Stockholm University

Climate change and organic contaminants

Emma Undeman

Baltic Nest Institute

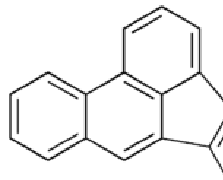
Some background…

Major environmental problems in the Baltic Sea addressed e.g. by the HELCOM BSAP

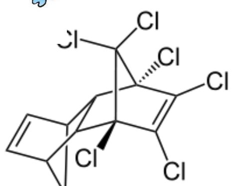
Eutrophication	Hazardous substances	Loss of biodiversity	Maritime activities

Hazardous substances

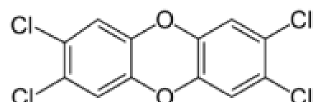
>100 000 commercially available chemicals
Metals, ionisable, polymers, neutral organic compounds…



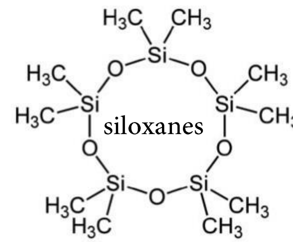
PAHs



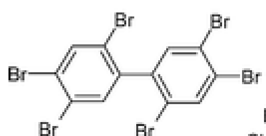
aldrin



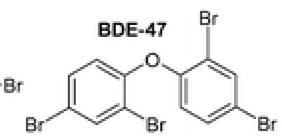
dioxins



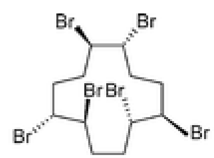
siloxanes



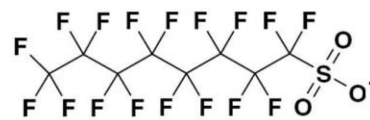
BB-153



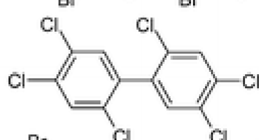
BDE-47



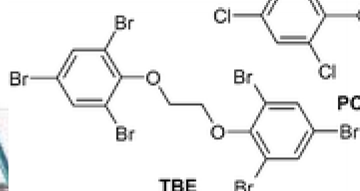
γ-HBCD



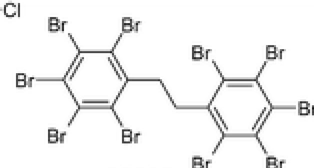
Perflourinated alkyl acids



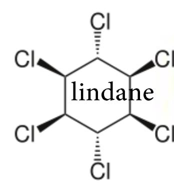
PCB-153



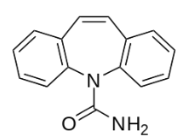
TBE



DBDPE



lindane



carbamazepine

Environmental organic chemistry: Emissions, Environmental fate and transport + bioaccumulation of organic contaminants

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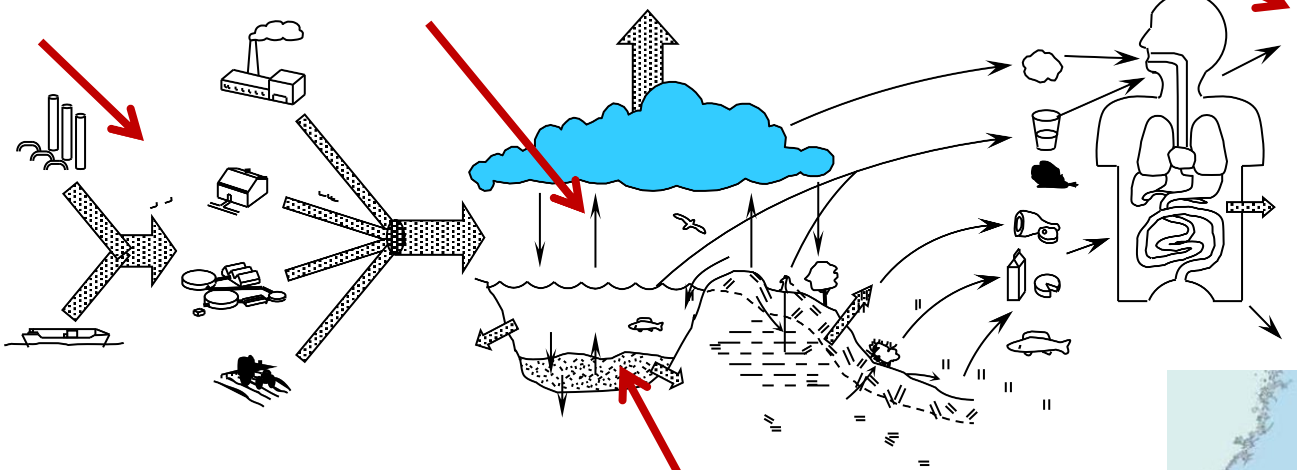
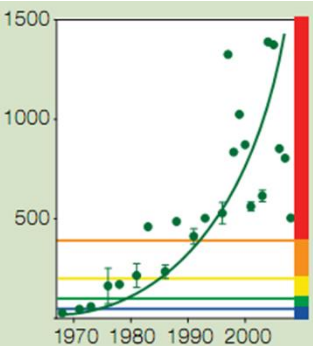
Various transport routes

Temporal response of system

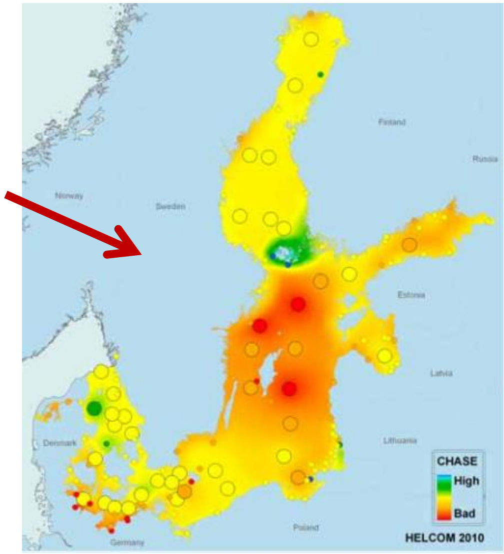
Emission sources



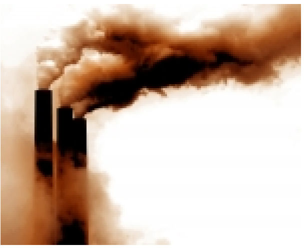


Regional differences

Environmental sinks and secondary sources

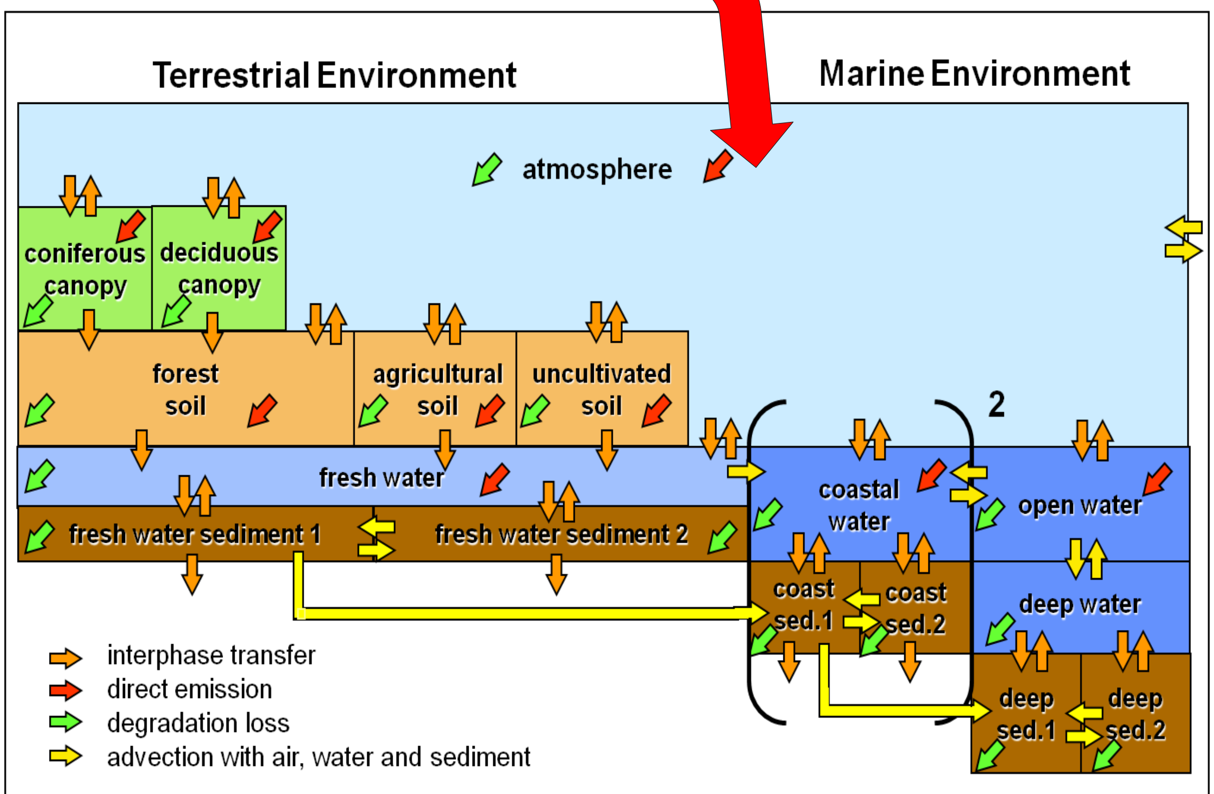


Where do they come from, where do they go, how do they get there? What level is toxic and to whom?





Emissions to air, soil, water



Today's topic:
How will these processes be impacted by climate change?

Global climate change projections for 2090 to 2099 compared to 1980 to 1999 (IPCC)

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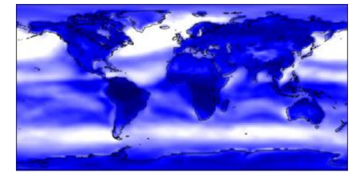


- Mean temperature +1.1 to 6.4 °C
- Sea-level + 0.18 to 0.59 m

- Precipitation +/- 20%

- Ocean acidity -0.14 to -0.35 pH units
- Sea-ice cover decrease

- Ocean circulation +/-

- Wind speed +/- 10 to 20%
- Change in wind direction, increase in peak wind intensity and frequency of tropical storms

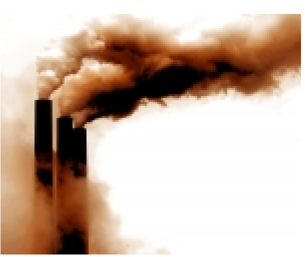
from Gouin et al 2013

Impact on contaminants

- Emissions
- Environmental fate
- Bioaccumulation
- Toxicity

Impact on contaminants - emissions

- Temperature change emissions → change rate of mobilization from materials and stockpiles = difficult to predict, chemical and use specific
- Changing land use patterns
  - Types of crops, crop yield
  - Possibility to grow crops (e.g. in the north)
  - Availablity of arable land
  - → shifts in type and timing of pesticides applied. Regional scale differences can be large





Impact on contaminants – emissions cont.

- Vector control
  - Projections of distribution of pests and infectious diseases highly uncertain
  - Population growth, socioeconomic growth, agricultural practices, ecosystem changes + increasing temperatures, precipitation rates
  - Use of insecticides (e.g. DDT for malaria)

- Energy use and forest fires → emissions of PAHs (Polycyclic aromatic hydrocarbons), dioxins and other combustion by-products

Gouin et al 2013, Balbus et al 2013

Impact on contaminants

- Emissions
- Environmental fate
- Bioaccumulation
- Toxicity

Environmental fate and transport of contaminants

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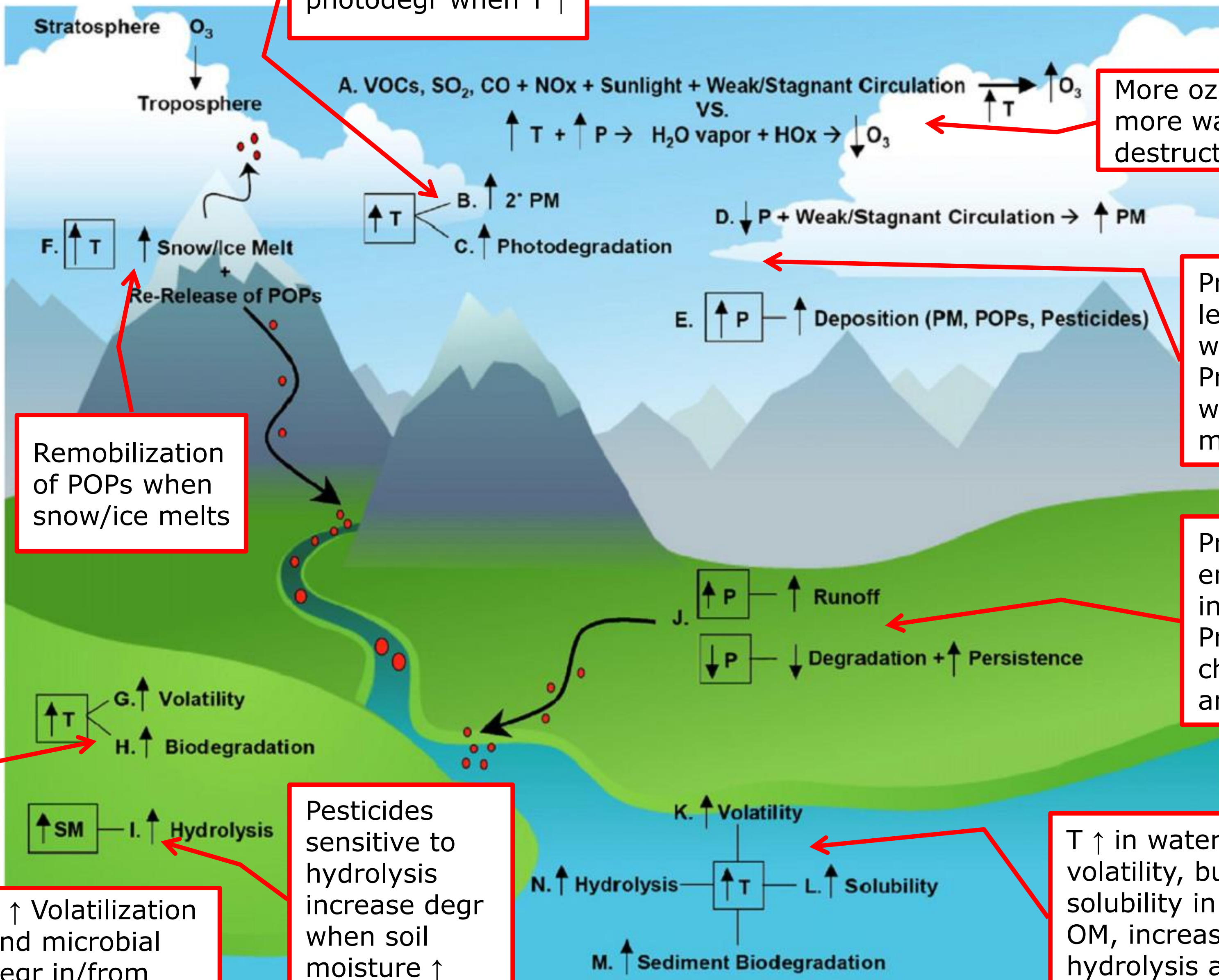
- Partitioning – air-surface exchange, wet/dry deposition
- Reaction rates (photolysis, biodegradation, oxidation in air)
- Snow/ice melt
- Biota lipid dynamics
- Organic carbon cycling
- Melting permafrost → remobilization of ”contaminant archive”
- More frequent occurrence of extreme events (storms) → sediment resuspension, coastal erosion

nt International 35 (2009) 971–986

Stockholm University



Formation part. matter and increased photodegr when T ↑

More ozone when T ↑, but more water vapor → O3 destruction

Remobilization of POPs when snow/ice melts

Precipitation ↑ can lead to increased wet deposition
Precipitation ↓ and weak circulation may increase PM

Precipitation ↑ enhance transport in rivers
Precipitation ↓ less chemical runoff and lower degr

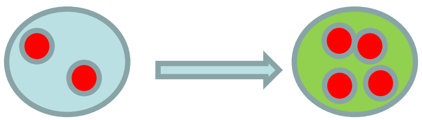
T ↑ Volatilization and microbial degr in/from soil/sed increase

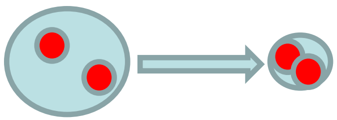
Pesticides sensitive to hydrolysis increase degr when soil moisture ↑

T ↑ in water will enhance volatility, but also solubility in water and OM, increase rate of hydrolysis and microbial degr

Some basics: Contaminants concentrate in env media through two fundamentally different processes

”solvent switching” and ”solvent depletion”





$K_{12} = C_1 / C_2$

E.g. $K_{air\text{-}water} = C_{air} / C_{water}$

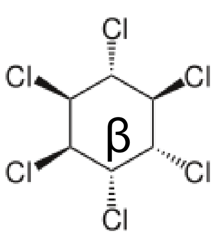
Temperature dependent!

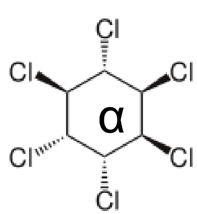
Partitioning – ”solvent switching”

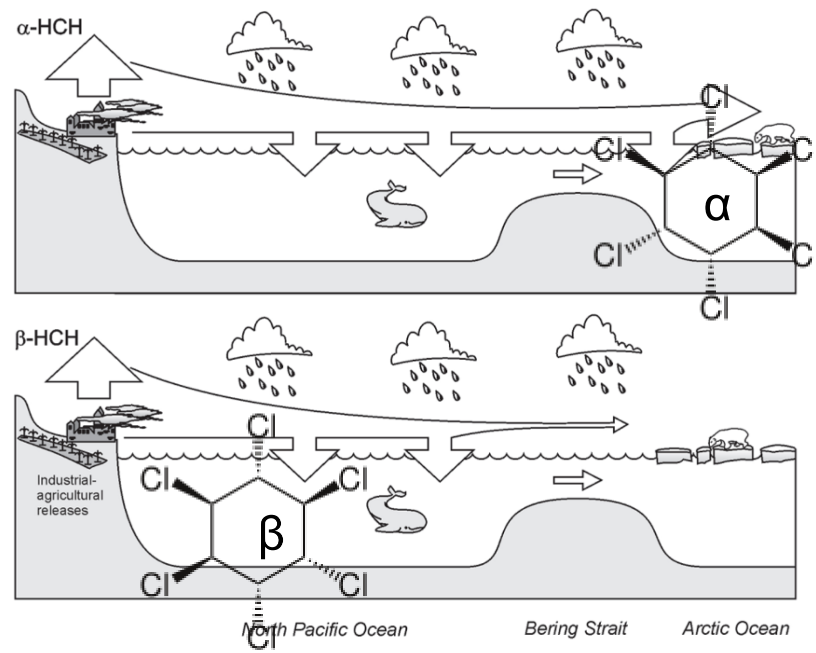
- → doesn’t require energy input because it runs toward thermodynamic equilibrium
- Example: hexachlorocyclohexane (HCH) has a low air-water part coeff (K_{AW})→ partitions spontaneously out of air into water
- Cold water → lower K_{AW} → more HCH partitions into the cold water
- Warmer water → chemicals driven back out of the water

Alpha and beta isomers of HCH, classified as POPs. (Byproduct from insecticide lindane production, emitted from 50’s until early 90’s)

β-HCH partitions ca 20 times stronger into water than α-HCH → doesn’t reach the Arctic Ocean via air (travels fast m/s) but via water (travels slowly cm/s).



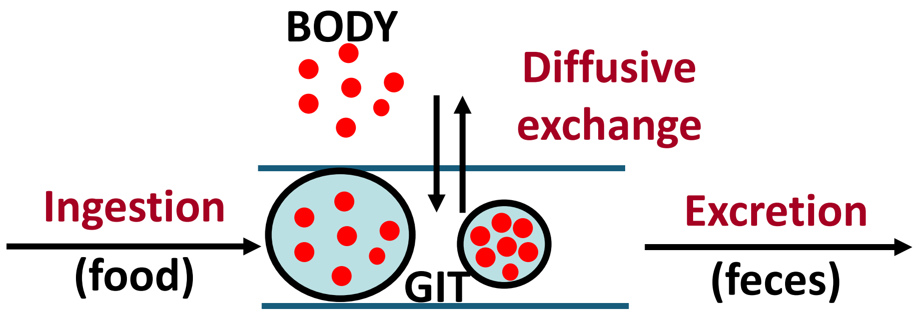


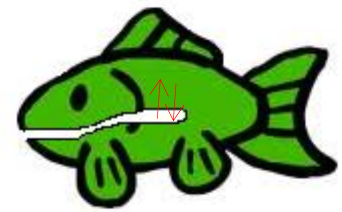


”Solvent-depletion”

- Solvent removed by some mechanism = less solvent → higher concentration (higher fugacity)
- Requires energy
- → can produce concentrations higher than thermodynamic equilibrium!
- Example biomagnification:
  - Hydrophobic chemical partitions strongly from water into lipids of detritus and plankton
  - Higher trophic level organisms eat them and metabolize lipids in their guts
  - → concentration of chemical increases radically, more chemical can diffuse over membranes in GIT
  - = predator can achieve much higher conc than thermodynamic equilibrium

Uptake from food - biomagnification





Following ingestion there are two competitive fate processes:

- transport through the gastro-intestinal tract (GIT), and
- transfer between GIT and fish

Digestion causes a reduction in food volume and a reduction in its ability to store chemical (e.g. by removal of lipid).
This increases the chemical's fugacity, tending to "drive" it into the fish.

= Mechanistic explanation of food chain biomagnification.

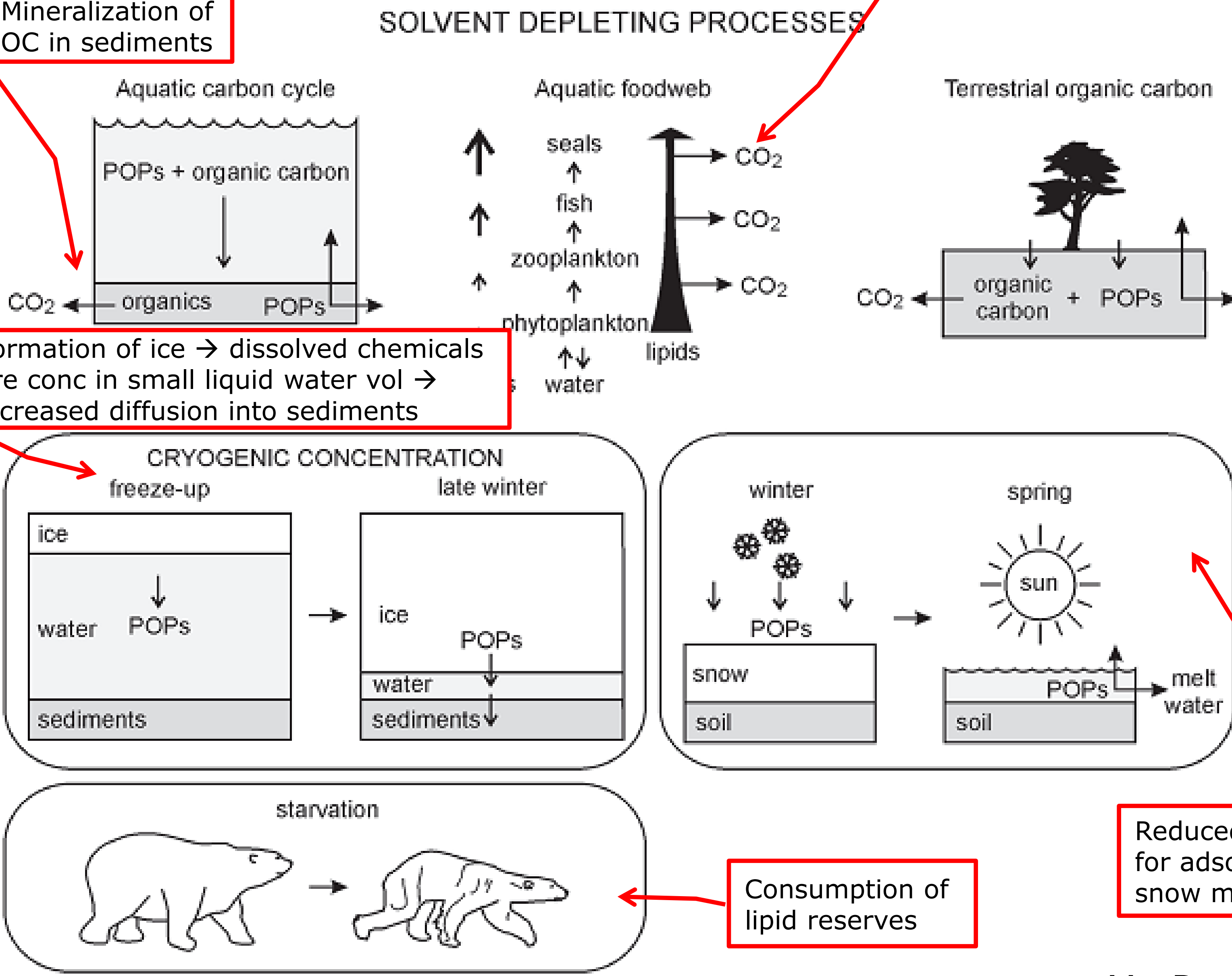
"Solvent-depeletion"

Biomagnification due to lipid metabolizm

Mineralization of OC in sediments

Mineralization of terrestrial OC

Formation of ice → dissolved chemicals are conc in small liquid water vol → increased diffusion into sediments

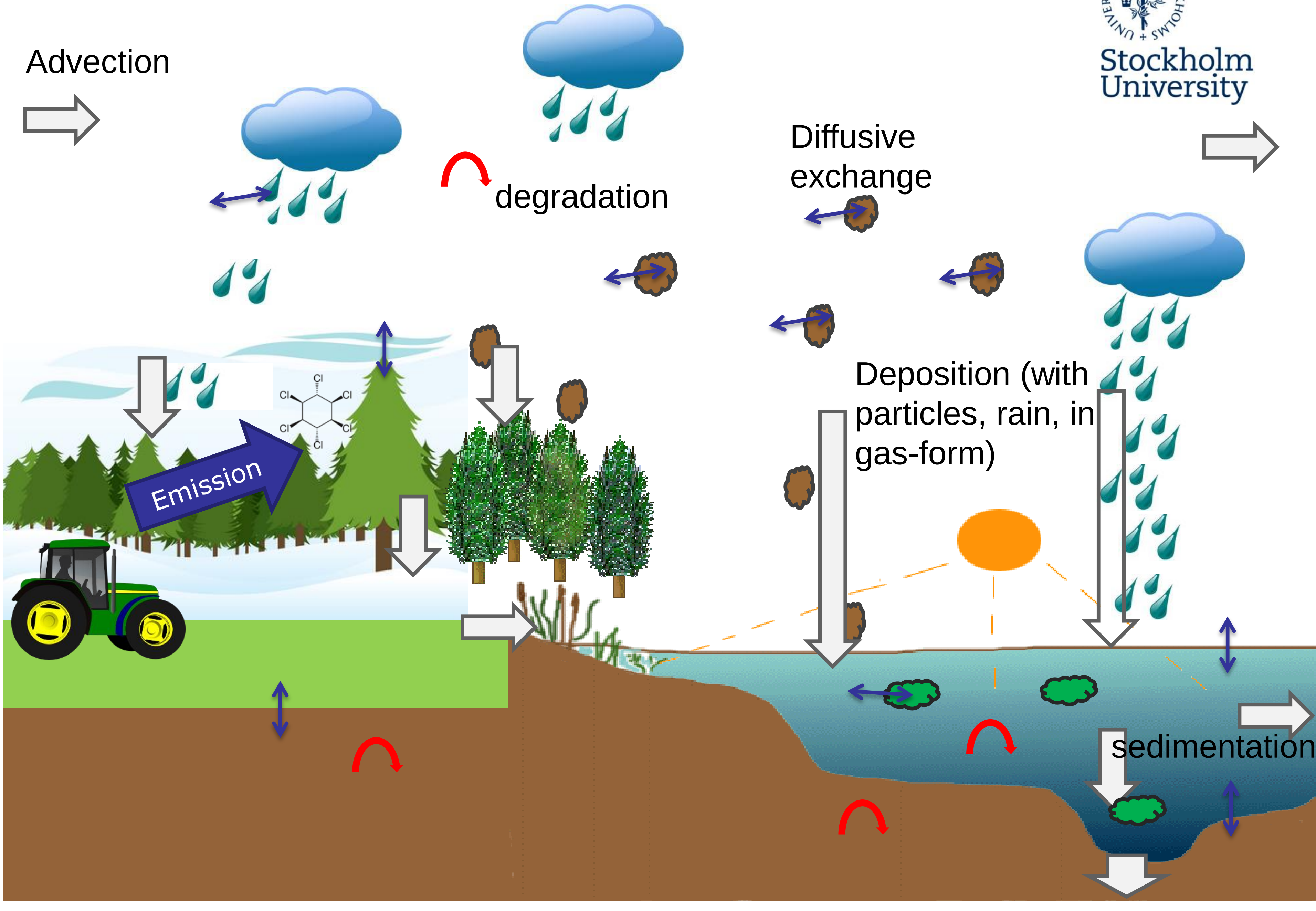


Consumption of lipid reserves

Reduced surface area for adsorption when snow melts

MacDonald et al 2005

How to quantify this? Models can be used…



How to quantify this? Models can be used…

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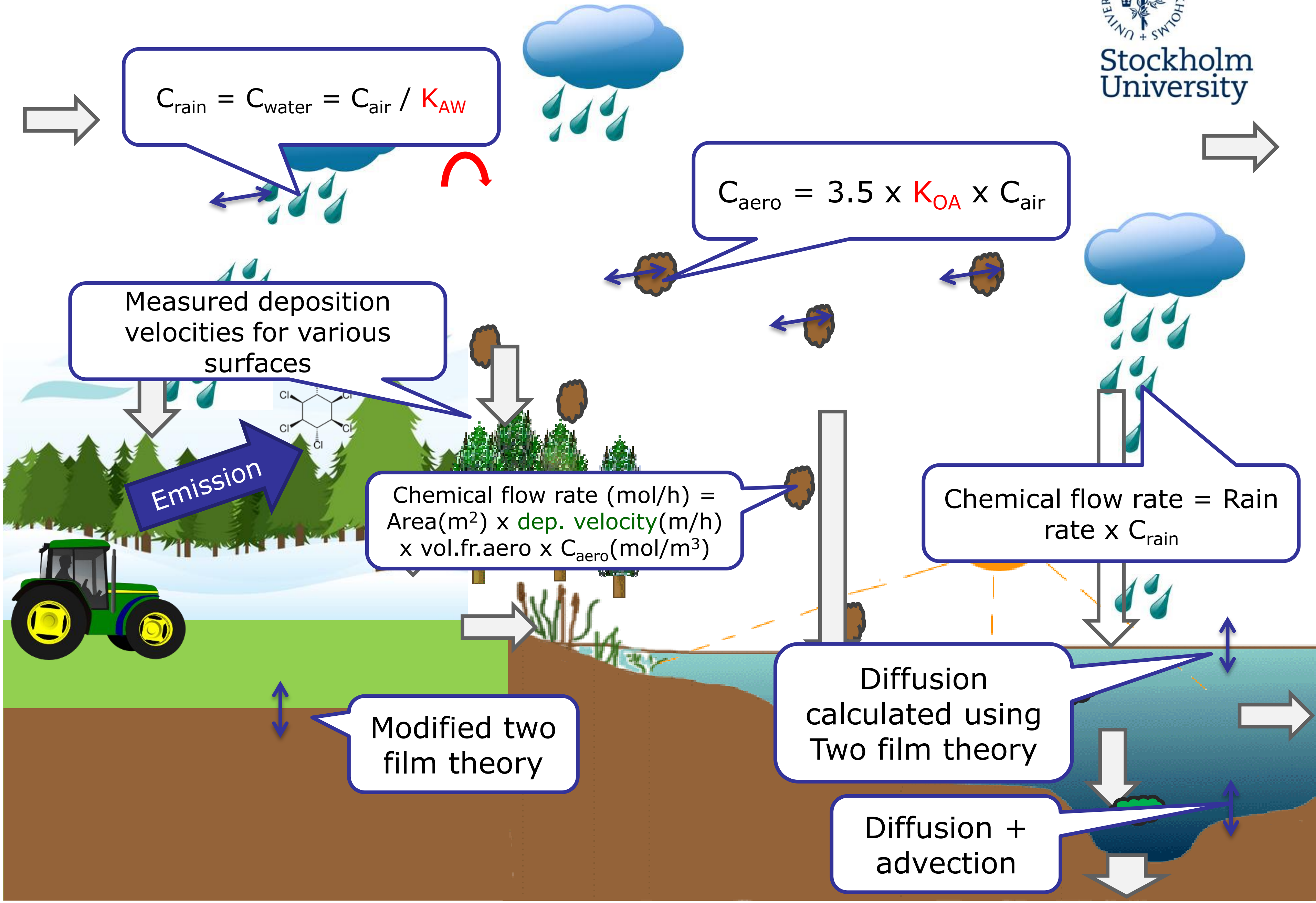

Models are used to predict impact of climate change on contaminant transport, transformation and fate

- In general these studies:
  - compare baseline and future scenario
  - parameterize the model with temperature, precipitation, atmospheric circulation patterns, degradation half-lives
  - Model output generally within a factor of 2 or less of baseline results
  - Air concentrations = elevated
  - Conc in other media = lower
  - Long-term average patterns, not local scale
- Models limited ability to simulate ice/snow conditions, organic carbon inputs (land based, primary production), hydrology etc. Difficult to parameterize.

Gouin et al 2013

Physical-chemical properties determine fate in the environment

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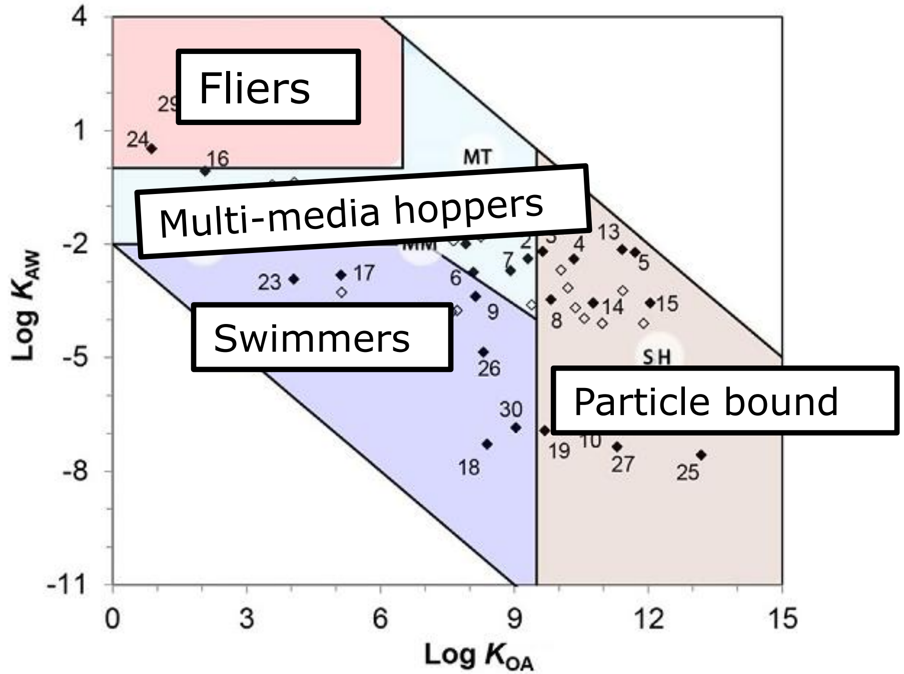
$$K_{AW} = \frac{C_{air}}{C_{water}}$$

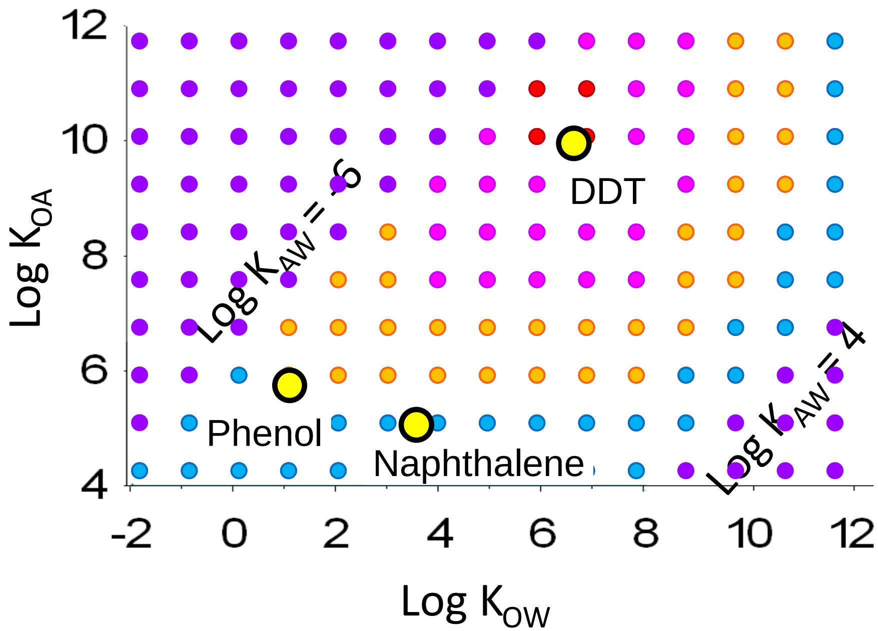
$$K_{OA} = \frac{C_{octanol}}{C_{air}}$$

Octanol = lipids, organic matrices



Kong et al 2014

Chemical partitioning space plots



Hypothetical chemicals

Example:

Chemical properties

Impact…

Where?
When?

Mode of emission (to e.g. air, soil, water)?

Which parameter (conc in air, soil, sed, water, bioaccumulation etc etc)?

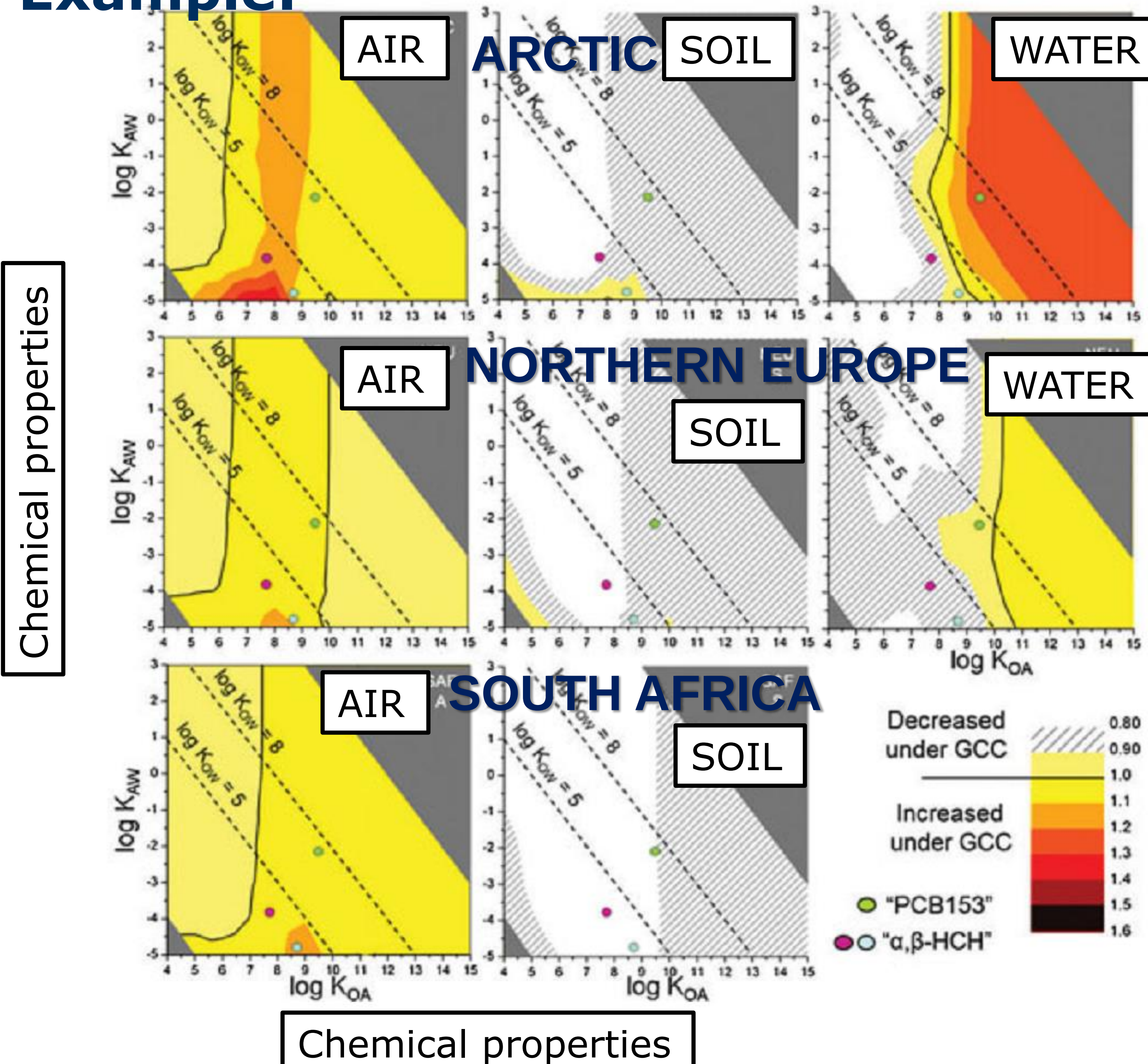
Which chemical….?

Steady state output for Climate change scenario compared to ref scenario using global contaminant model BETR

Chemical properties

Gouin et al 2013

Example:



Impact…

Where?
When?

Mode of emission (to e.g. air, soil, water)?

Which parameter (conc in air, soil, sed, water, bioaccumulation etc etc)?

Which chemical….?

Steady state output for Climate change scenario compared to ref scenario using global contaminant model BETR

Gouin et al 2013

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:

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

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]	D coupled bioenergetics/ bioaccumulation model		projections for Lake Superior surface water temperatures	C_{FISH} ↑ vs control species-specific and confounded by predator–prey dynamics F_{MAX} = approx 3

Gouin et al 2013

Impact on contaminants

- Emissions
- Environmental fate
- Bioaccumulation
- Toxicity

Bioaccumulation – some direct effects

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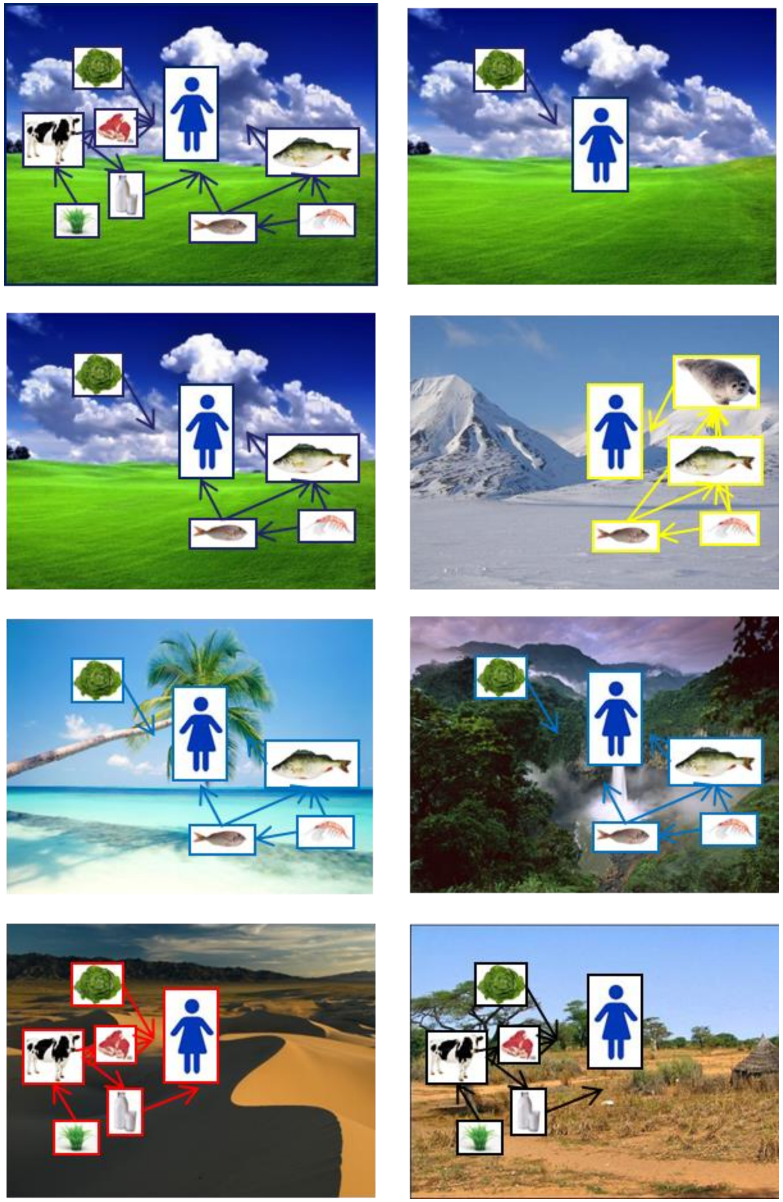
- Limited number of modeling studies
- Considers temperature dependent chemical fate, bioenergetics, changes in trophic linkages (i.e. diet compositions), species metabolic rates
- Borgå et al: temp dependent respiration, consumption and growth rate + increased prim prod → reduced conc in fish (0-50%)
- Ng and Gray: Temperature increase in Great Lakes impact on fish. Thermal relationships for consumption, respiration and growth → small impact only

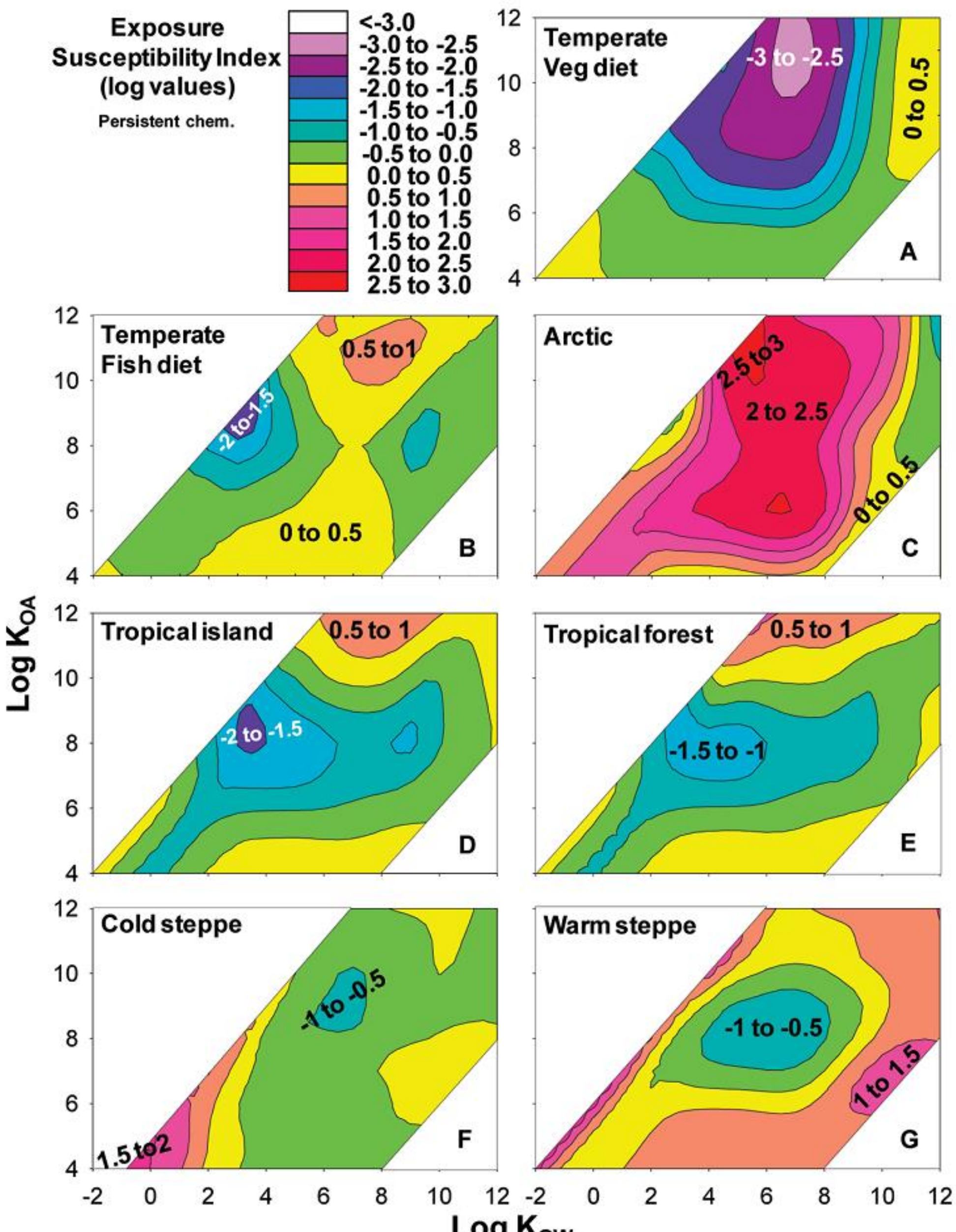
Indirect effect are larger – changes in food webs



Modelling study with 6 hypothetical climate regions and 6 diets, same emissions in each environment

Undeman et al 2010

Indirect effect – changes in food webs



Modelling study with 6 hypothetical climate regions and 6 diets, **same emissions in each environment**

Graphs show ESI =

Uptake in human in region i

____

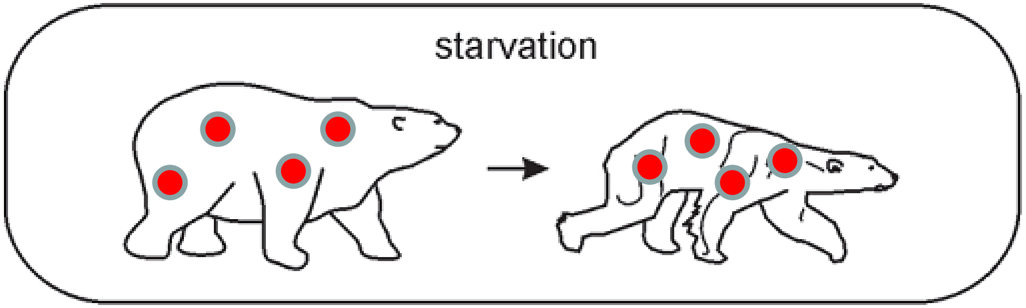
Uptake in reference human (temperate climate, mixed diet)

Up to 1000 times higher uptake in Arctic human with seal blubber in diet compared to Temperate human on mixed diet.
Most differences attributed to differences in diet rather than environmental concentrations.

Undeman et al 2010

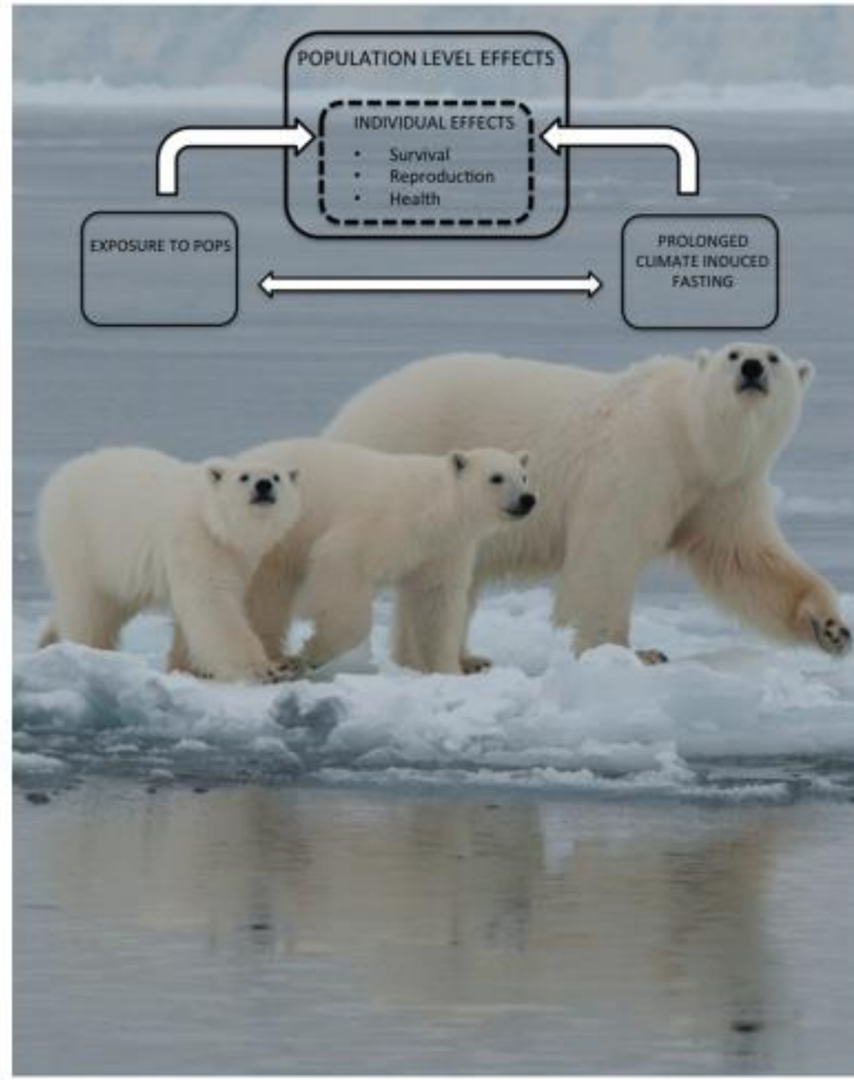
Example: Indirect effect on polar bears

- Climate change → earlier break-up of ice, less ice extent
- Polar bears forced onshore
- Limits access to preferred prey (ringed seal)
- 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

- Longer distances to food → higher energy need → higher feeding rate → higher dietary exposure to POPs
- Although change in diet to <u>less contaminated diet</u> (plants, berries, caribou) <u>can lower exposure</u>. Seabird eggs → higher exposure…
- Global warming → spreading of new diseases and micro-pathogens
- POPs effect immune system, reproduction, metabolic rates, neurological processes and cognitive abilities (impacting e.g. mating behavior, communication, learning) → **higher mortality, lower reproduction**



Jenssen et al 2015

Change in food chain

- E.g. Shift from large diatoms to smaller dinoflagellates → additional small zooplankton grazing step = Additional trophic level
- Increase in one trophic level → conc in lipids can increase by factor 5 to 10

Impact on contaminants

- Emissions
- Environmental fate
- Bioaccumulation
- Toxicity

Impact on contaminants – toxicity

- Temperature: toxicity of e.g. dieldrin, carbaryl, atrazine, endosulfane to freshwater darter, green frog, catfish, juvenile rainbow trout respectively increased with increasing temperature
- Pyrethroids (commercial household insecticides) and DDT less toxic in higher temperature, but this is species specific (e.g. not in leopard frog)

- Biotransformation to toxic metabolites may be enhanced
- Uptake and excretion rates generally increase with temperature, but toxicity will depend on whether changes in metabolism lead to increased bio-activation or detoxification

Noyes 2009

Impact on contaminants – toxicity

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- Fitness of organisms impaired due to toxicants, less able to cope with higher temperature
- Species on the edge of physical tolerance range less able to cope with dual stressors (climate change + toxicants). E.g. temperature tolerance lowered for perch, rainbow fish, carp and trout when exposed to endosulfane and chlorpyrifos. Same for trout and slamon with DDT
- Timing of exposure (i.e. at sensitive life stages) is also important
- Hypoxia → reduce induction of detoxification pathways (e.g. CYP 1A) in fish, disrupts endocrine system of fish (carp, zebrafish),
- POPs (e.g. PCBs, DDT, dioxins, furans) = previously believed to be cofactors in mass mortality incidences caused by morbilliviruses (e.g. 10000 Caspian seals yr 2000 had elevated POP levels = more susceptible to disease), but this was recently disproved (Wilson et al 2014 PLOS)

Noyes 2009

What about the Baltic Sea?

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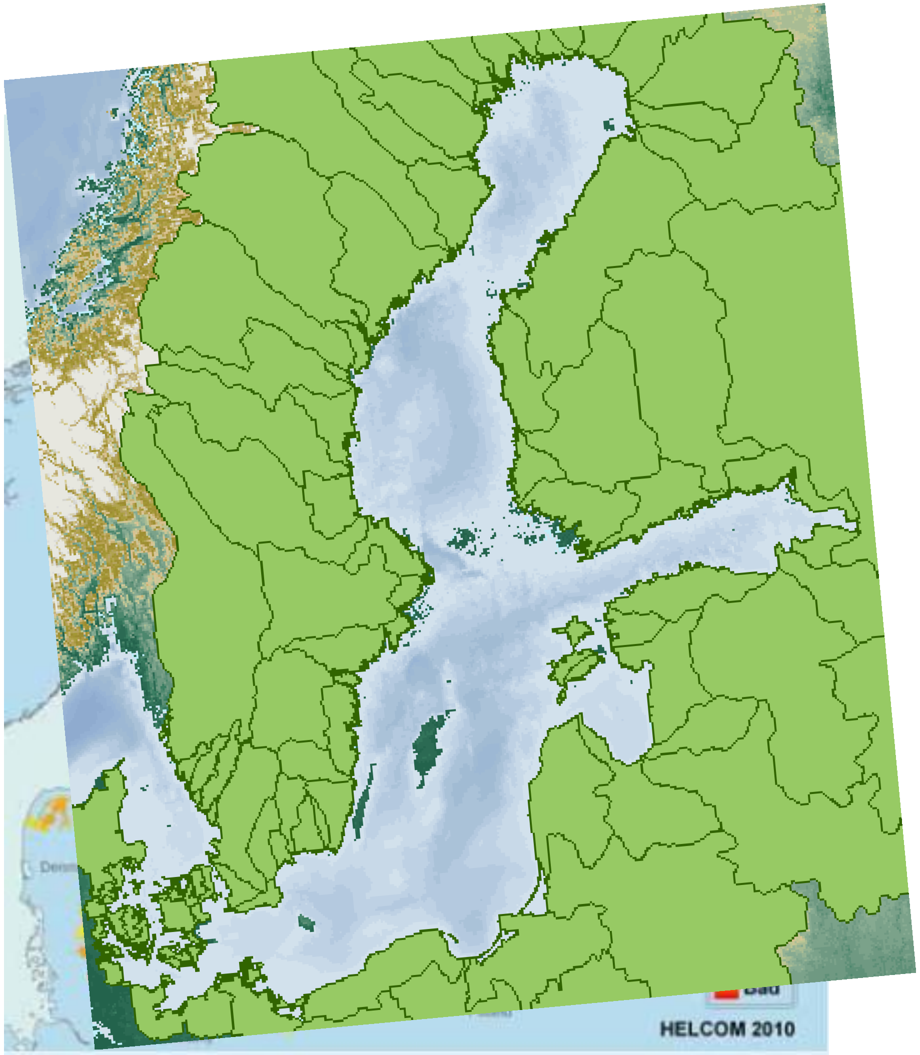
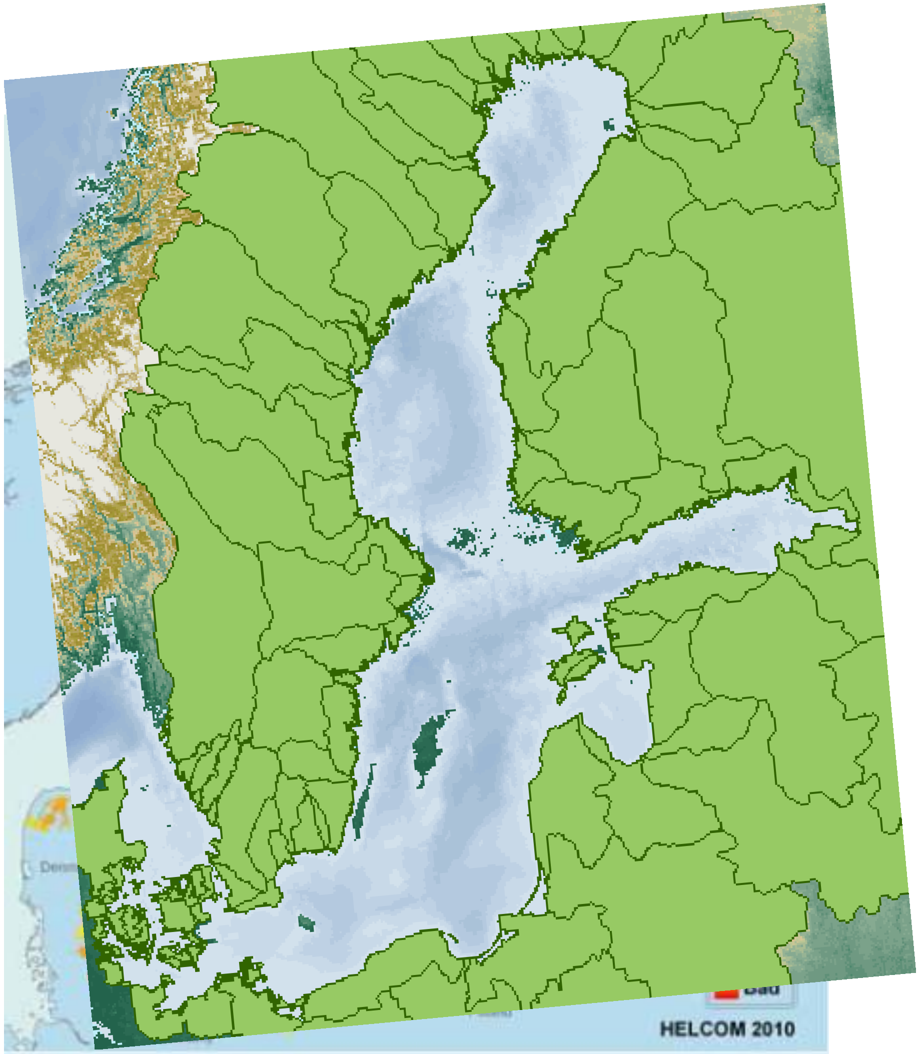


Organic pollutants in the Baltic Sea

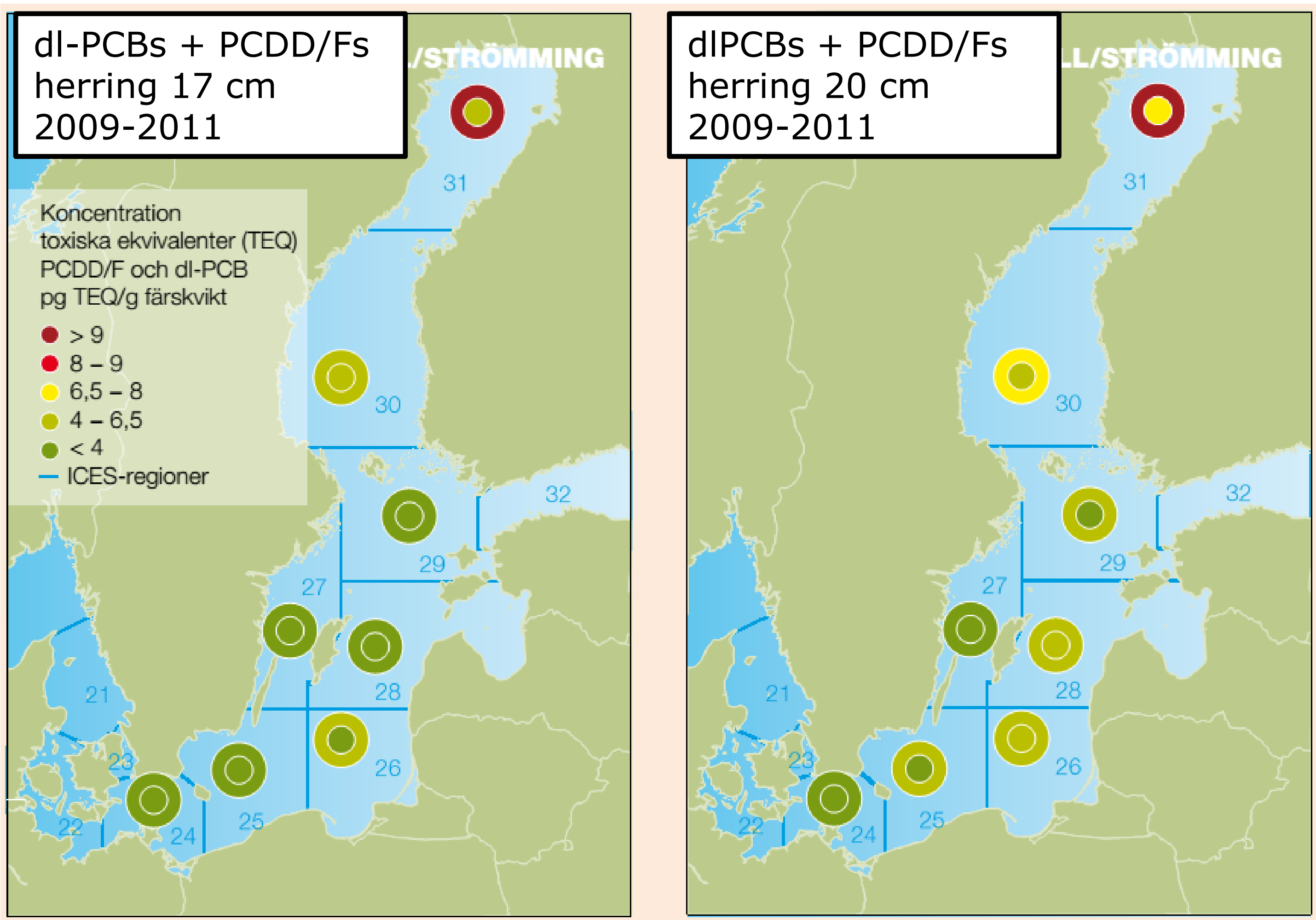


Many compounds monitored, e.g.:
PCBs
Dioxins
DDT, DDE
HCB
PAHs
PFAS (e.g. PFOS, PFOA PFNA,PFUNDA)
BFRs: PBDEs (BDE47,BDE99,BDE100), Bromophenols, HBCDD, OH-PBDEs

But many more are present in unknown concentrations.

Pollutants in the Baltic Sea

Toxic equivalents (TEQs) = toxicity of dioxins, furans, PCBs compared to the toxicity of the most toxic dioxin, 2378TCDD.
Threshold in fish for sum dioxins+dioxin-like PBCs 6.5 pg TEQ / g ww, threshold for dioxins 3.5 pg TEQ/ g ww



Inner circle = mean conc

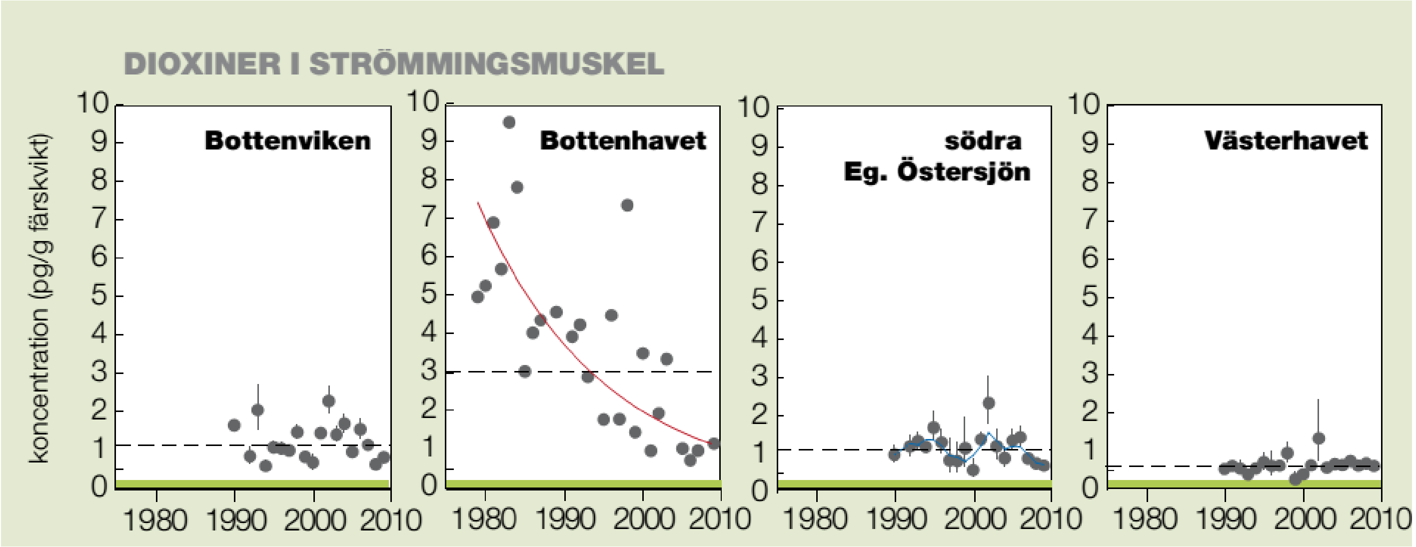
Outer circle = 95% confidence interval

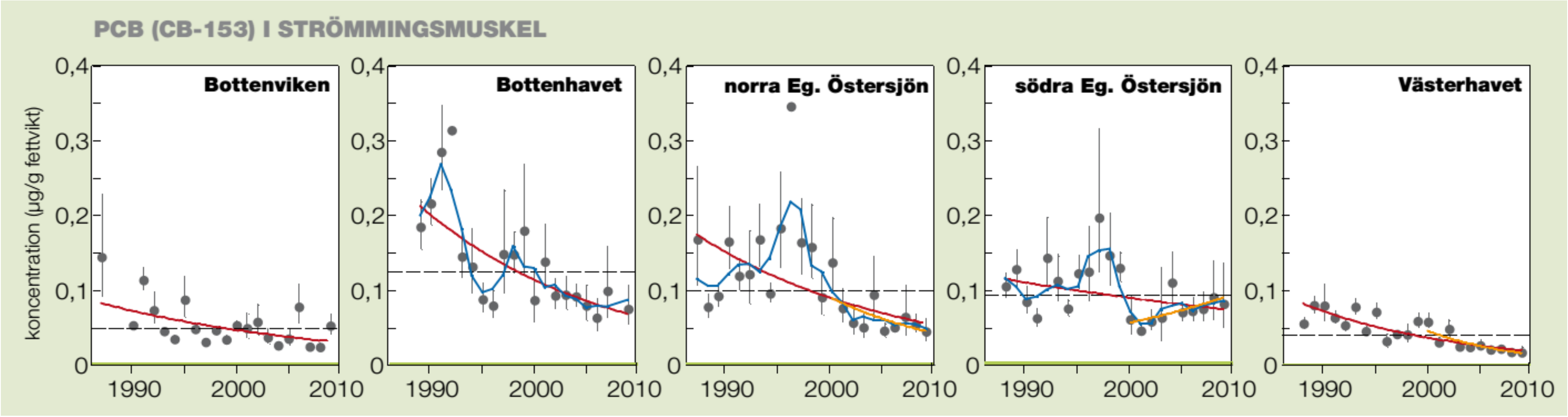
Outer circle yellow or red → conc not significant below threshold of 6.5 pg TEQ/g ww

Havet 2012

Montoring data herring muscle

Decreasing trends for PCBs and dioxins in herring muscle, but trends in recent years unclear

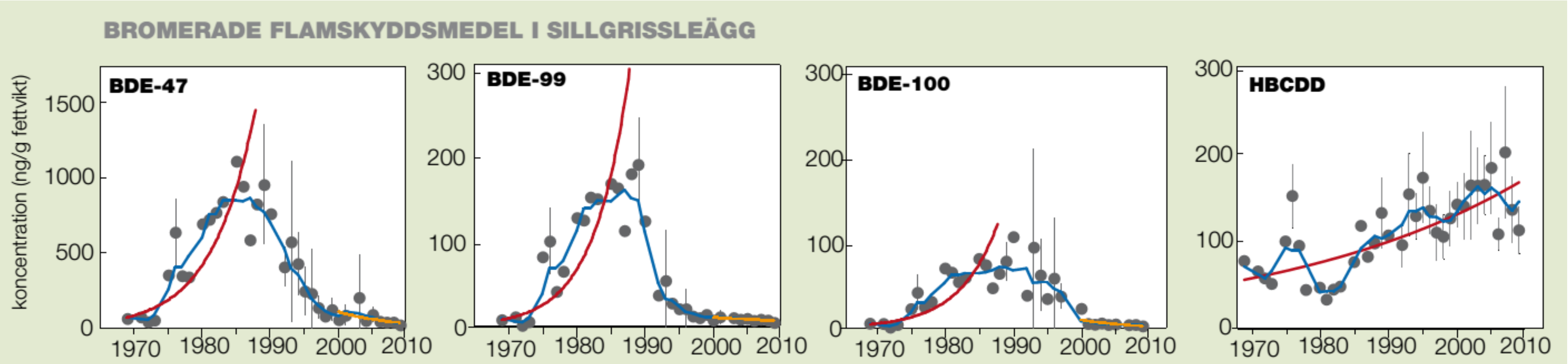




Havet 2010,2011,2012,2013/2014

Montoring data from guillemot eggs

Decreasing trends for some brominated flame retardants, but not for HBCDD (still in use)

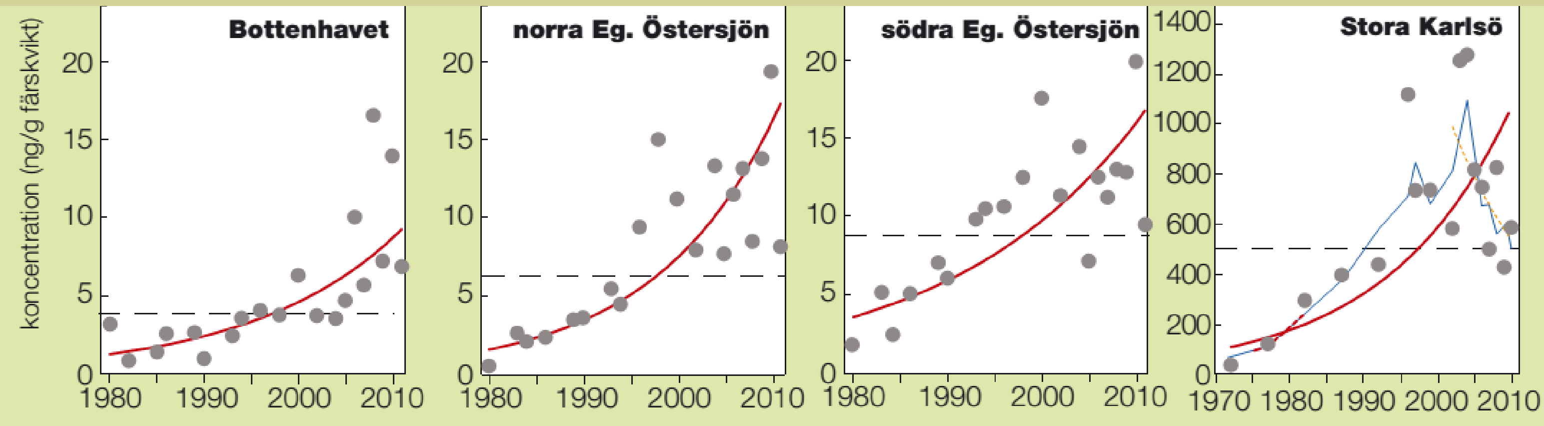


Havet 2010,2011,2012,2013/2014

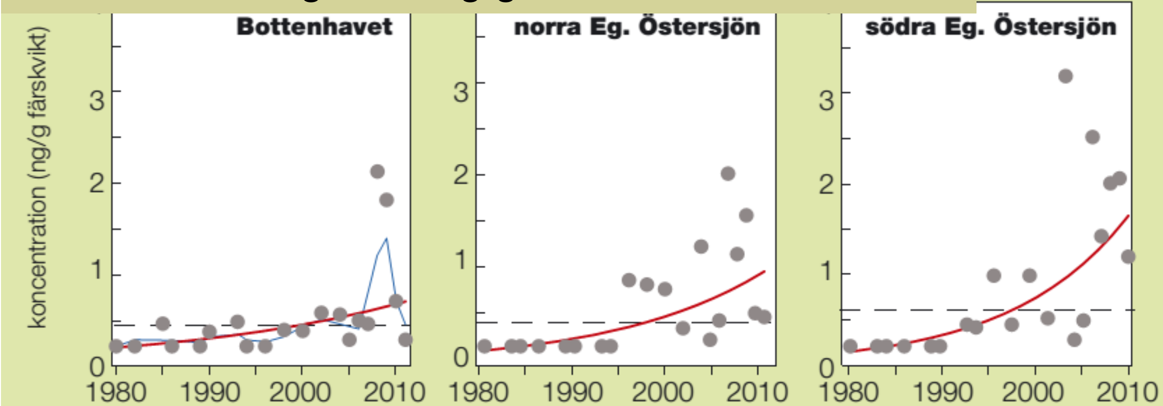
Monitoring data from herring liver and guillemot eggs

Stockholm University

PFOS in herring liver and guillemot egg, ng/g ww



PFOA in herring liver, ng/g ww



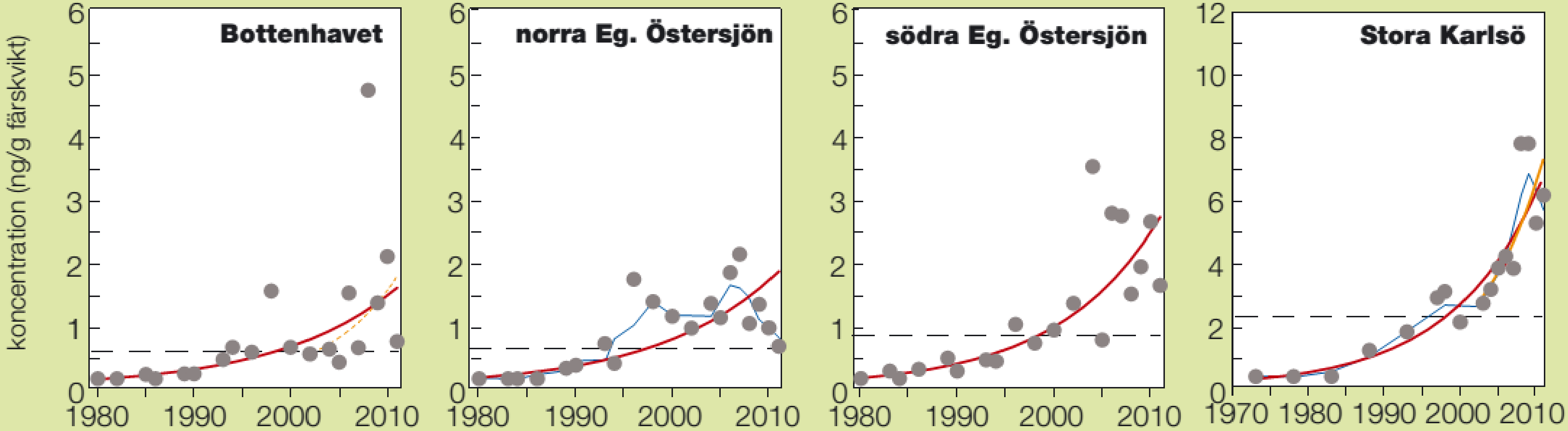
PFOS=Perfluorooctan sulfonate
PFOA=Perfluorooctanoic acid

Havet 2010,2011,2012,2013/2014

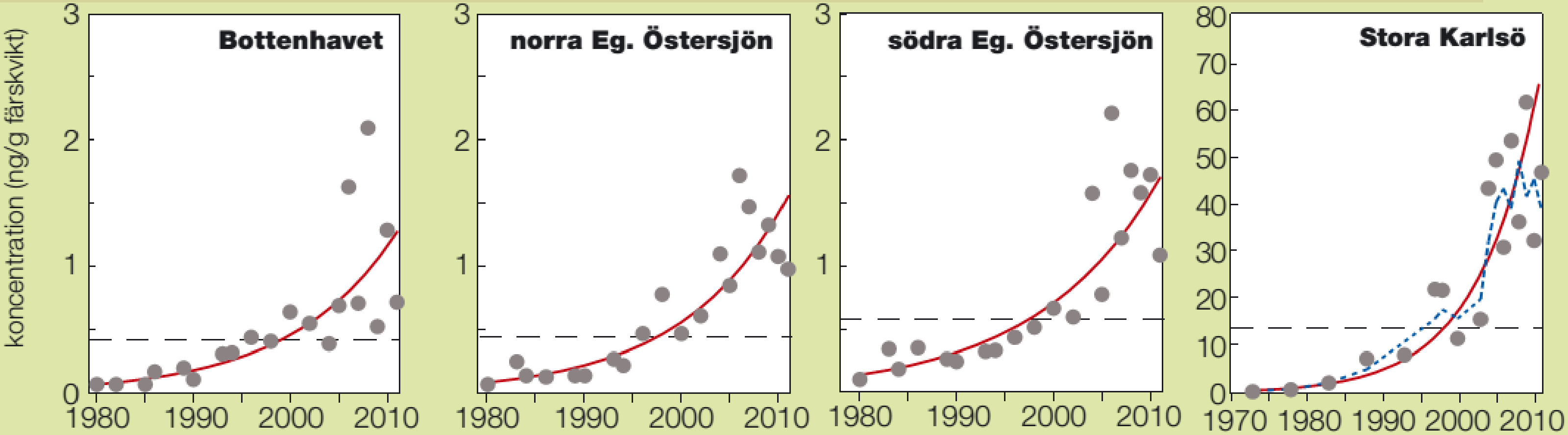
Increeasing trends for perflourinated compounds

Stockholm University

PFNA in herring liver, ng/g ww



PFUNDA in herring liver, ng/g ww



Havet 2010,2011,2012,2013/2014

Climate change impact in the Baltic Sea – predicted physical changes

Stockholm University

- Surface water will warm more than deep water
- Sea surface temperature: 1 to 4 °C increase, increase 2 °C in the south, 4 °C in the north (high in north due to ice albedo feedback)
- Sea-ice extent: 50-80% reduction by 2100, length of ice season 1-2 month shorter in north e.g. Bothnian bay, Gulf of Finland and by 2-3 months in central BS
- Increased wave height in the North in spring, increased well-mixed layer depths in Bothnian Bay and Gulf of Finland
- Salinity decrease due to increase of runoff (freshwater) increase by 15-22%
- Wind – small changes (max 1 m/s increase)
- Runoff – increase 15-22%

Summary by Andersson et al 2015, Shiedek 2007

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

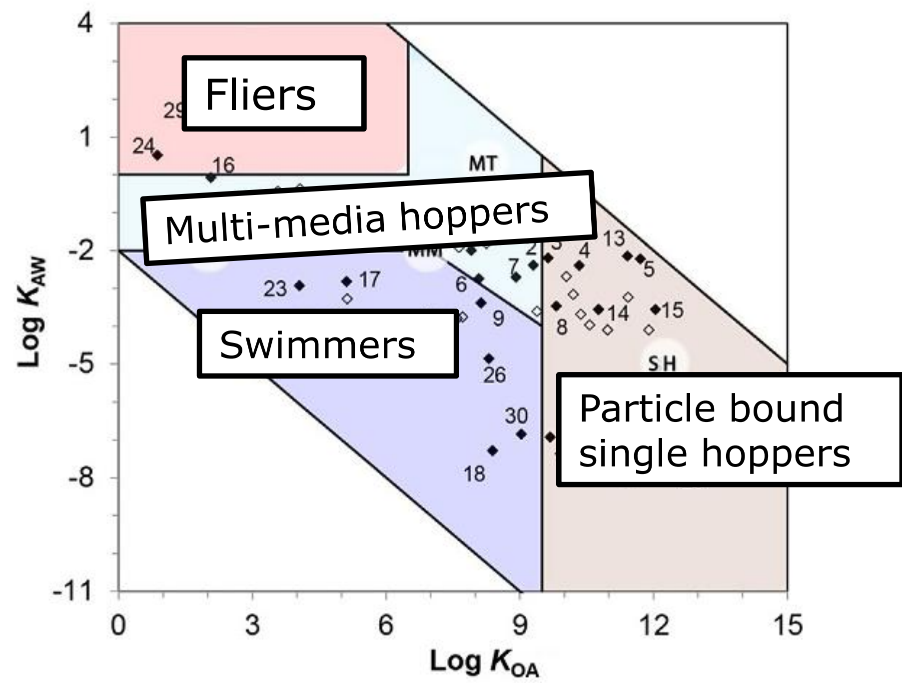


Table 1
Summary of the modelled climate change-induced impacts on the concentrations of hypothetical perfectly-persistent organic chemicals (considering all four studied climate variables).

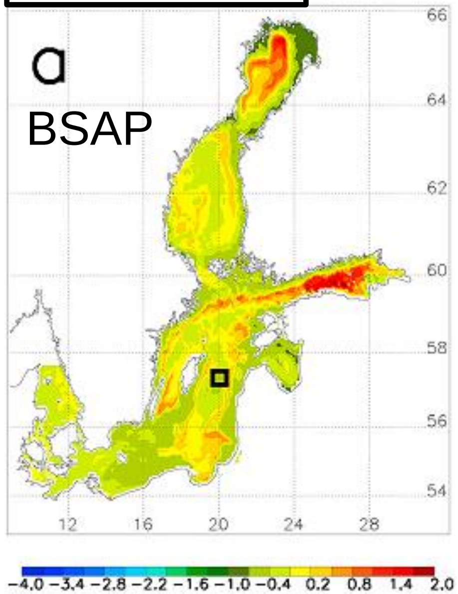
	Air	Forest canopy	Forest soil	Agricultural soil	Fresh water	Fresh water sediment	Coastal and open ocean water	Coastal and open ocean sediment
Volatile fliers	+/+/+	+/+/+	±/±/–	±/±/–	+/–/±	+/–/±	+/±/+	+/–/±
Water soluble and relatively volatile multiple hoppers	+/+/+	+/+/+	±/+/–	+/+/–	+/±/+	+/±/+	+/±/+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

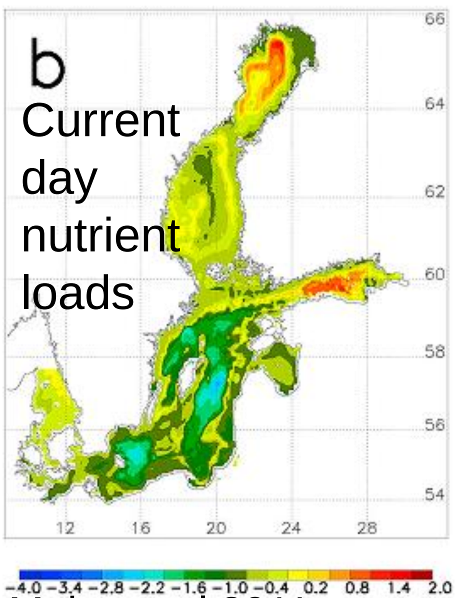
"+" indicates increase; "–" indicates decrease; "±" indicates both increasing and decreasing impacts were observed for that specific group of chemicals. Symbols from left to right correspond to emission to air, water and soil. Note that here the predicted impacts are not discriminated according to the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

Kong et al 2014

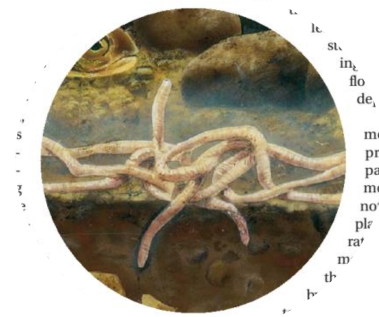
Re-oxygenation → Bioturbation

Change in oxygen (mg/L) concentration





Meier et al 2011



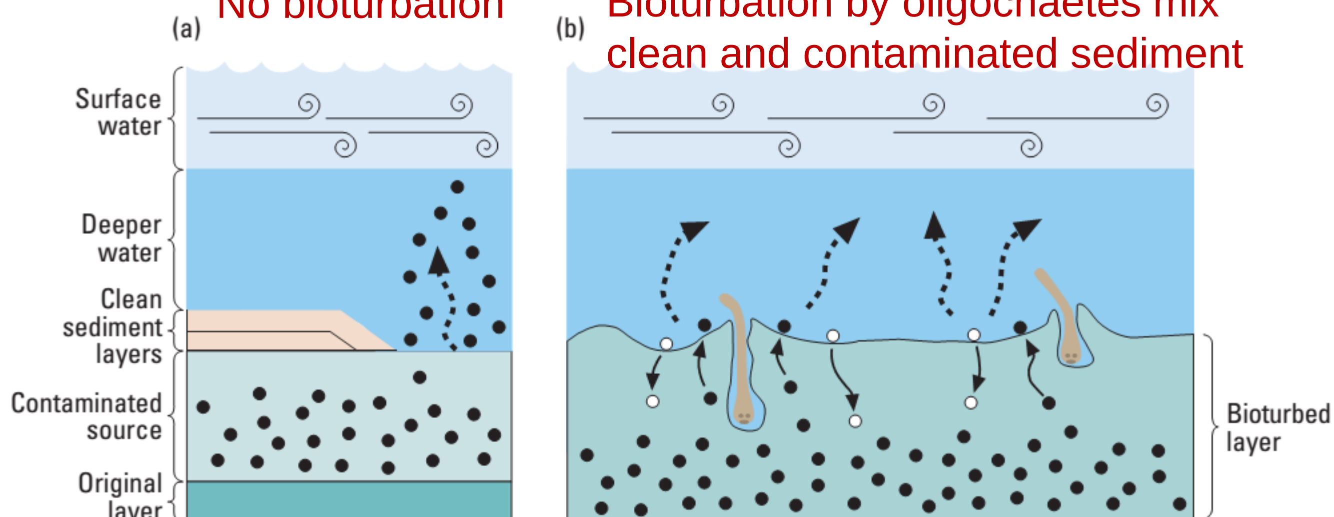
Maps show O2 concentration (mg/L) change in two nutrient + climate change scenarios

-Reduced hypoxia (red, yellow)
-Also, invasive species (e.g. polychaete *Marenzelleria sp* burrow 10-35 cm deeper than indigenous Baltic Sea fauna, less sensitive to low oxygen)

→ increased bioturbation
→ Release of "sediment archive" of contaminants
→ Up to 3 times higher diffusive release of POPs due to bioturb measured in lab (Granberg 2008)

No bioturbation

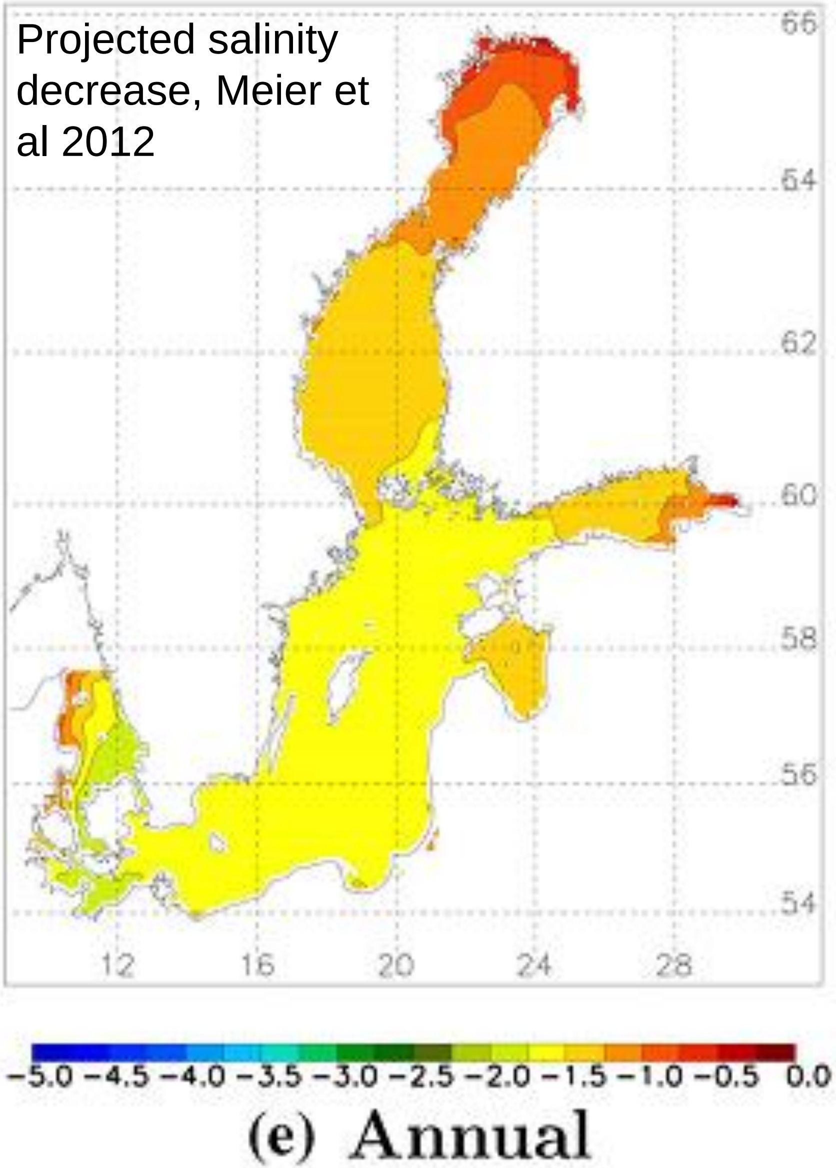
Bioturbation by oligochaetes mix clean and contaminated sediment



Thibodeaux 2003

Salinity

Projected salinity decrease, Meier et al 2012



Direct impact on pollutants:

”Salting out effect” (i.e. lower solubility lower bioavailability in saline water) = Water molecules strongly bound to salt making them unavailable for dissolution of organic contaminants

Likely small effect…

Example: Malathion longer half life in sea (3-5 days) water compared to freshwater (1 day) due to lower bioavailablity (in Noyes 2009) (obs, uncertainty in numbers probably high…)

Elevated salinity → higher cost to maintain fitness (osmoregulation) → higher sensitivity to toxicants

River discharge
Grey = present day
Red/blue = climate scenarios

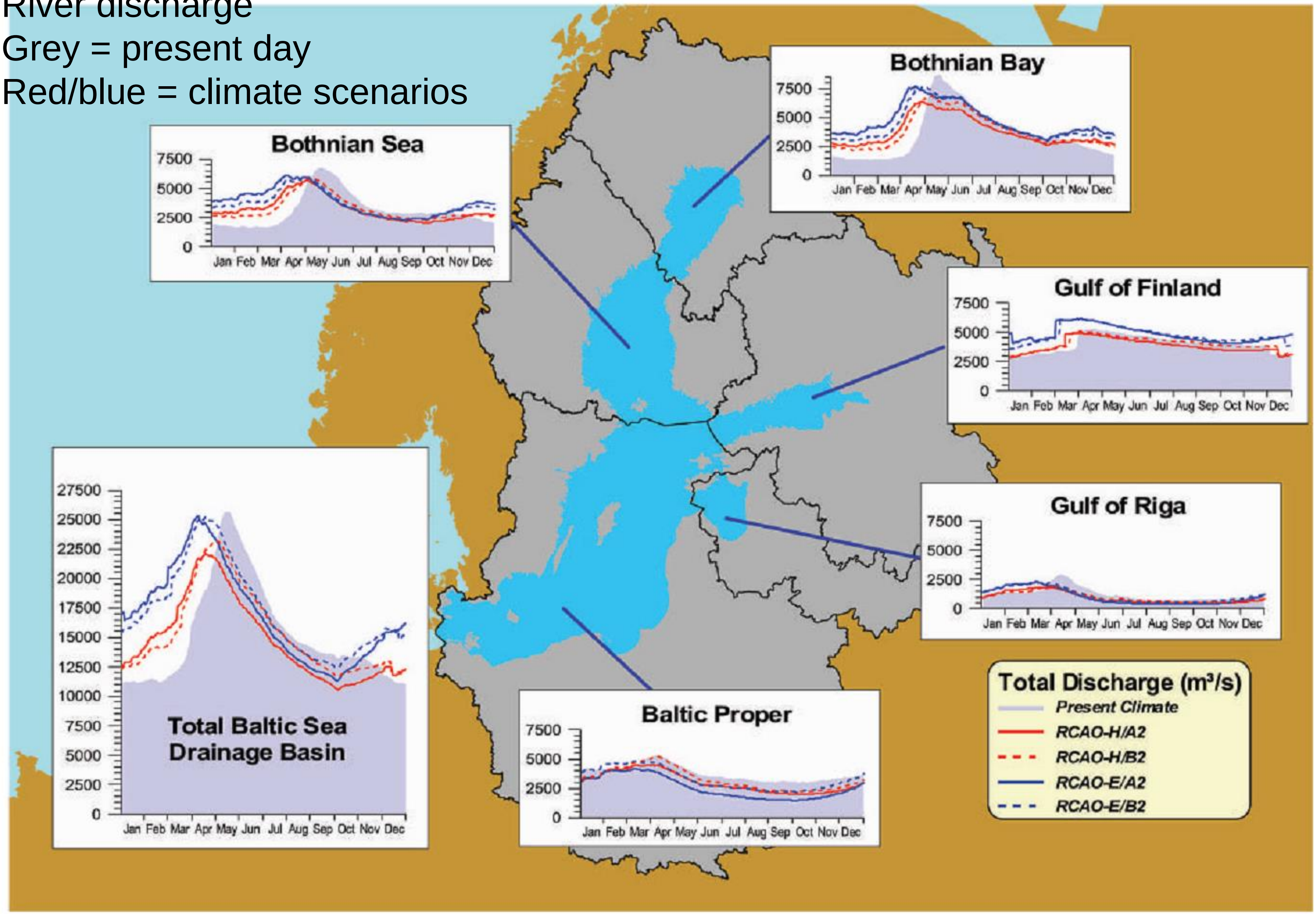
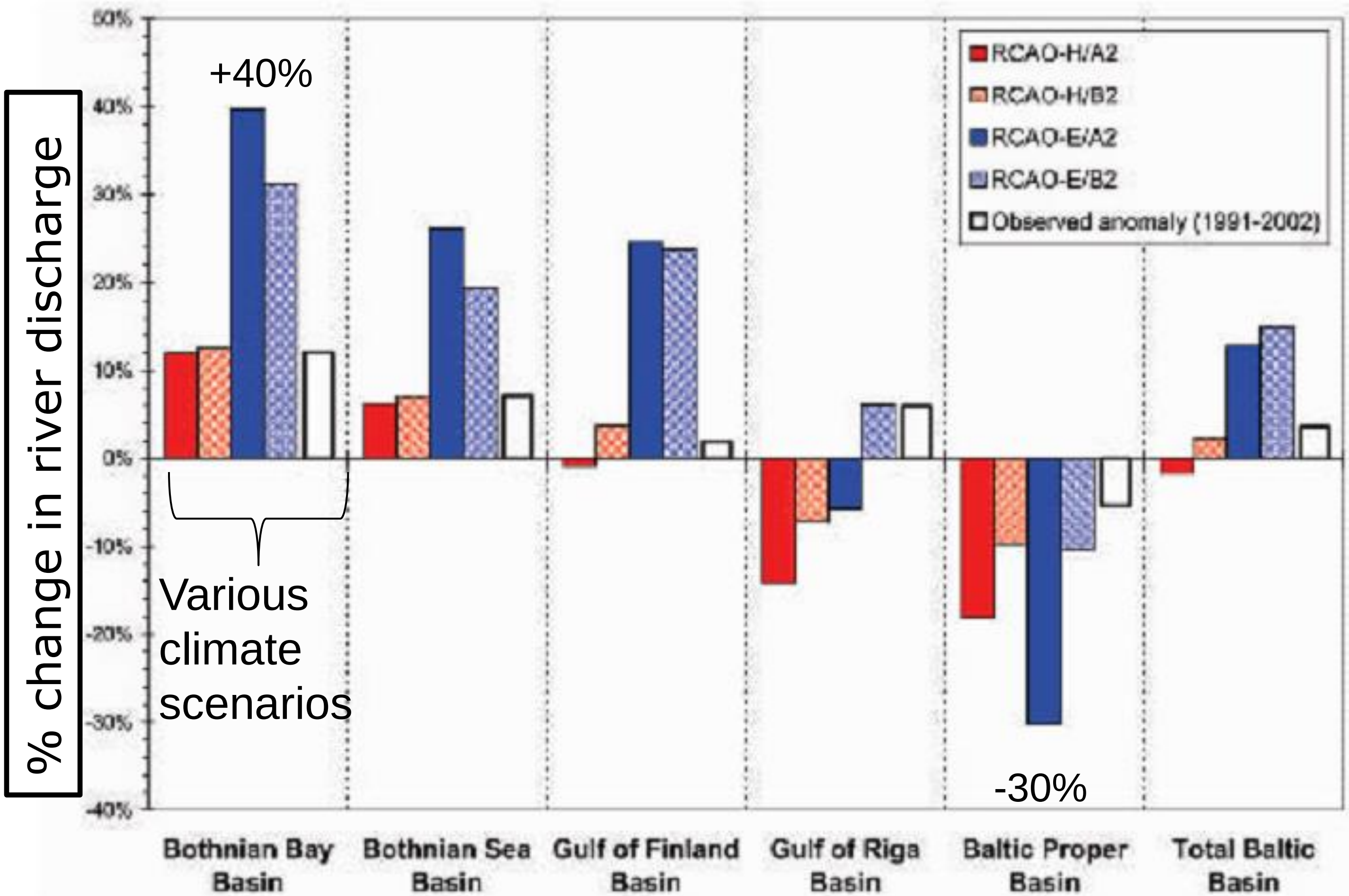


Figure 1. Modeled seasonal river discharge to the Baltic Sea from HBV-Baltic for present-day conditions (shaded) and four climate change scenarios. Shown are daily means over the 23-year modeling period. All plots are drawn to the same X and Y scales.

Graham 2004



– increased winter flows;
– reduced summer flows;
– increased flow from northern basins;
– decreased flow from southern basins;
– no pronounced increase in magnitude of high flow events;
– more frequent medium to high flow events.

→River transport of pollutants impacted (e.g. increased POC, DOC in rivers bringing chem from land and air)

Graham 2004

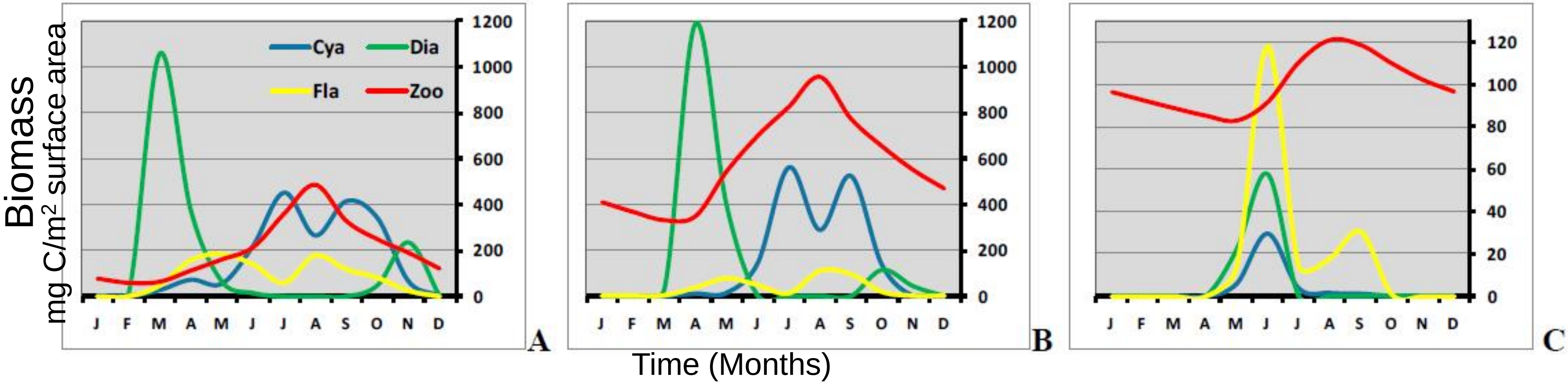
Primary production – impact on contaminants

Possible impact on contaminant distribution of increased biomass (i.e. euthrophication)

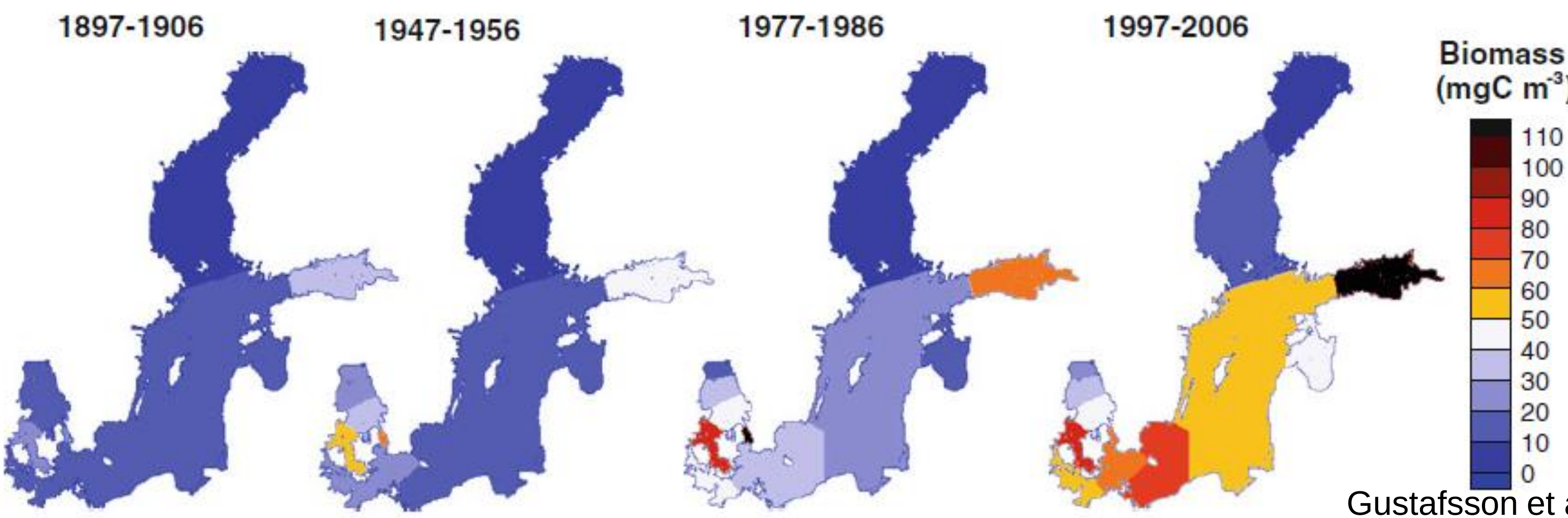
- Sinking phytoplankton and detritus may deplete dissolved water conc in surface layers and purge chemicals from the atmosphere into the water phase
- ”growth dilution” = temporary diseqilibrium between water and plankton
- ”Biomass dilution” = dilution in larger volume of organic material (if not replenished)
- Reduced volatilization
- Oxygen depletion in sediment → reduced bioturbation

Variations in organic carbon – seasonal and annual

Seasonal variation:
E.g. cyanobacteria, Diatoms, Flaggelates, Zooplankton

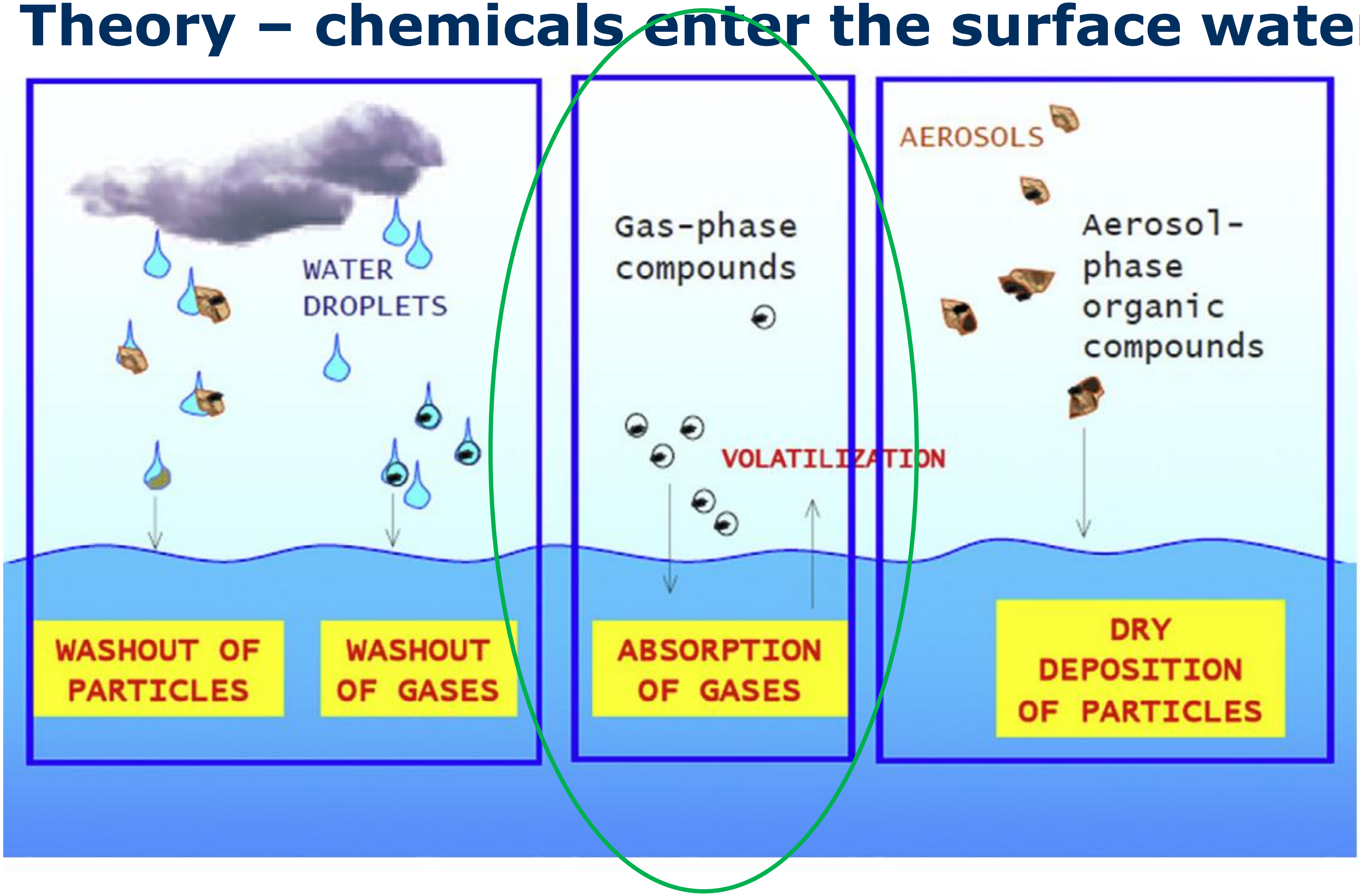


Variation between years:
E.g. phytoplankton biomass in upper 10 m



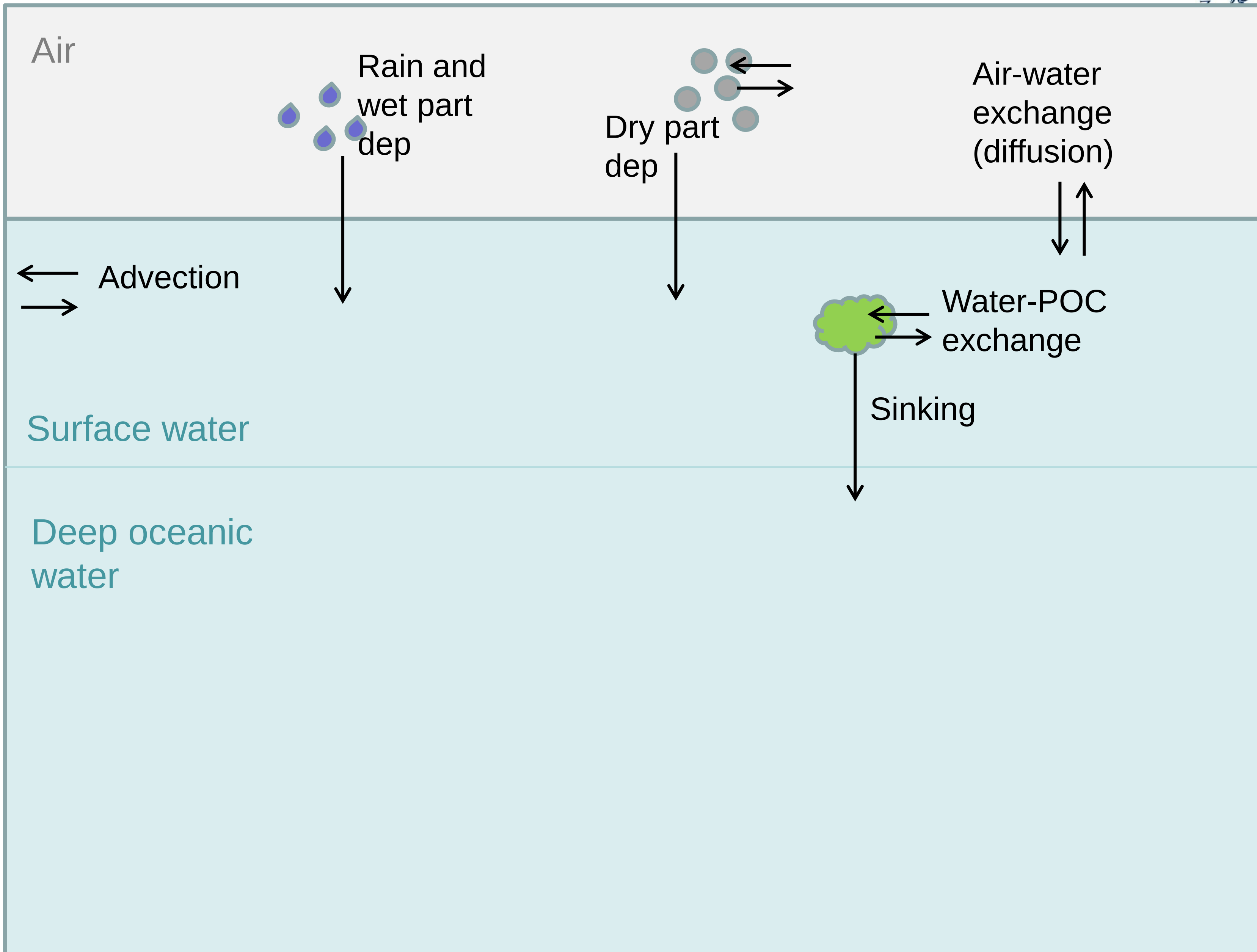
Gustafsson et al 2012

Theory – chemicals enter the surface water



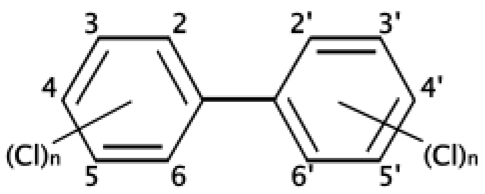
- For chemicals like PCBs, gaseous exchange is the most important process

Theory – transfer to deep water

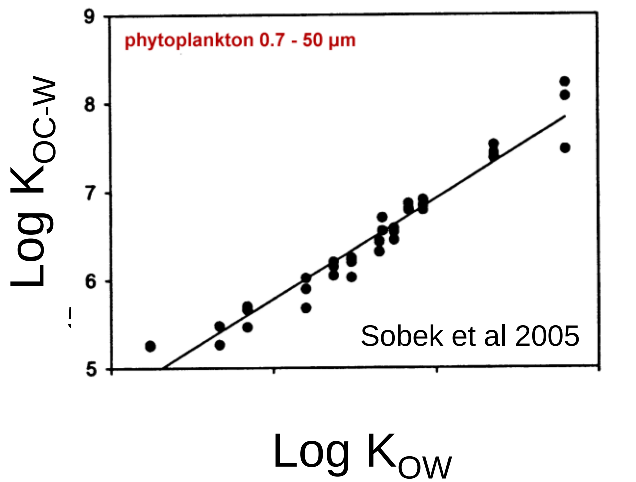


Hydrophobic organic contaminants accumulate in organic matrices

Because they are soluble in organic matter (e.g. lipids) and less soluble in water.



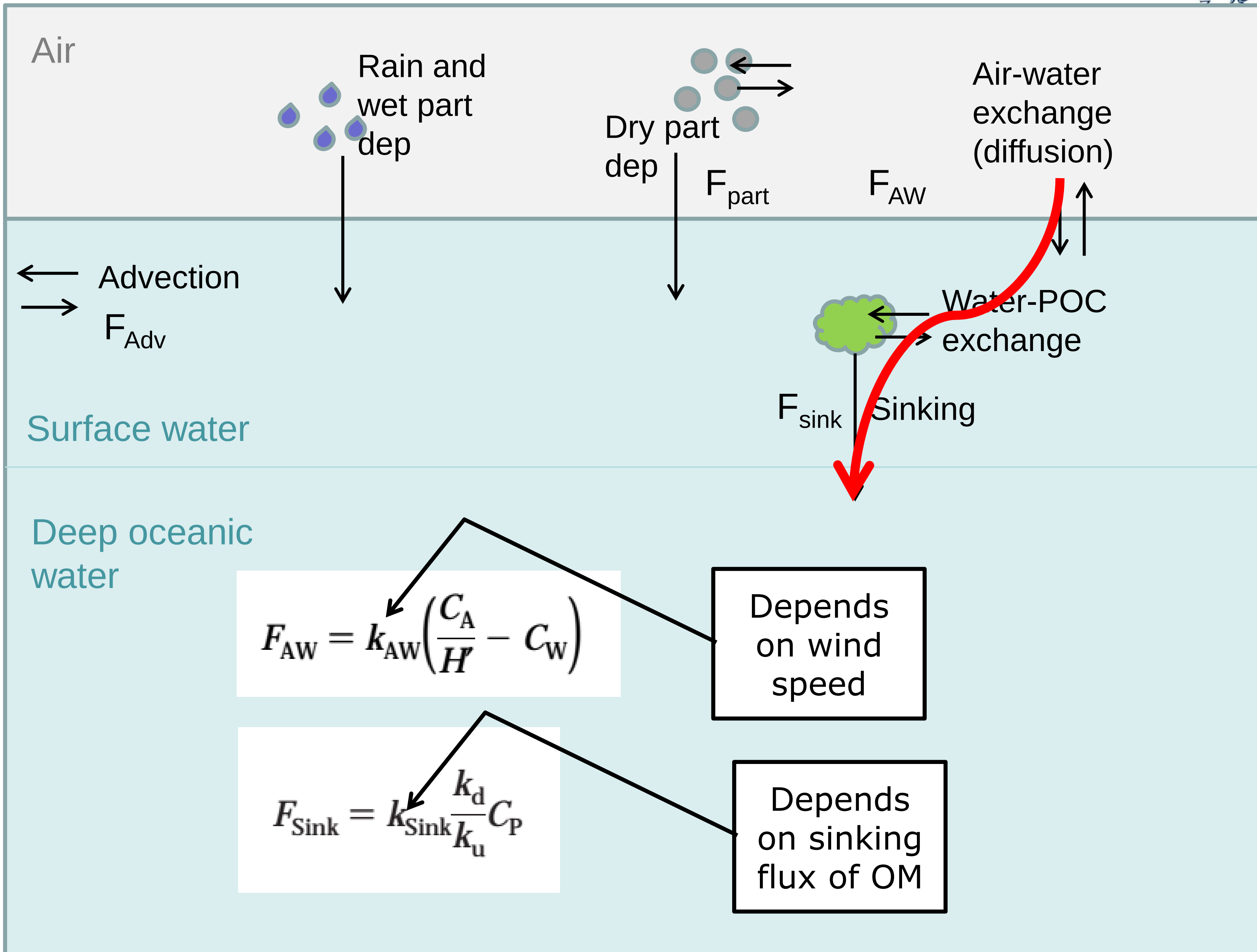
E.g. PCBs:



$C_{plankton}$ = ca 10^5 to 10^8 times C_{water}

(depending on the chemical properties)

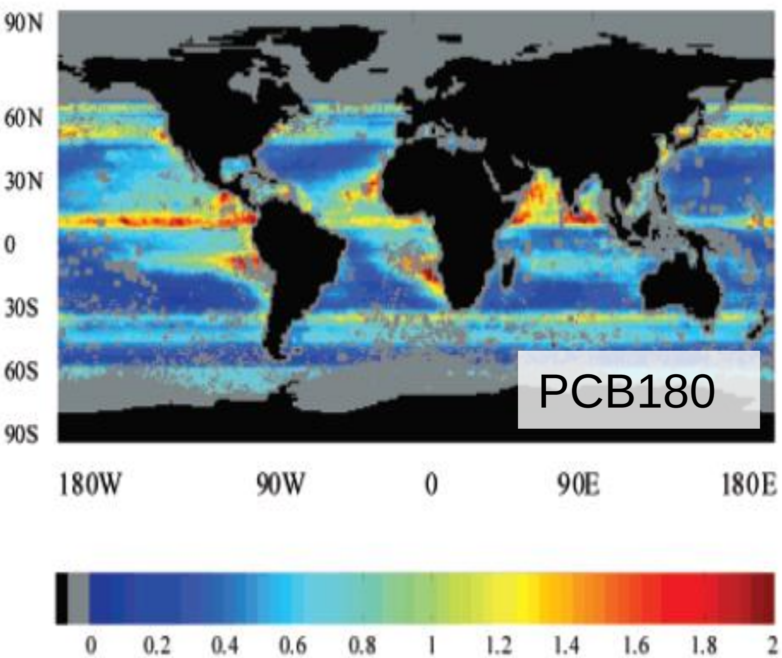
Theory – transfer to deep water



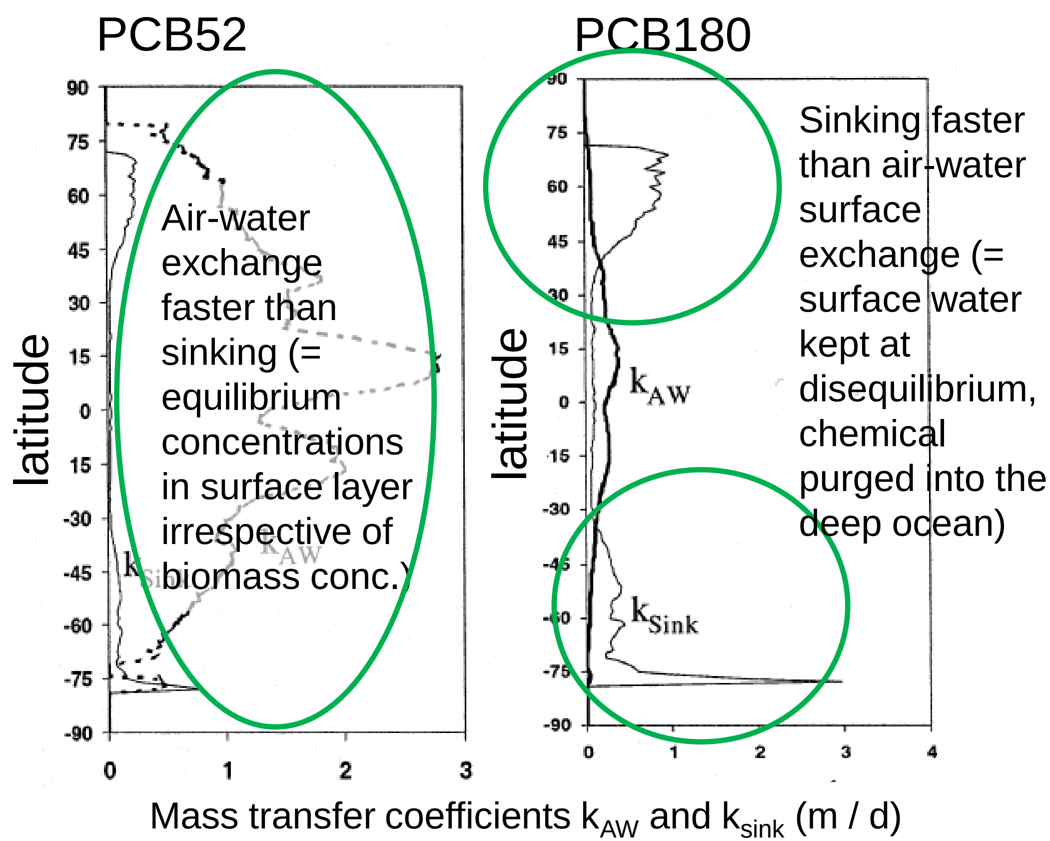
Possible impact on contaminant distribution of increased biomass (i.e. euthrophication)

Stockholm University

- Sinking phytoplankton and detritus may deplete dissolved water conc in surface layers and purge chemicals from the atmosphere into the water phase



Flux from air to deep water $ng\ m^{-2}\ d^{-1}$

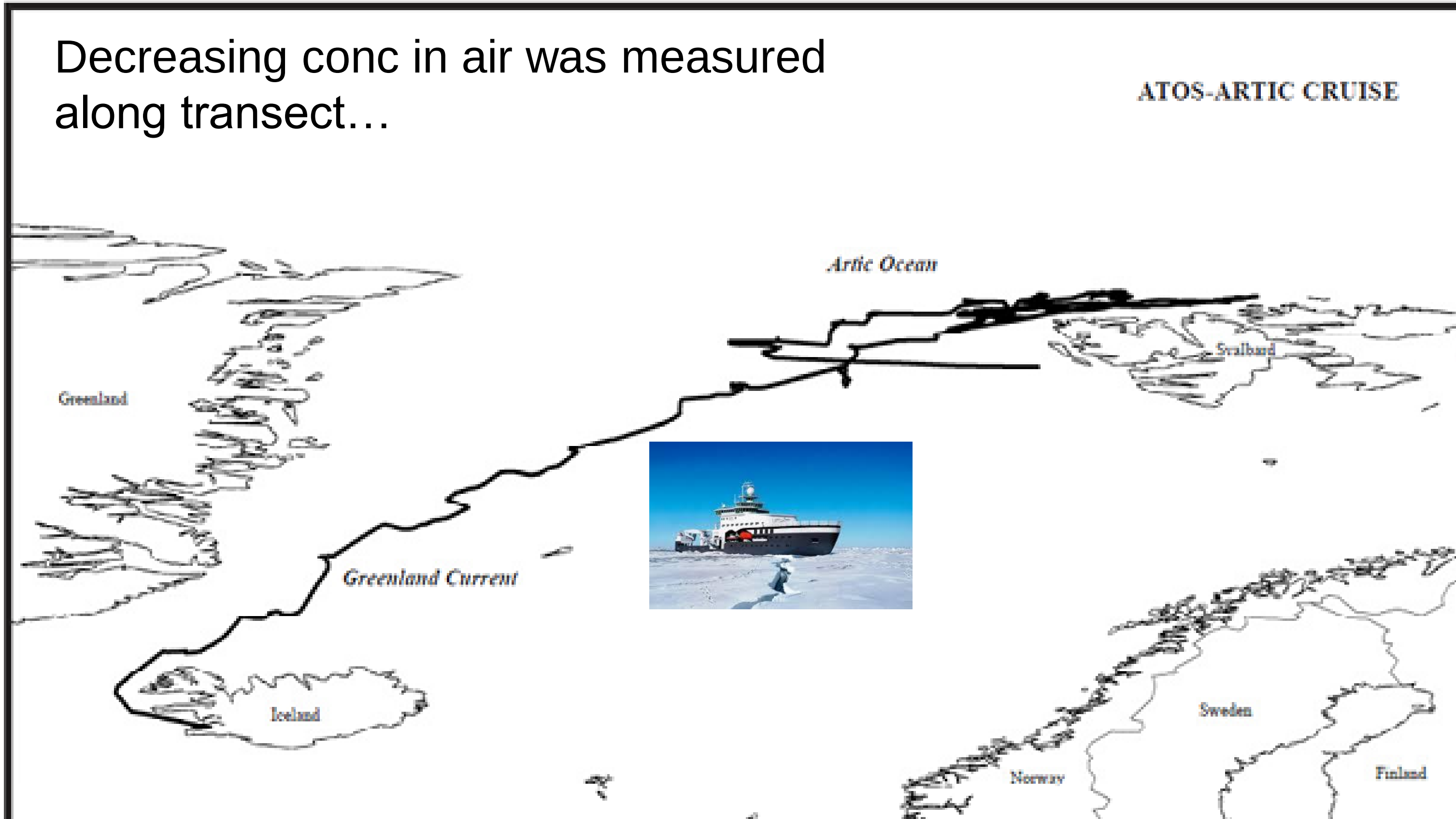


Model predictions by Dachs et al 2002

Does it happen?
Confirmation by field sampling…

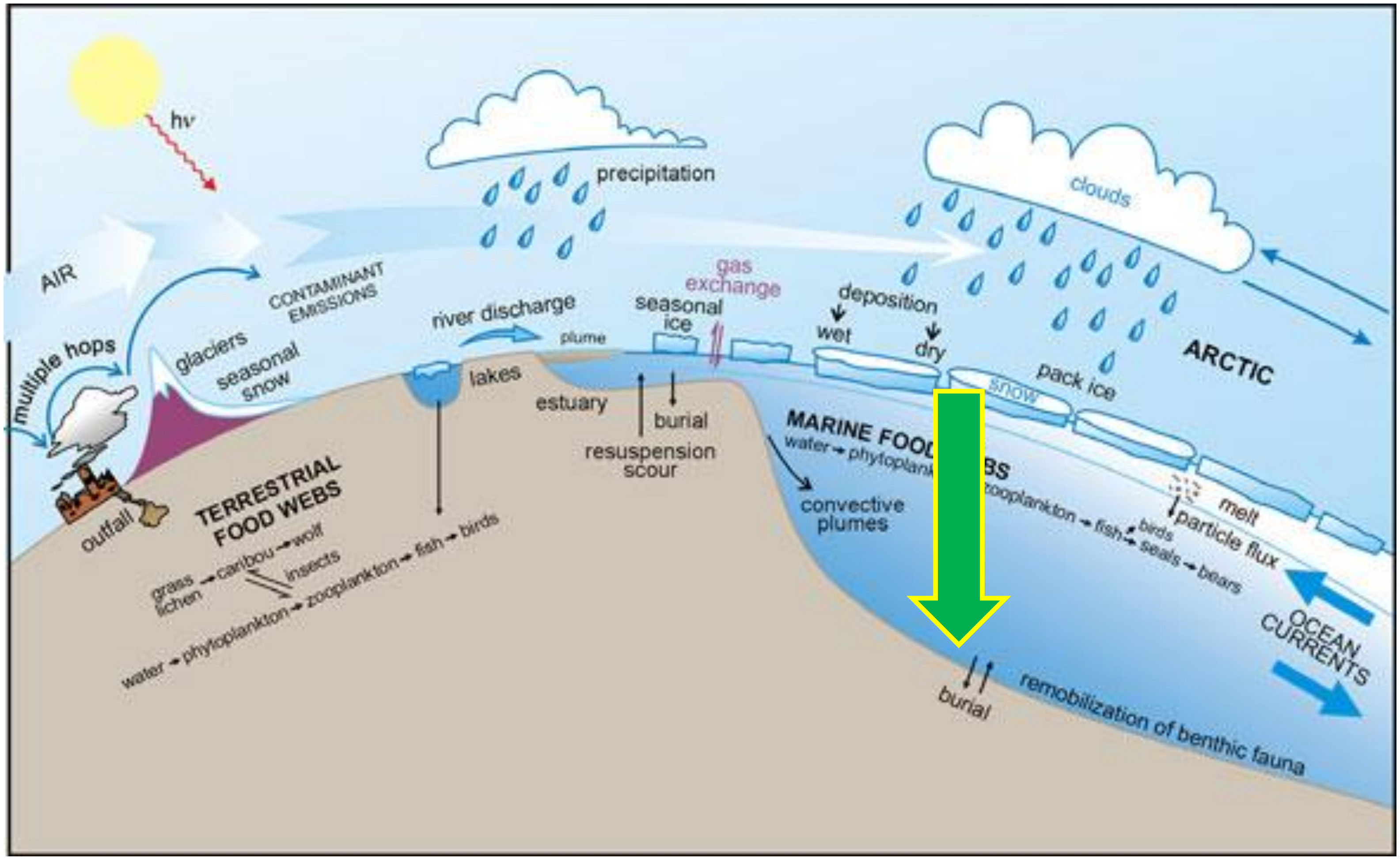
Sampling of air, water and phytoplankton. Analysis for PCBs

Decreasing conc in air was measured along transect…



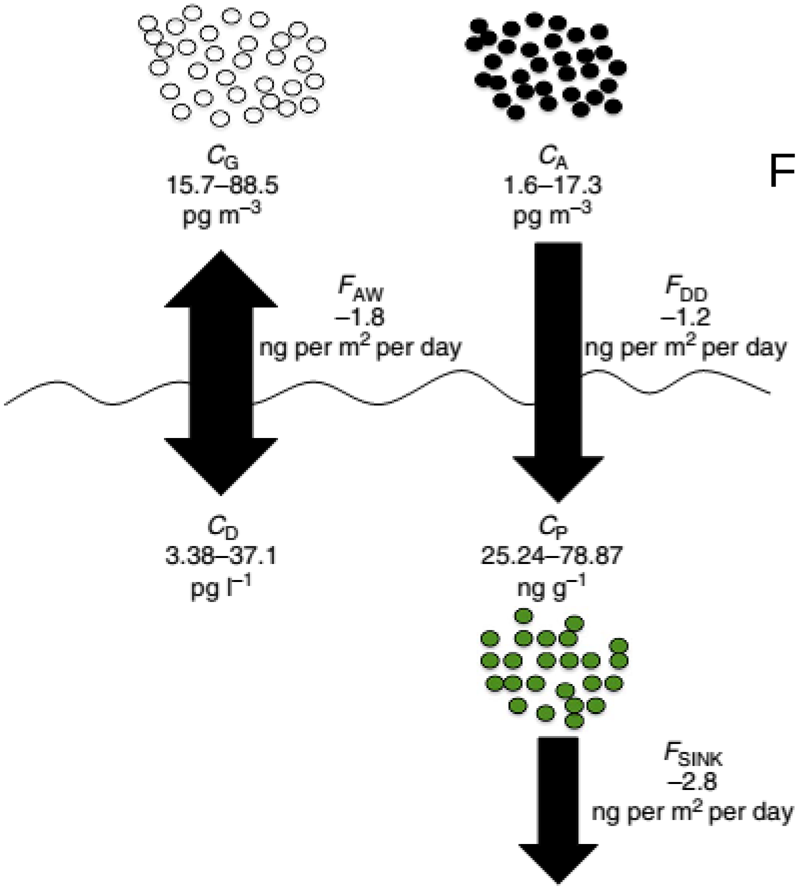
Galban-Malagon et al 2012

Hypothesis: decline due to "biological pump"



MacDonald 2005, Galban-Malagon et al 2012

Sinking organic matter strongly retards transport of PCBs to the Arctic



Fluxes of PCBs

Net Air-water diffusive flux and dry deposition flux

≈

Settling flux

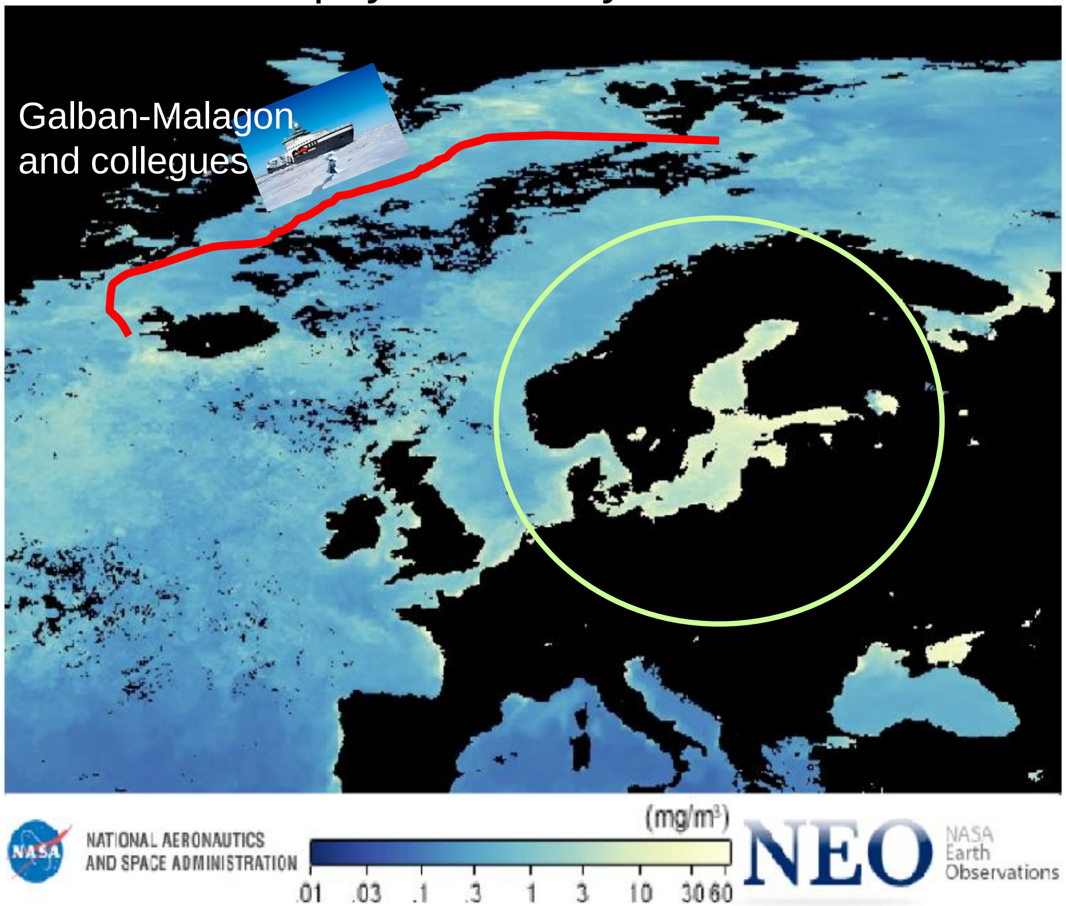
→

Atmosphere stripped of PCBs,
In particular the more hydrophobic ones

Galban-Malagon et al 2012

High primary production in the Baltic Sea

Surface chlorophyll conc July 2007

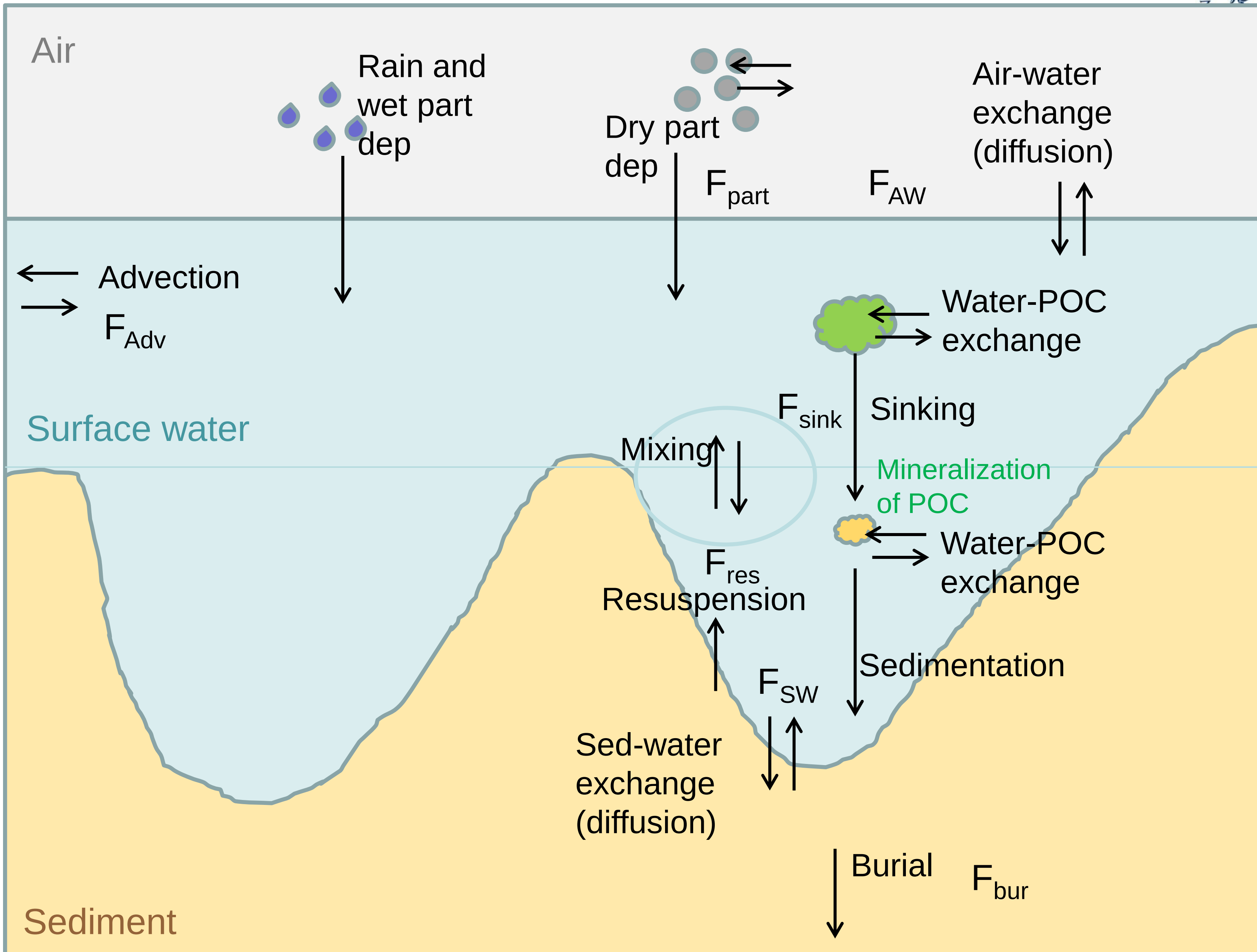


How about the Baltic Sea?

What happens if eutrophication increases?

Or decreases?

Theory – feedback from sediments



Mass balance modeling PCBs

Baltic Proper

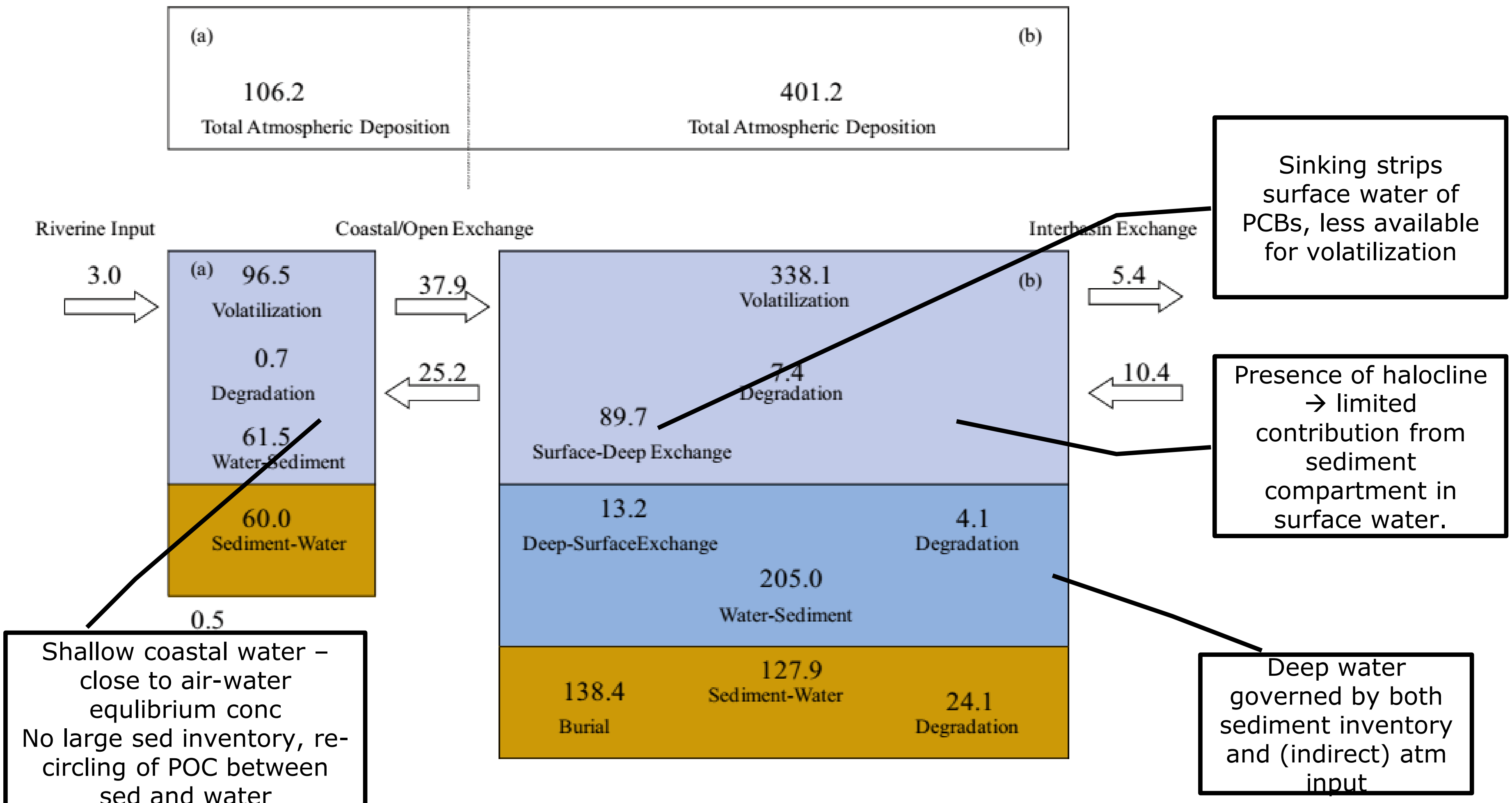


Figure 43. Model estimates of current mass flows of ΣPCB_7 in the coastal (a) and open water (b) compartments of the Baltic Proper (in kg yr[1]).

Wiberg et al 2009

Mass balance modeling

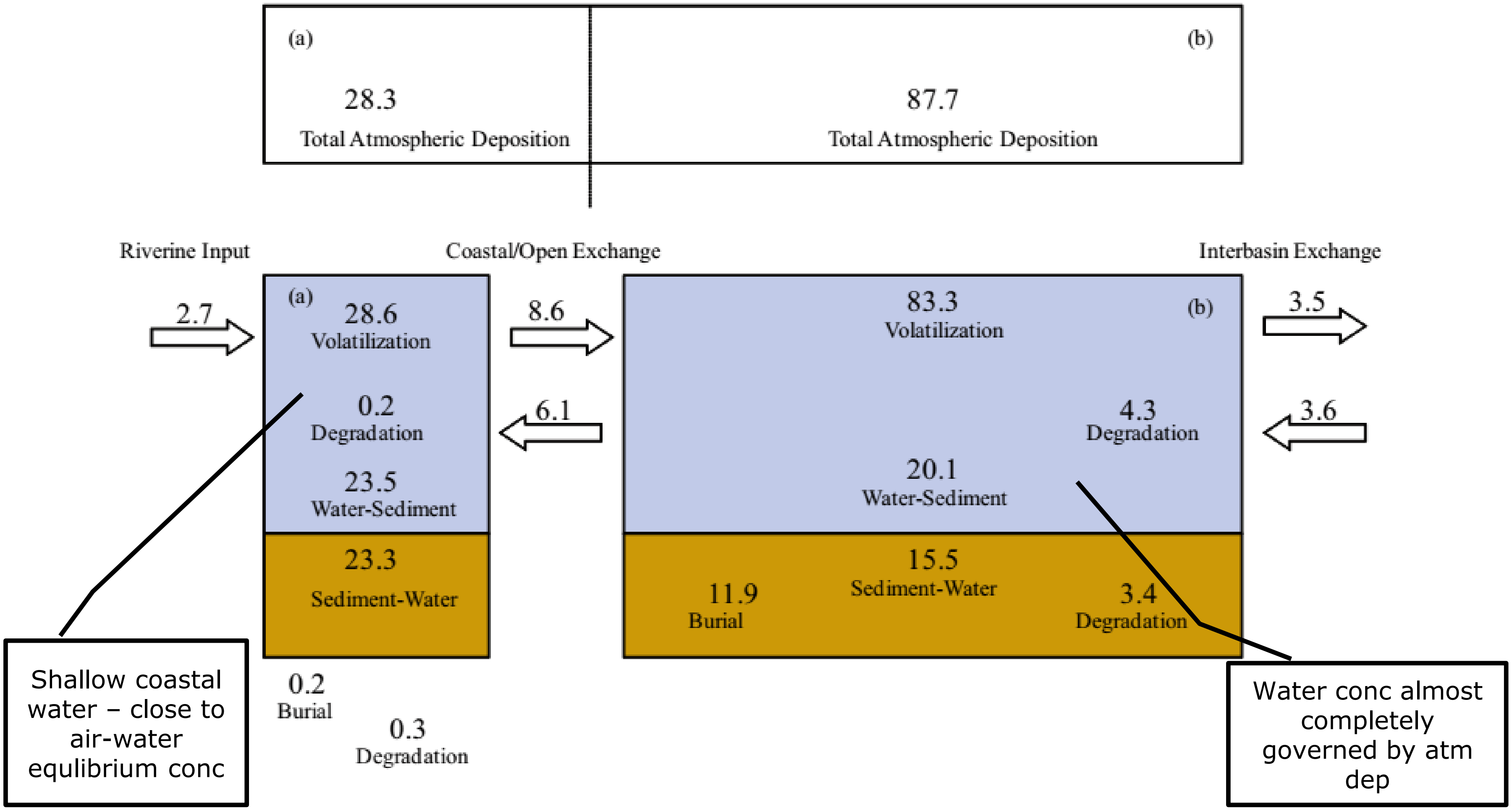


Figure 44. Model estimates of current mass flows of ΣPCB_7 in the coastal (a) and open water (b) compartments of the Bothnian Sea (in kg yr^{-1}).

Wiberg et al 2009

Mass balance modeling

But, Bruhn and McLachlan 2003 state that it is almost impossible to estimate (with >95% certainty) the direction of air-water flux!

This due to large uncertainty in H…

Large variability due to temperature, winds, wind direction…

$$F_{AW} = k_{AW}\left(\frac{C_A}{H'} - C_W\right)$$

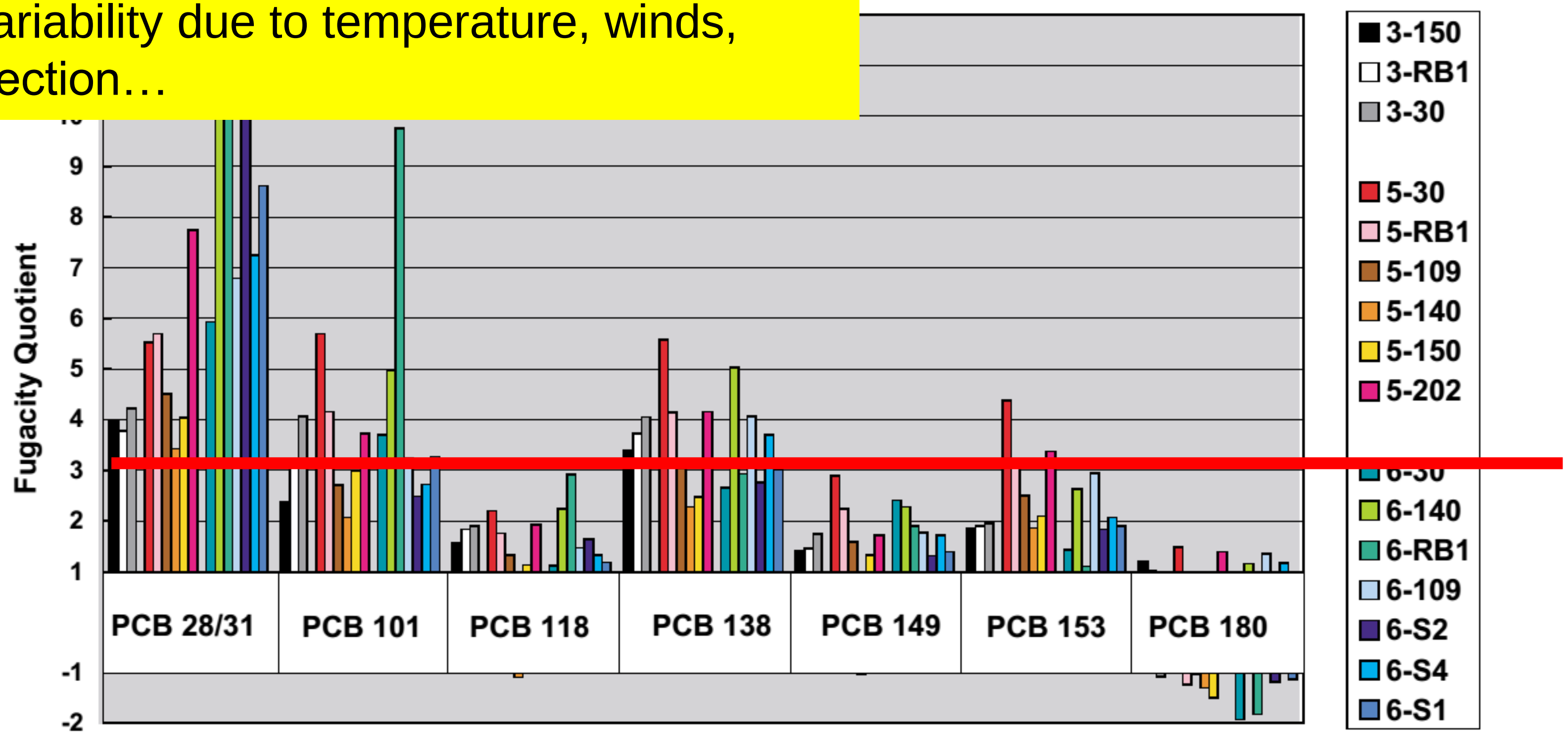
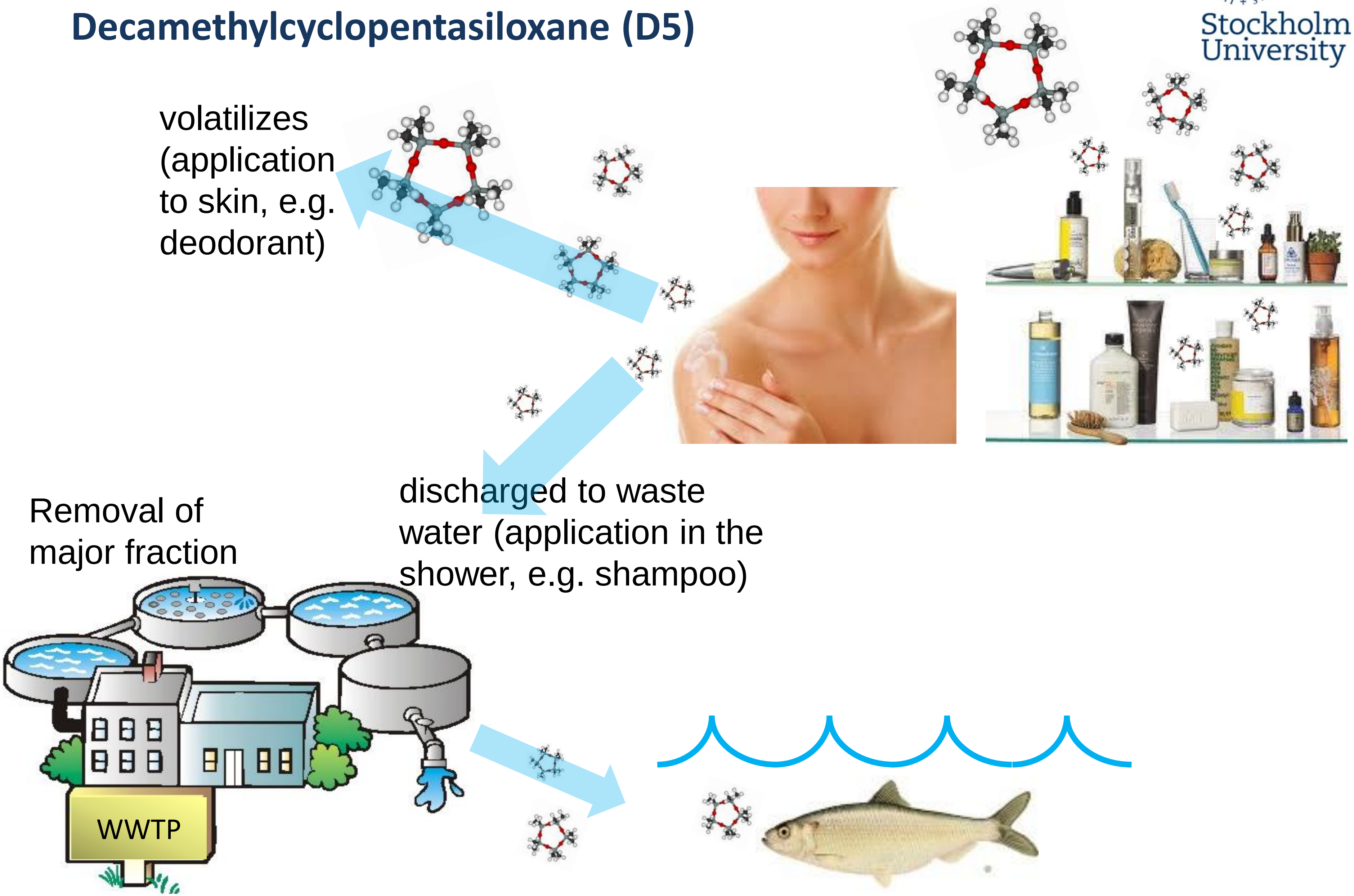


Fig. 3. Quotient of the PCB fugacities in water and air. A positive quotient denotes a net volatilisation (f_W/f_A), while a negative value denotes a net deposition ($-f_A/f_W$). The legend gives the month of the cruise and the station/transect number of the water sample.

Algal bloom last week outside Gotland…

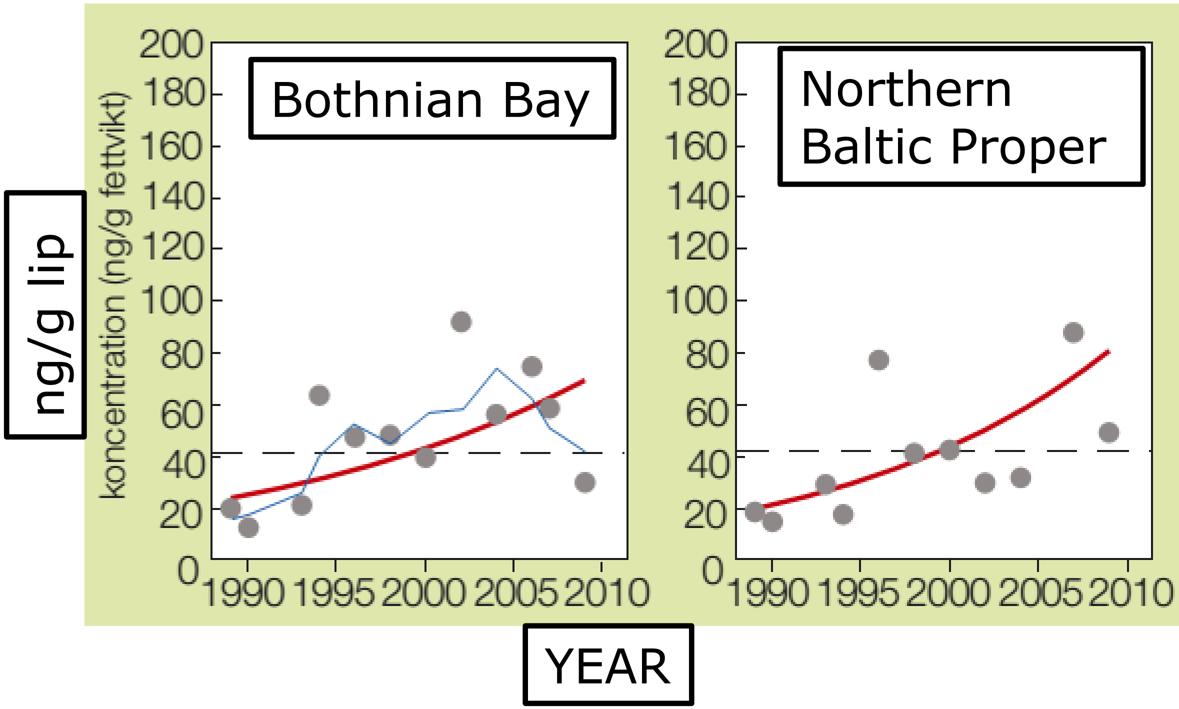
Final example – multistressor impact on contaminants

Example: Management of Decamethylcyclopentasiloxane (D5)



Siloxanes (silicon oil, dimethicone) in the Baltic Sea

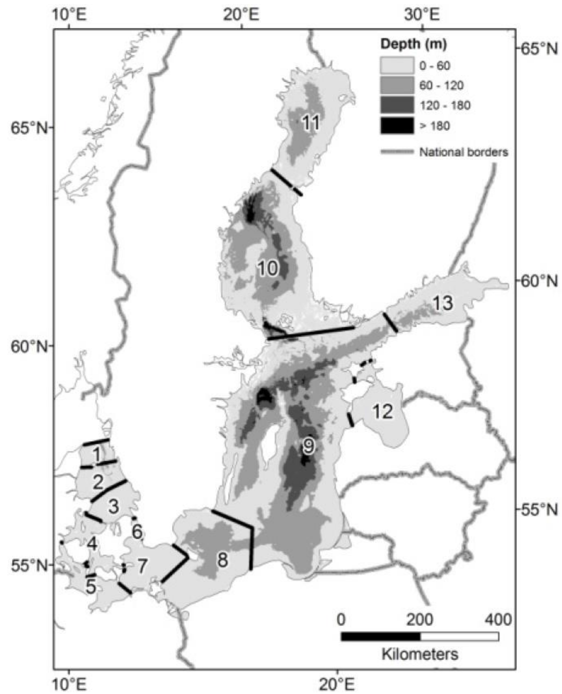
Measurements of D5 in herring muscle

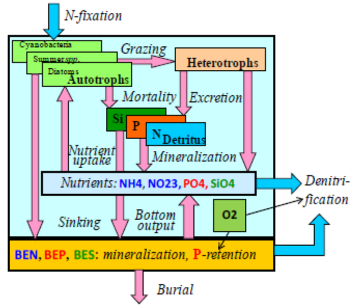


What about the future?

Two linked models ...

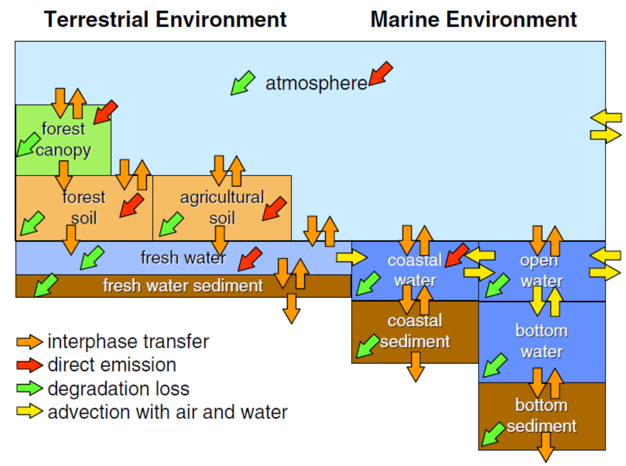
BALTSEM from the Nest system





+

Contaminant state-of-the-art POPCYCLING (marine part)



=

BALTSEM-POP =
hydrodynamics + biogeochemistry + organic contaminants

Model experiment:

Input:

Phys-chem properties of D5

D5 Air concentration (measured values)

D5 River loads (est from UK per capita data + BSR population densities)

Nutrient emission scenarios

Climate scenarios

BALTSEM-POP
(physical+biogeochem+contaminants)

Output: Simulated D5 concentrations (dissolved) in surface water between years 2006 and 2100

What about eutrophication and climate change?

Stockholm University

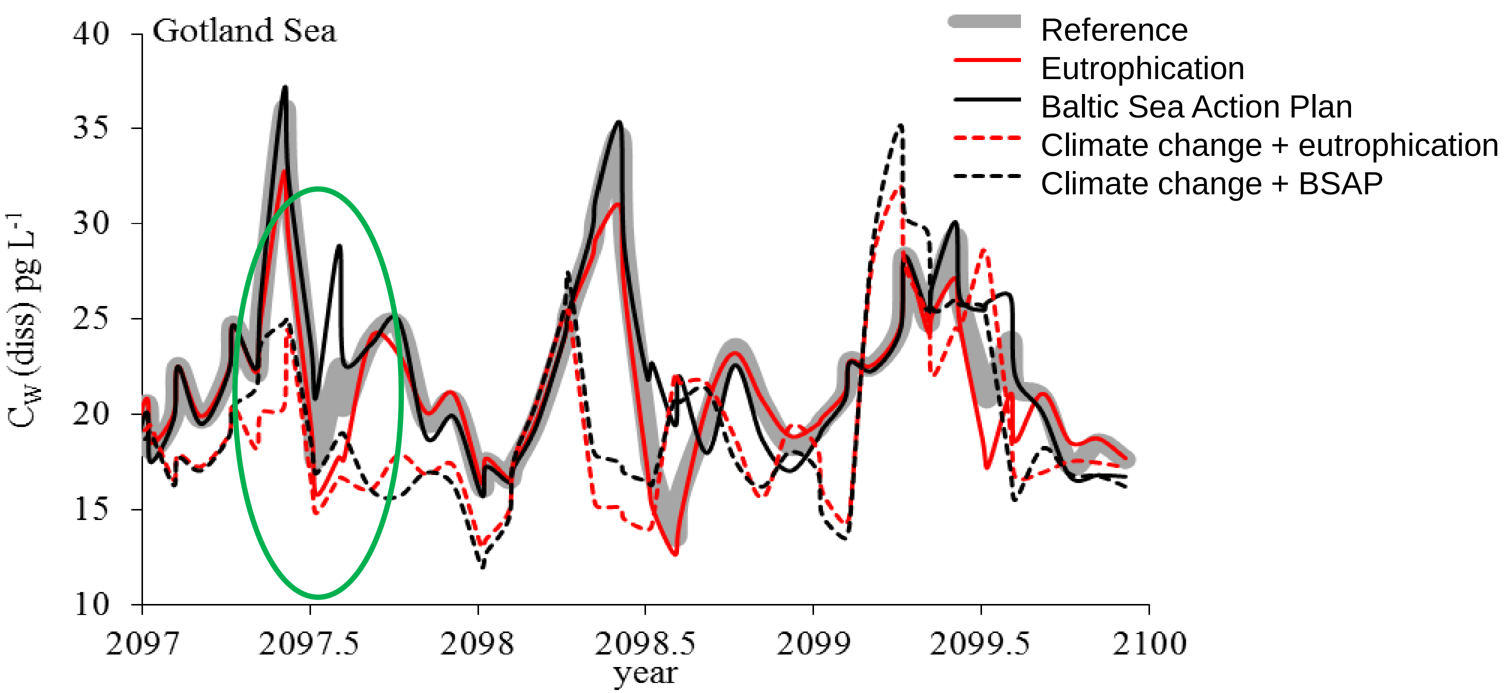
5 "multi-stressor scenarios":

1. "Reference" = same climate as today, same nutrient emissions (constant load)
2. "Eutrophication" = Increasing nutrient loads
3. "BSAP" = Baltic Sea Action Plan implemented (reduced nutrient emissions)
4. "Climate + Eutrophication" = Climate change scenario a1b and increasing nutrient loads
5. "Climate change + BSAP" - Climate change and BSAP implemented

"Climate change" =
Baltic Sea average
Wind +7%
Temperature +60%
Precipitation + 20%
Compared to reference (today)

"Eutrophication" =
denser livestock → ca 50% increase in TP and TN river loads)

Results: Last 3 years of the simulated time period

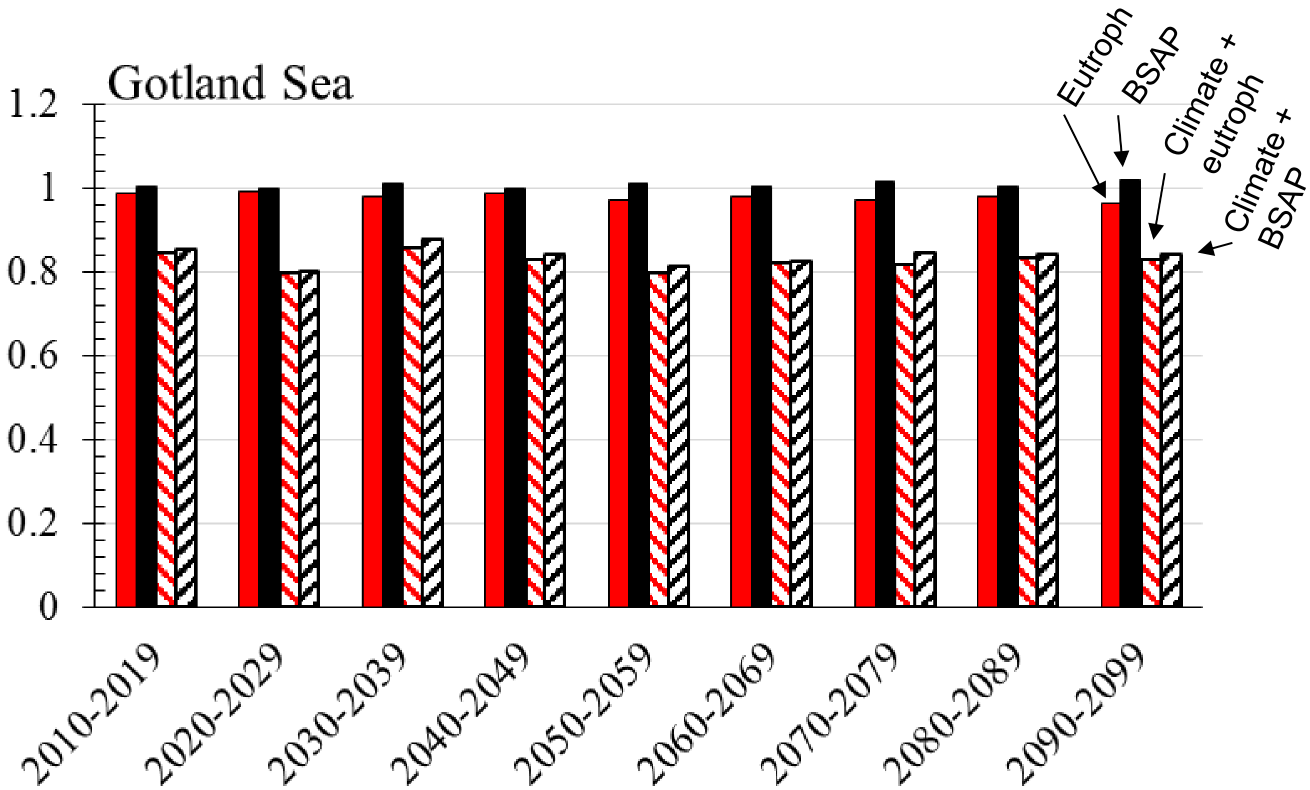


Eutrophication:
Lower [D5] due to increasing phytoplankton biomass in eutrophied Gotland Sea

Climate change:
Randomness of weather conditions, has stronger influence on [D5] than long term trends in climate

Results: 10 year average D5 concentration (normalized to reference scenario)

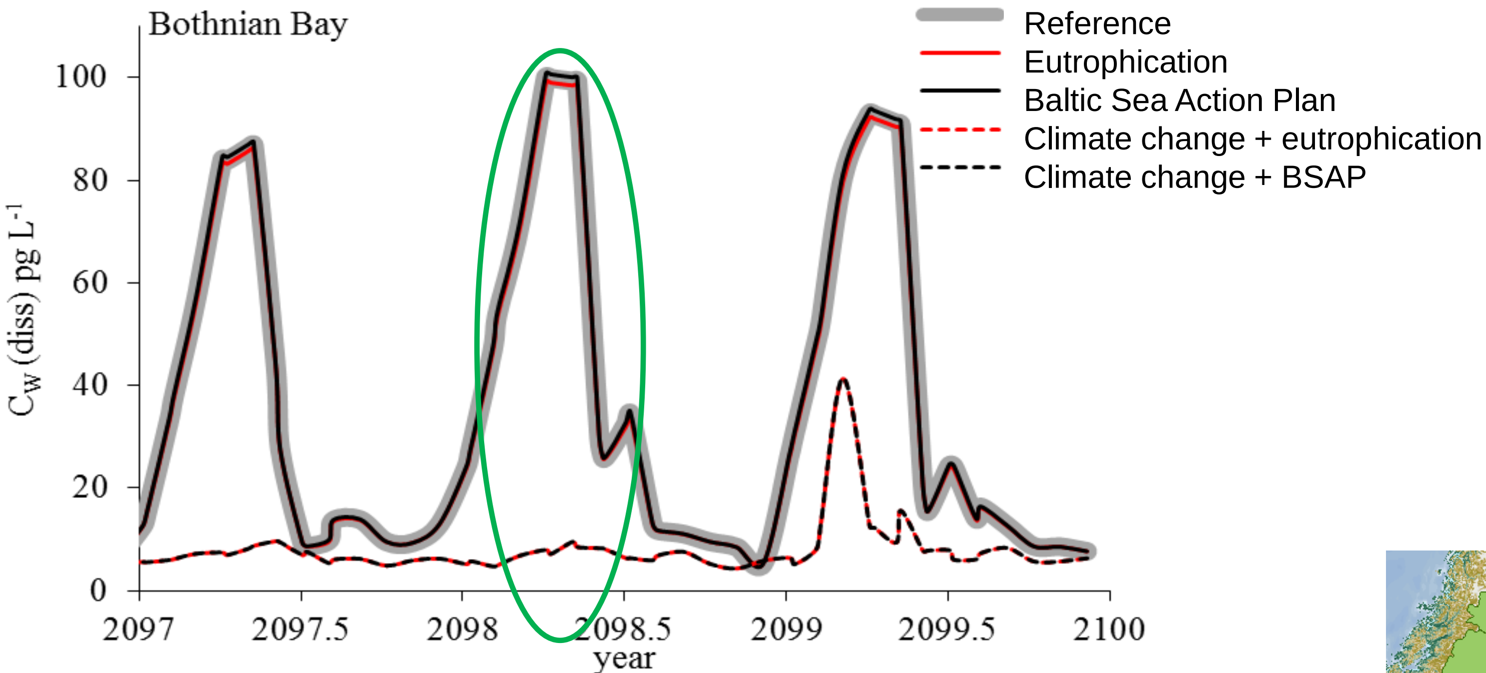
Stockholm University



Small differences due to increasing phytoplankton biomass in eutrophied Gotland Sea

Example application: Assess combined impact of climate change and eutrophication on D5 surface water concentrations

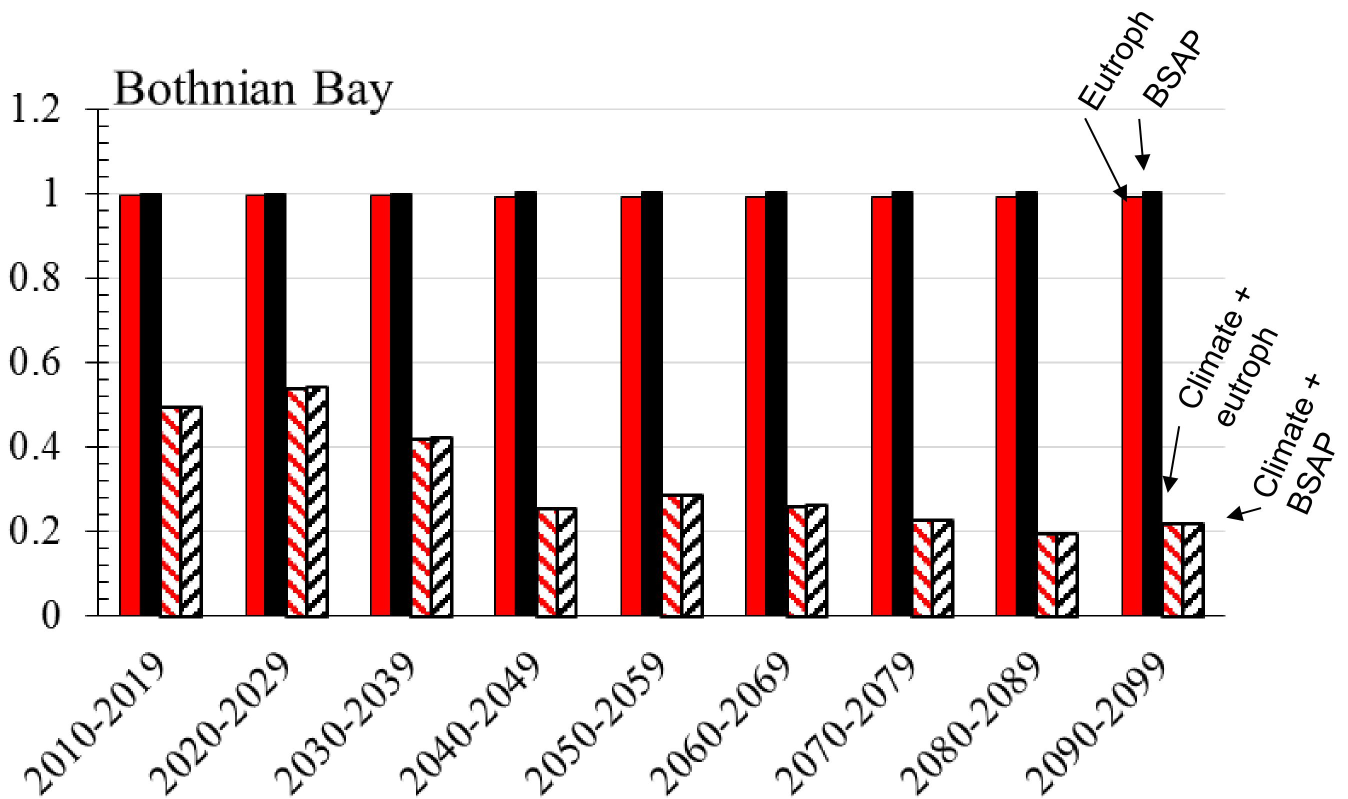
Stockholm University



- No significant effect of eutrophication on D5 concentrations
- Reduced ice cover in the Bothnian Bay due to climate change lowers future D5 concentrations

Results: 10 year average D5 concentration (normalized to reference scenario)

Stockholm University



Result:

- No significant effect of eutrophication on D5 concentrations
- Reduced ice cover in the Bothnian Bay due to climate change lowers future D5 concentrations

Thank you

Emma Undeman