+	+/±/+
Water soluble swimmers	±/+/+	–/–/–	–/±/–	–/±/–	–/±/–	–/–/–	–/±/±	+/+/+
Multimedia multiple hoppers	+/+/+	±/±/±	–/–/–	–/–/–	–/–/–	–/–/–	+/±/±	+/±/±
Very hydrophobic and semi-volatile multiple hoppers	+/+/+	±/+/+	–/–/–	–/–/–	±/–/–	±/–/–	+/+/+	–/–/–
Particle-bound single hoppers	–/+/+	±/+/+	±/+/–	–/±/–	±/–/–	±/–/–	±/±/±	±/±/+

"+" indicates increase; "–" indicates decrease; "±" indicates both increasing and decreasing impacts were observed for that specific group of chemicals. Symbols from left to right correspond to emission to air, water and soil. Note that here the predicted impacts are not discriminated according to the studied climate scenarios, because in general the impacts from the two climate scenarios are the same.

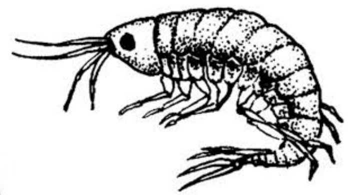
Kong et al 2014

Climate change and bioaccumulation in an Arctic food chain – modelling study

Fixed total water concentration:

Scenario:
Temperature
POC ⬆

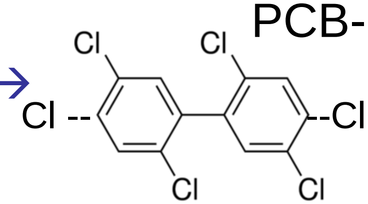
Temperature influences:
Lipid fraction (-)
metabolic degradation (+)
growth rate (+)
feeding rate (+)
ventilation rate (+)



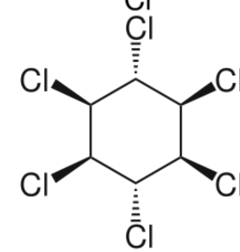
POC concentration influences:
dissolved and particle bound concentrations in water

Δclimate&POC → 50% lower conc bioavailability

PCB-153



Δclimate&POC → <20% lower conc lipid content

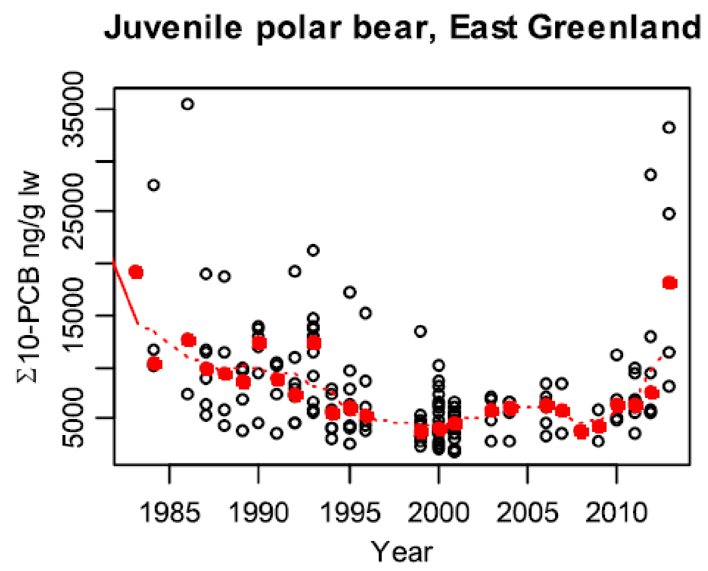


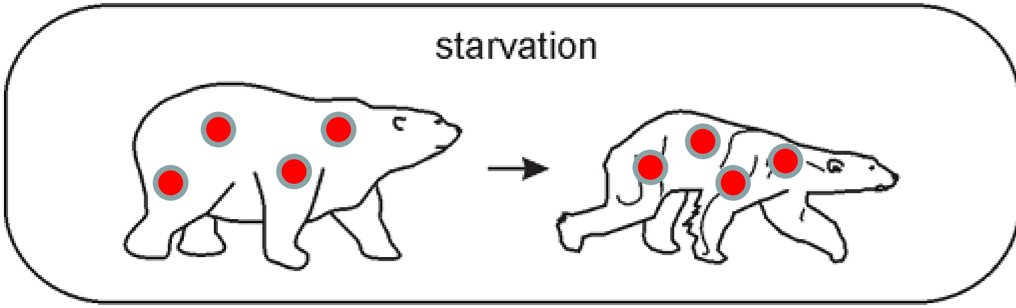
HCH

Borgå et al 2010

Example: Indirect effect on polar bears

- Climate change → earlier break-up of ice, less ice extent
- Polar bears forced onshore
- Limits access to food (seals)
- Starvation → consume lipid reserves ("solvent depletion")
- POPs not excreted, concentrated in smaller volume of lipid → higher concentrations in blood and target tissues. More likely to exceed toxicity threshold levels





Jenssen et al 2015, Riget et al 2015

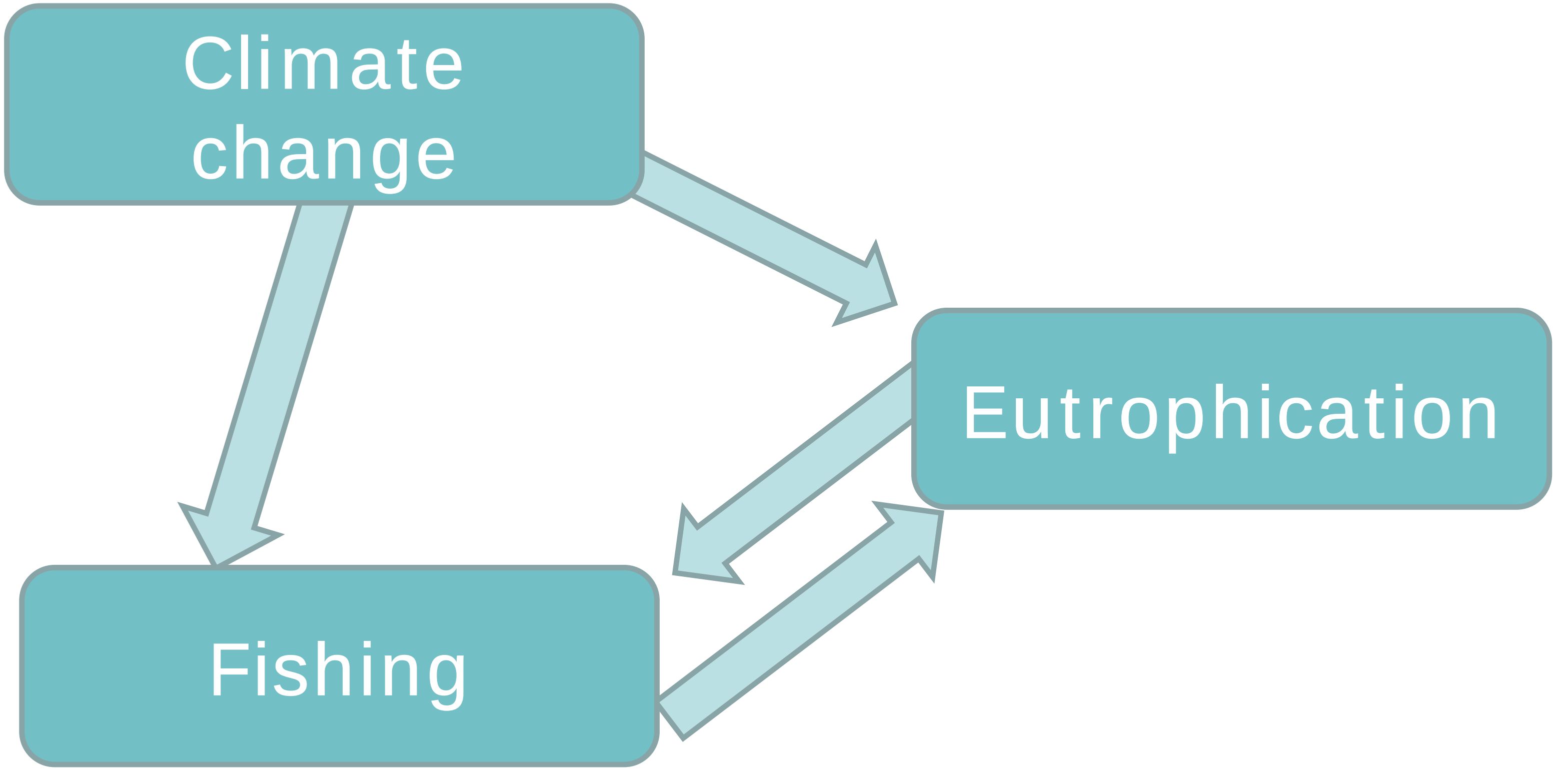
Fisheries

changes in food web structure →

- number of trophic levels
- changing diet, type of food chain e.g. pelagic to benthic
- age of organisms

fitness of organisms →

- lipid content
- growth rate


Climate change
Eutrophication
Fishing

Summary

Challenge:

Chemical dependent

Environmental compartment dependent

Organism/food chain dependent

Direct or indirect

Direct impact – usually within a factor 2 changing concentrations, but large uncertainties in estimations

Indirect impacts – potentially higher (changing emissions, trophic levels in food chain)

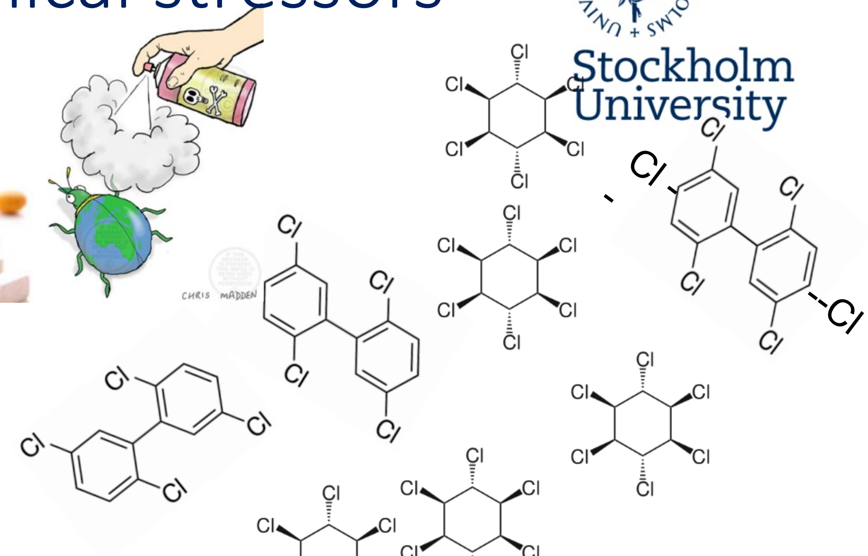
THANK YOU

Stockholm University

“Kalaset” island, Stockholm archipelago

Hazardous substances – chemical stressors



Other stressors → chemical concentrations and sensitivity to toxic compounds

Chemicals → organisms' sensitivity to other stressors