Sediment Quality - Ecotoxicology

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Who am I?

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1995: Biologist, PhD in Biological Oceanography, Institute for Marine Science, Kiel

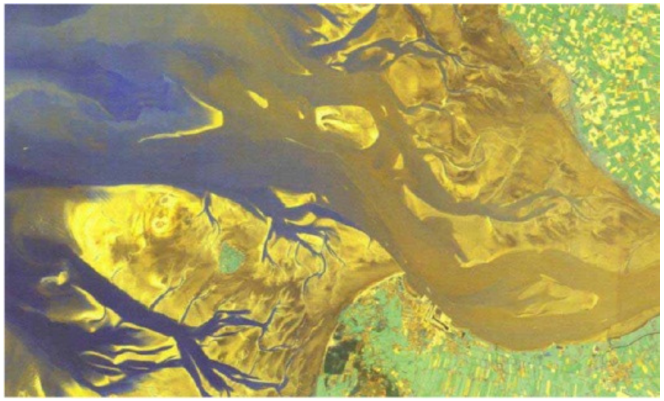
1995 – 2002: Researcher, TU Hamburg, Institute for Baltic Sea Research Warnemünde

2002 – 2008: Project leader, Consulting Centre for Integrated Sediment Management

Since 2008: Professor at Hamburg University of Applied Sciences

What is sediment?

Aquatic sediment is aquatic particulate material with differing physical and chemical properties that can be biologically influenced. It is made up of layers of increasing solid content with depth and includes suspended material, fluid layer, unconsolidated and consolidated material, so all matter that could *potentially* comprise the suspension – sedimentation cycle (SedNet, 2002)



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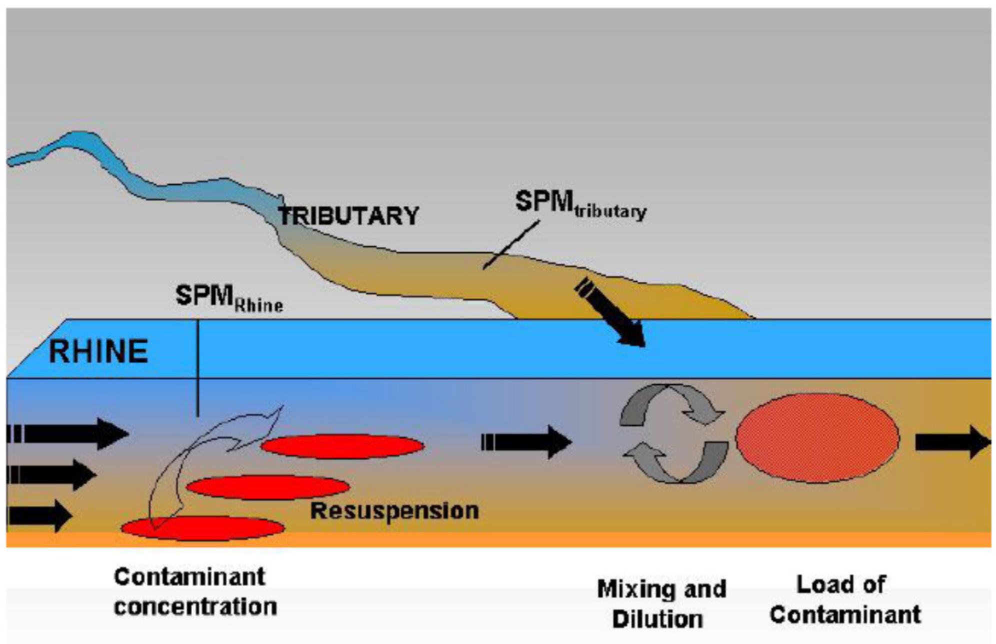
Vertical processes
Resuspension
accumulation



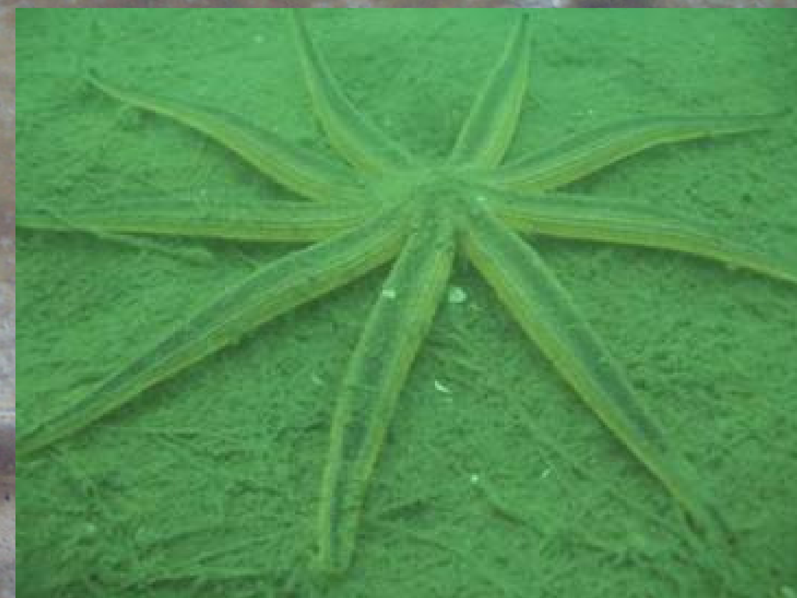
Horizontal processes
Erosion, transport, mixing, dilution

Ecological Importance of Sediments: Habitat

Taxon	Typical local species richness
Algae	0–1000
Fungi	50–300
Protozoa	20–800
Plants	0–100
Invertebrates	30–1500
Aschelminthes	5–500
Annelida	5–50
Mollusca	0–50
Acari	0–100
Crustacea	5–300
Insecta	5–400

[Palmer et al. 2000]

+ more than 100 000 bacteria species



(Foto: Dave Paterson)

Ecological importance of Sediments: Habitat

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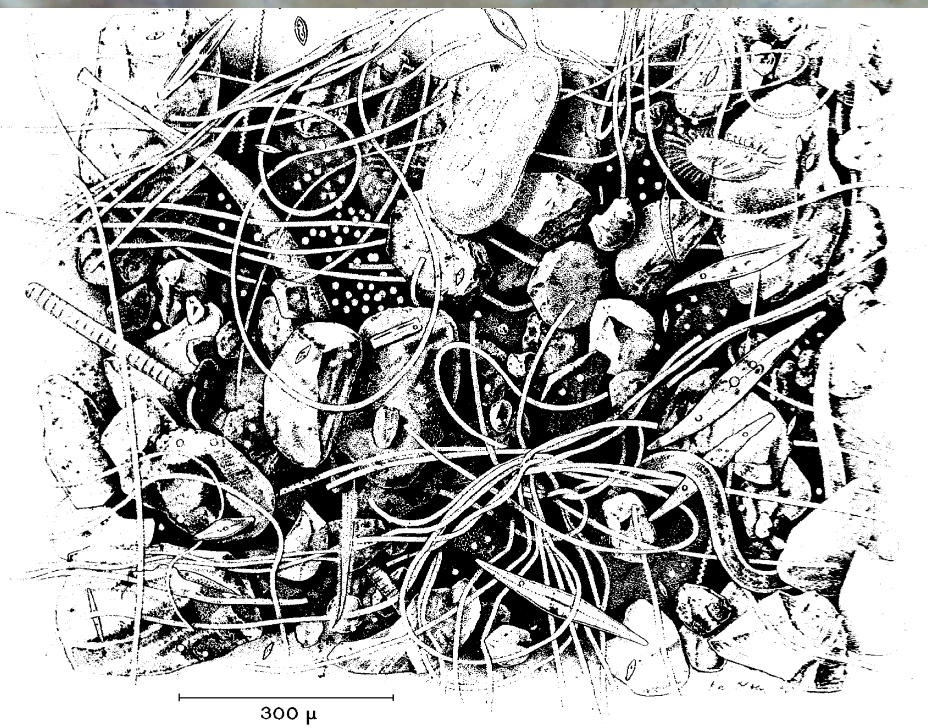
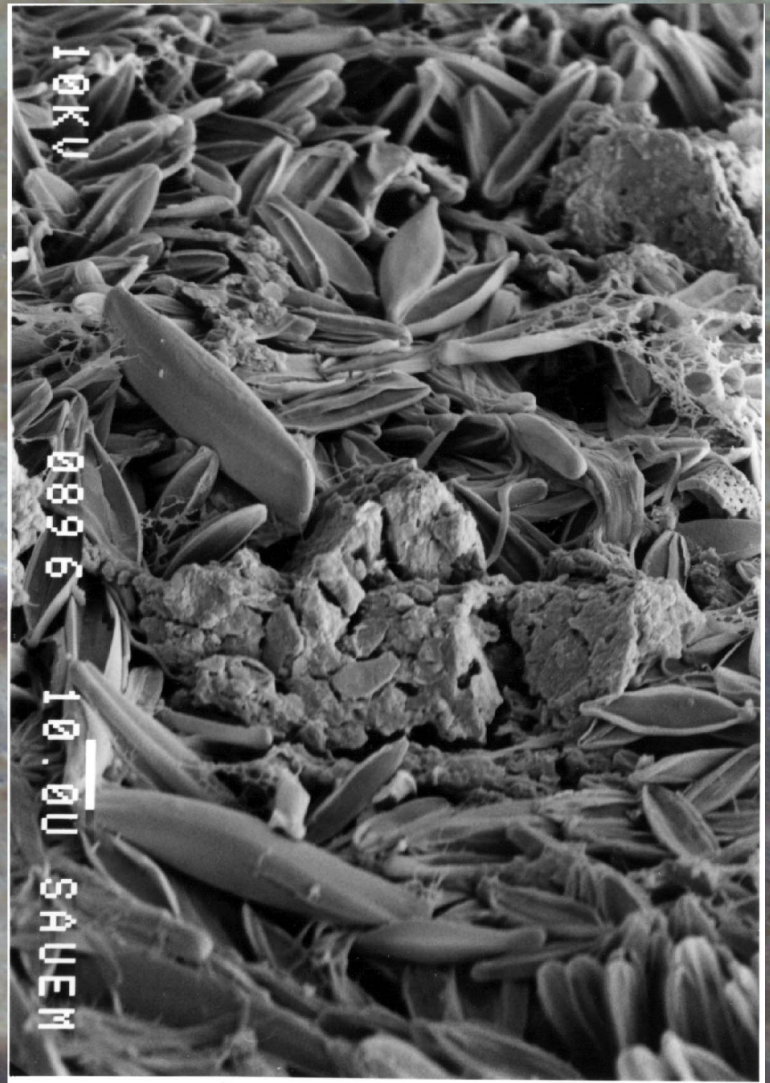


[from Fenchel et al.1992]



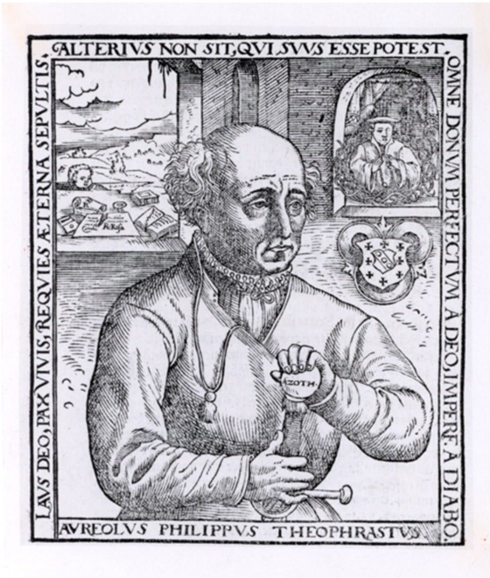
(Foto: Dave Paterson)

Ecotoxicology Versus Toxicology

"Ecotoxicity studies measure the effects of chemicals on fish, wildlife, plants, and other wild organisms" (US EPA, 2007)

Sediment ecotoxicology focuses on those contaminants that adsorb to fine particles, and on those organisms that either live in the sediment or are impacted by it and which are directly or indirectly exposed to adsorbed contaminants.

but by the way …. What exactly is “toxic”?



“All substances are poisons;

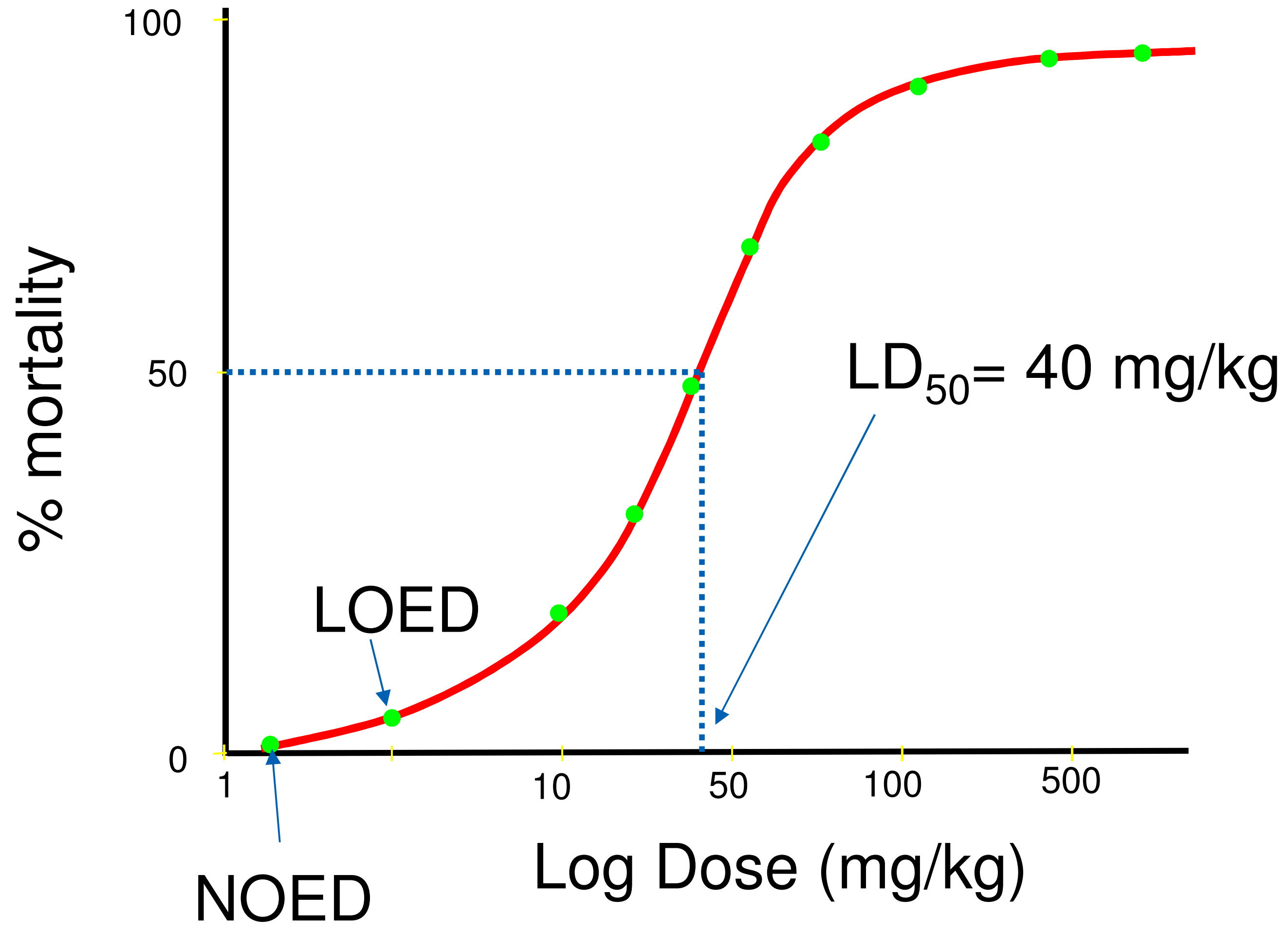
there is none which is not a poison.

The right dose differentiates a poison

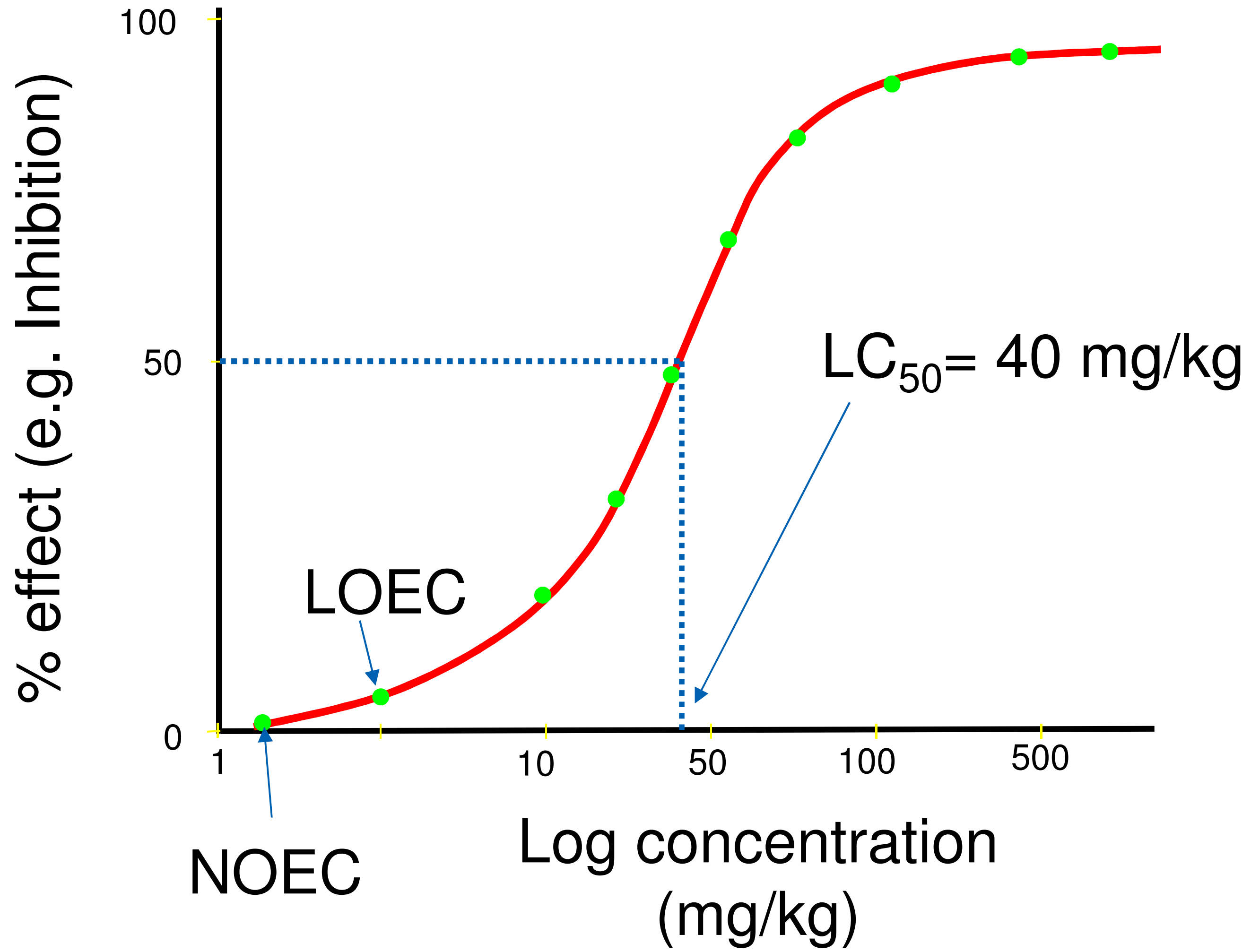
from a remedy.”

Paracelsus (1493-1541)

Dose-response curves in toxicology



Dose-response curves in eco-toxicology



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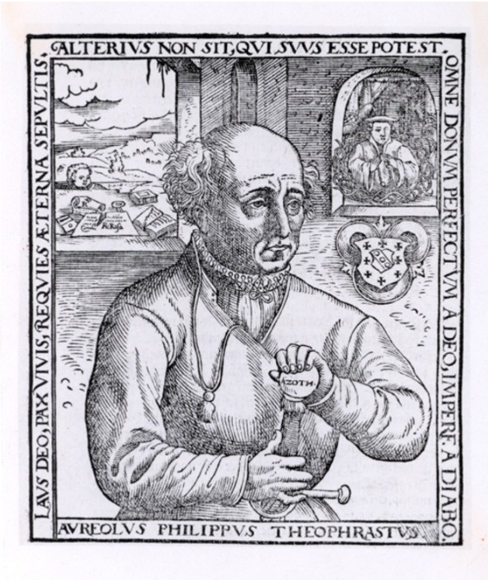

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Compound	Median lethal dose mg kg^{-1}
Ethanol	10000
DDT	100
Nicotine	1
Tetrodotoxin	0.1
Dioxin	0.001
Botulinus toxin	0.00001

The reasoning for ecotoxicological studies

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Currently, too little is known about

- the number of potentially effective contaminants adsorbed to sediments
- their fate
- their bioavailability
- their exposure pathways
- their toxicodynamic and toxicokinetic
- their impact on physiological processes

to dermine the toxicity of environmental matrices without on-site - ecotoxicological - investigations.

potentially effective contaminants adsorbed to sediments

What is monitored in sediments .....

Example Elbe River : e.g. ICPE / OSPAR / HABAK

Mostly:

- Heavy metals
- DDT et al.
- HCB
- HCH
- PAH
- PCB
- TBT

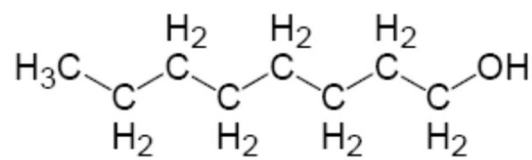
Historic contaminants
Historic sources

Why these substances?

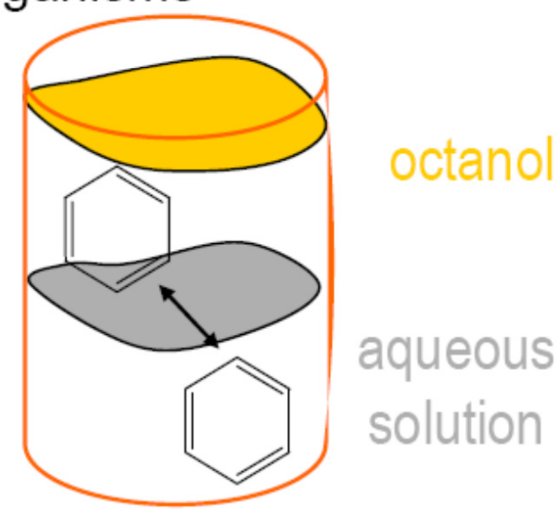
They have a high tendency to adhere to sediments:

The K_{OW} is an indicator of

- environmental transport
    - sorption to organic matter
    - uptake by organisms



$$K_{ow} = \frac{[A_{octanol}]}{[A_{water}]}$$



Sorption of organic substances: K_{ow} and K_{oc}

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Most important sorbant for organic contaminants:

Organic material e.g. humic substances, C_{org}

Partition coefficient C_{org}/water : K_{oc}

K_{OC} has been empirically correlated to K_{OW}

→ $K_{OC} = 0,63 * K_{OW}$ (Karickhoff et al, 1979)

Mostly K_{OW} values are available rather than K_{OC} values.

Affinity of contaminants to sediment and biota

Affinity	Soil / sediment Log K_{oc}	Animals, membranes Log K_{ow}
High	>5	>5
Medium high	4 – 5	3.5 – 5
Medium	2 – 4	3 - 3.5
Medium low	1 – 2	1 – 3
Low	<1	<1

(UNEP training module 3 on Environmental Risk Assessment, mod.)

Examples	Log K_{OW}
PCB 153	6.8
PCB 52	5.79
DDT	6.36
Benzo(a)pyrene (PAH)	6.35

Examples	Log K_{OW}
HCB	5.31
2,3,7,8-TCDD	6.42
Naphthalene (PAH)	3.35
γ-HCH	3.55

Contaminant cocktails in sediments

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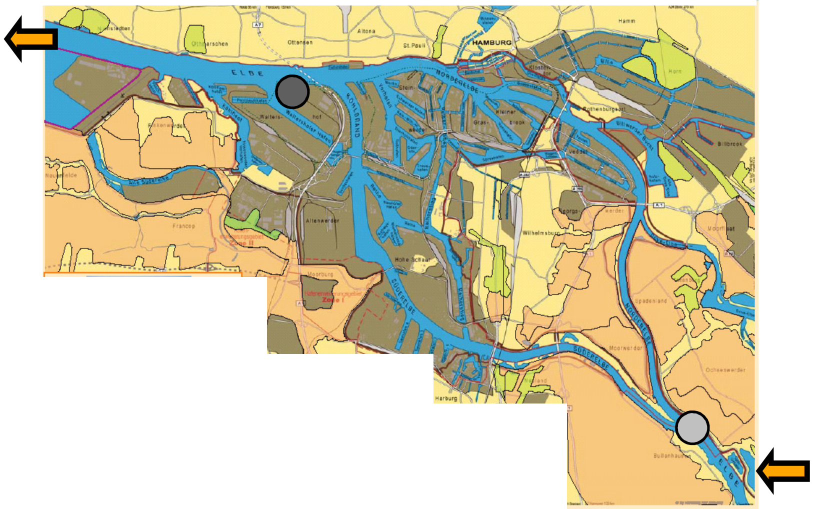
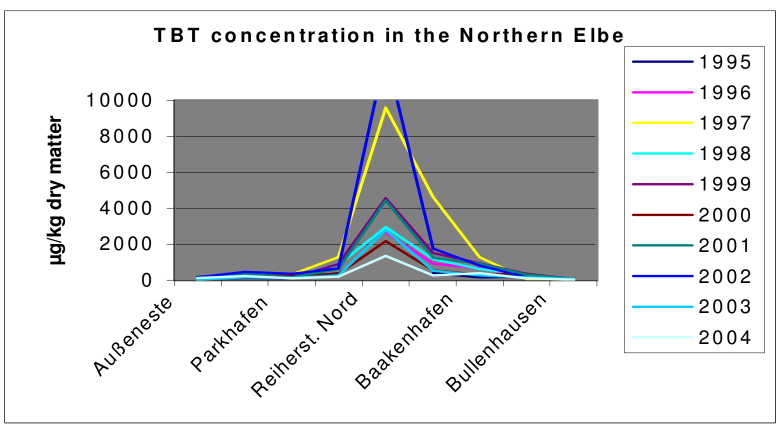
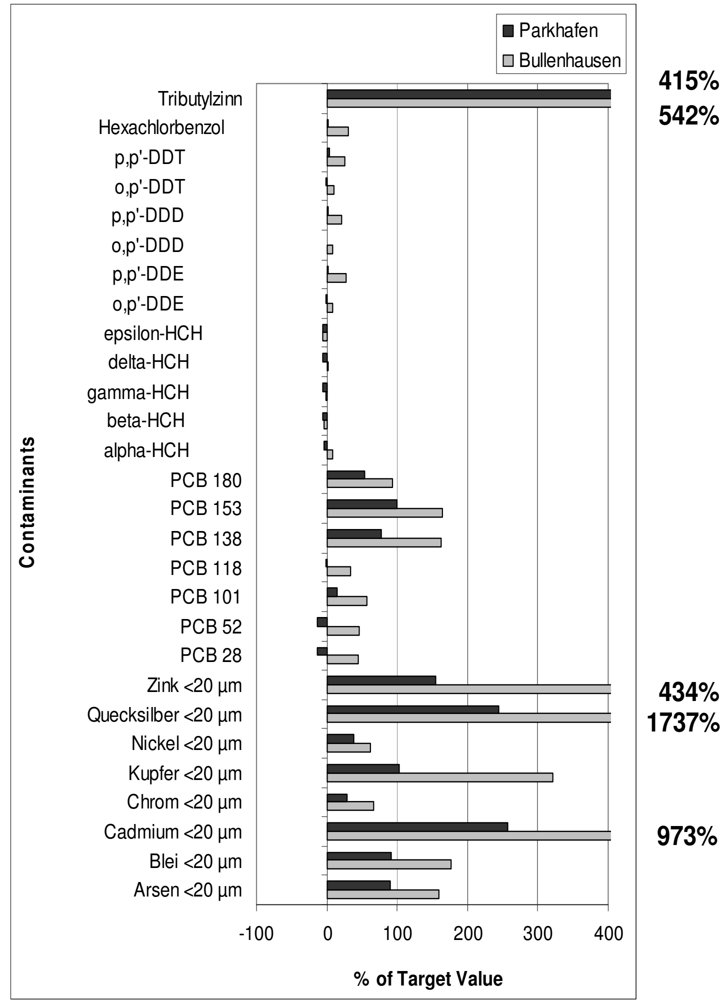
Most contaminants come from upstream!



Exception: TBT



Exceedance of target value



(Heise et al. 2006)

Development of contamination of SPM along the Elbe catchment

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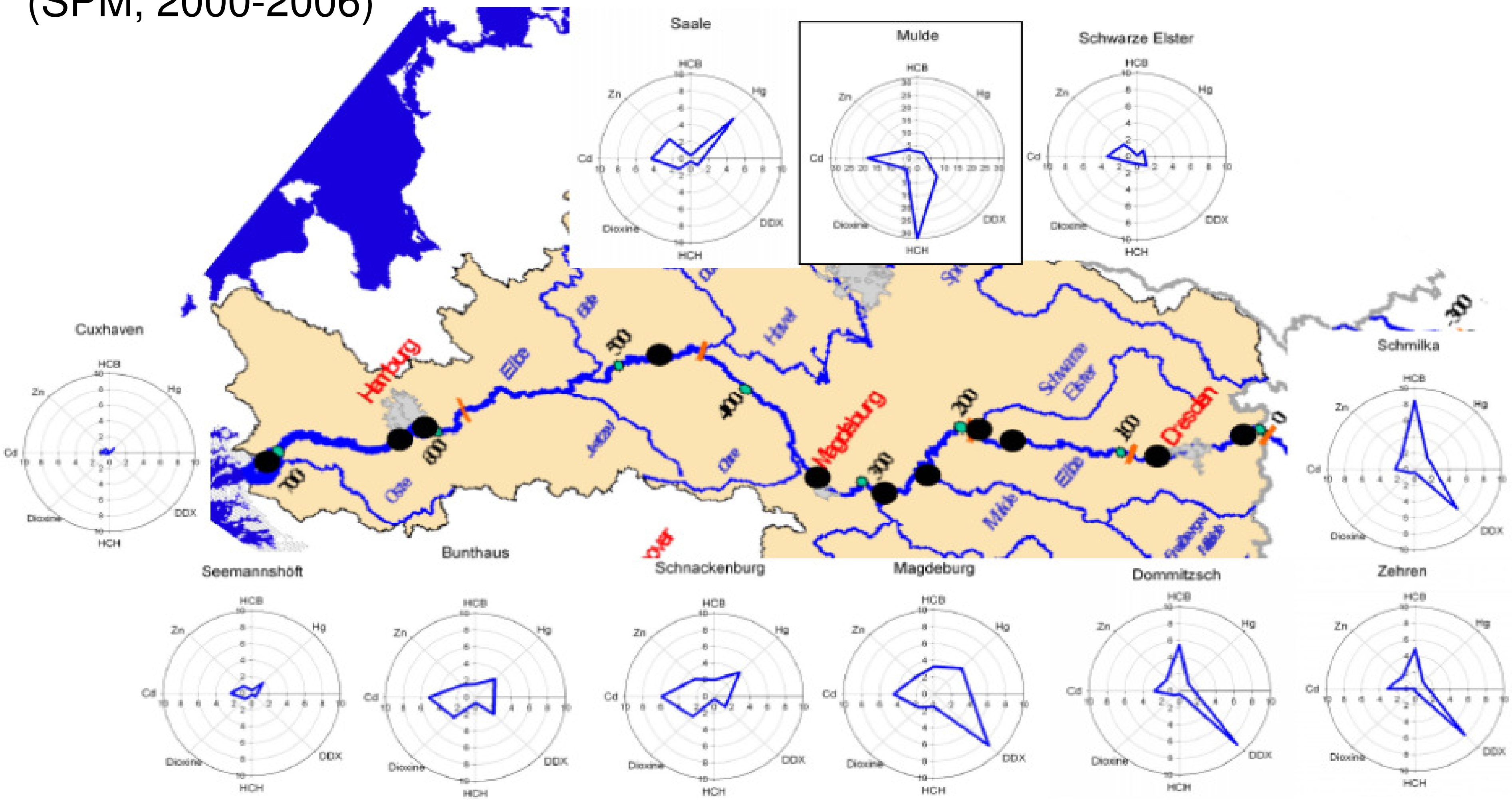
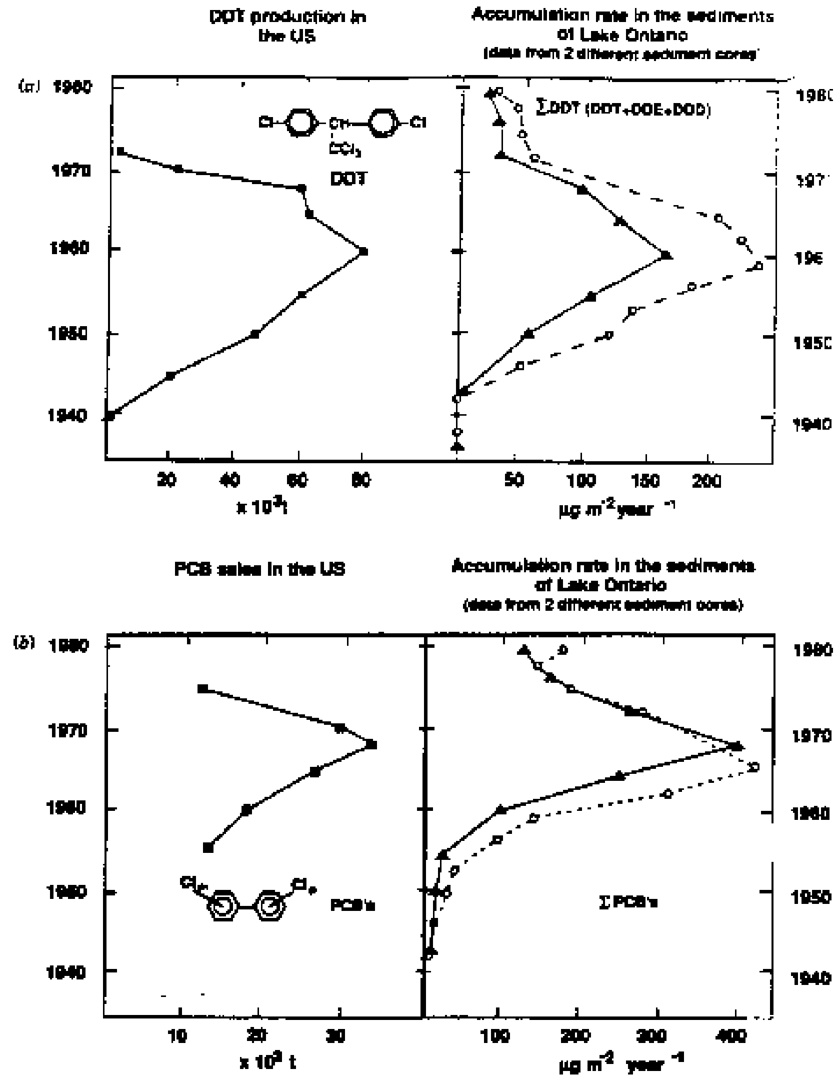
Exceedance of target level for the protection of the aquatic community (SPM, 2000-2006)



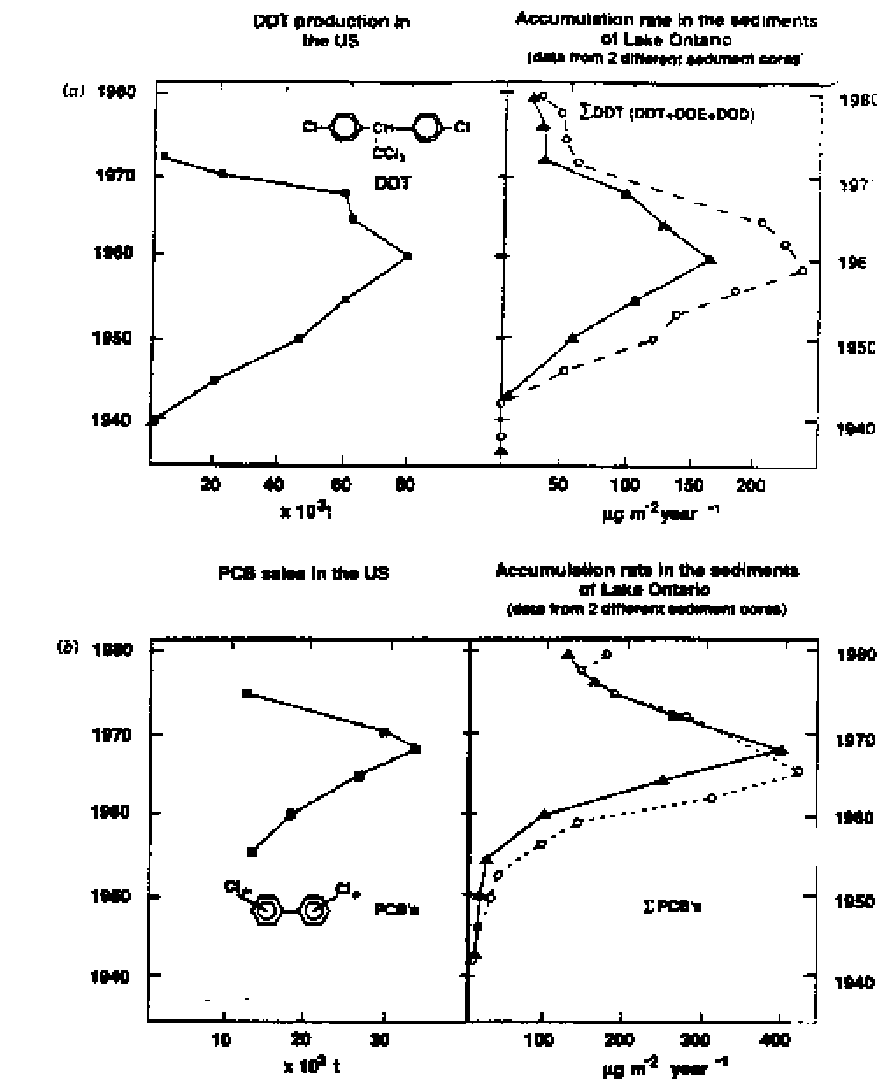
(Heise et al. 2008)

Sediments as the memory of industrial history



Many European Rivers:
historic contamination by mining and industrial emissions.
Recent emission from resuspension of contaminated soil and sediments

Sediments as the memory of industrial history



Every persistent substance ever produced will sooner or later end up in sediments

BUT: How many substances are out there?

EINECS – European Inventory of Existing Commercial Chemical Substances: more than 100 200 chemicals that have been recorded as being commercially available between 1971 and 1981. Registered under the Dangerous Substances Directive (67/548/EEC)

Little information on toxicology and ecotoxicology of more than 90% of these substances

We only find what we are looking for ....

Analysis costs per sediment sample:

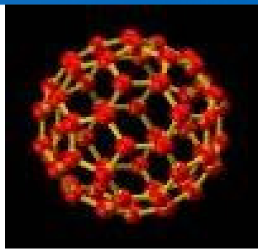
8 heavy metals (in < 20 µm fraction)
PCB, HCB, PAH, DDT, DDD, DDE
} Ca. 250 – 500 €

1 dioxin analysis in sediment (estimation!): 250 – 750 €

Who wants to measure the rest?

Or are we on the safe site and those, that are commonly measured, the most toxic substances?

Emerging Substances (not exclusive)



Nanomaterials – in personal care products, could provide a vector for other substances to move through sediment

Pesticides - Although many are water soluble, some may end up and persist in sediments

Pharmaceuticals, like antibiotics, drugs, X-ray contrast media (iopromide, iopamidol)

Life-style compounds (e.g. caffeine, nicotine)

Products of Personal Care (PPC): Insect repellants, UV filters, fungistatic agents in cosmetics etc

Industrial activities and by-products – breakdown products of known substances

Water-treatment by-products

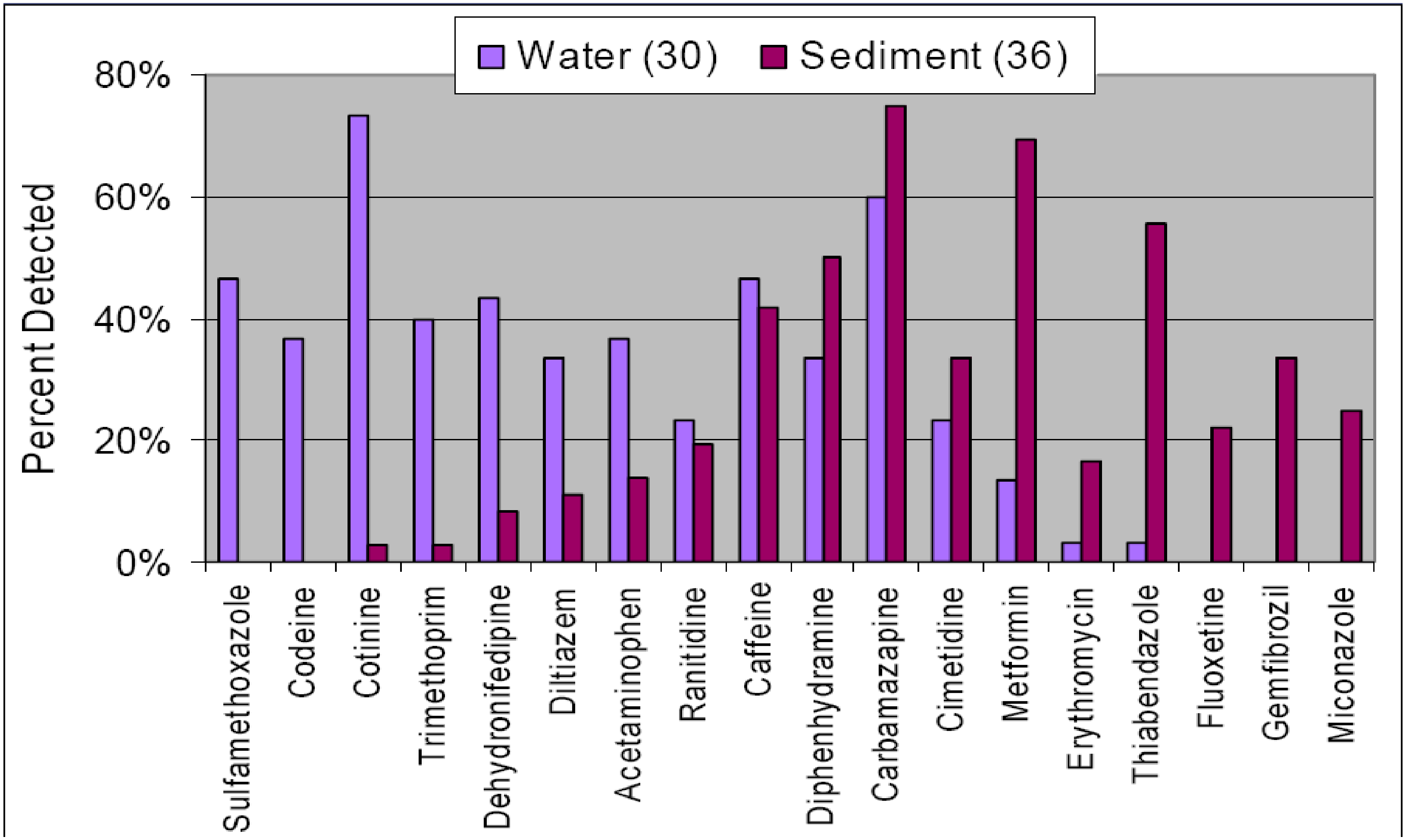
Flame retardants

Surfactants (PFOS, PFOA) – perfluorinated sulfonates and carboxylic acids

Hormones from contraceptives

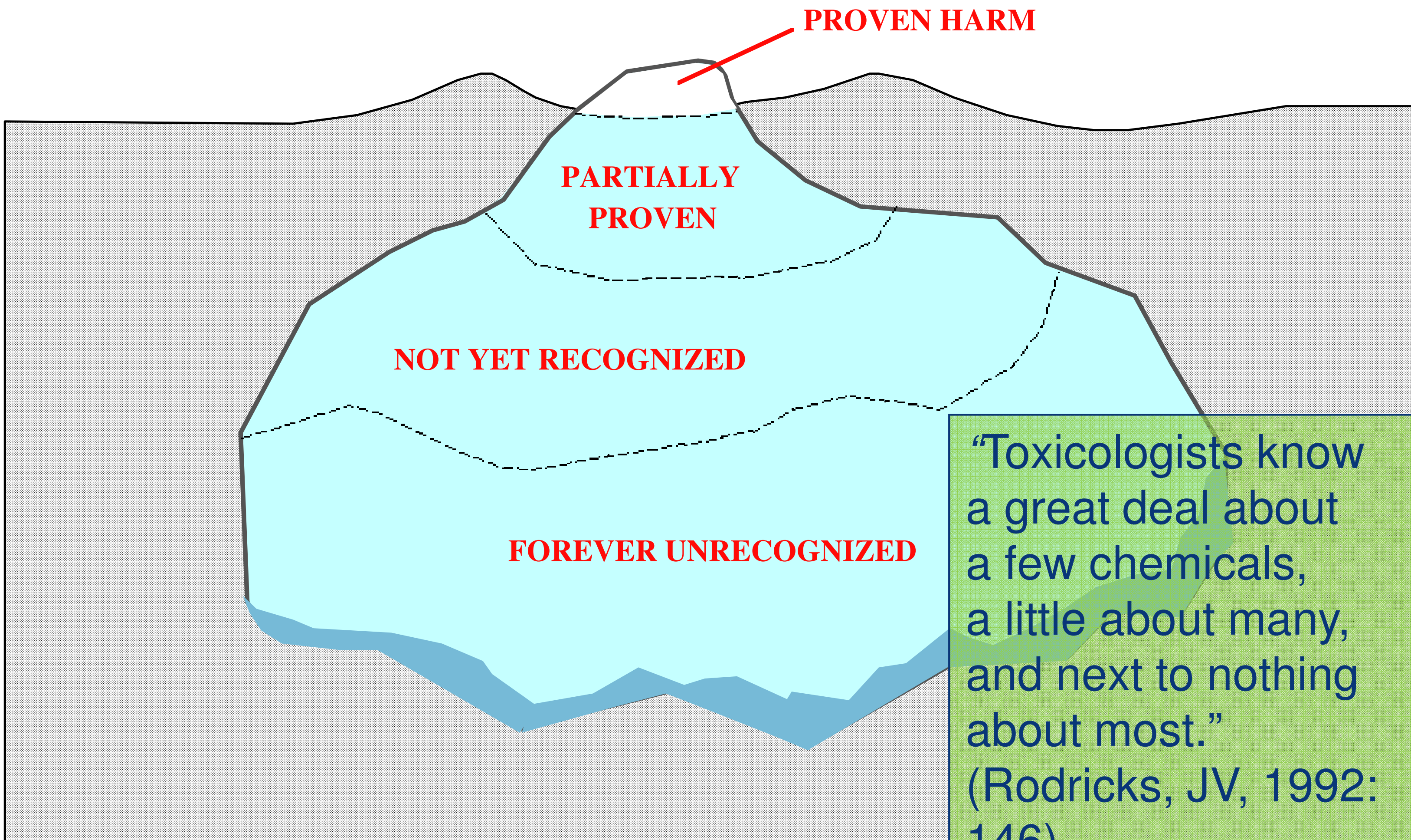
Detection of emerging substances in water and sediment

USGS Work in Boulder Creek, Boulder Creek, CO



http://www.state.nj.us/dep/wmm/Buxton%20Emerging%20Contaminants%20For%20Posting.pdf

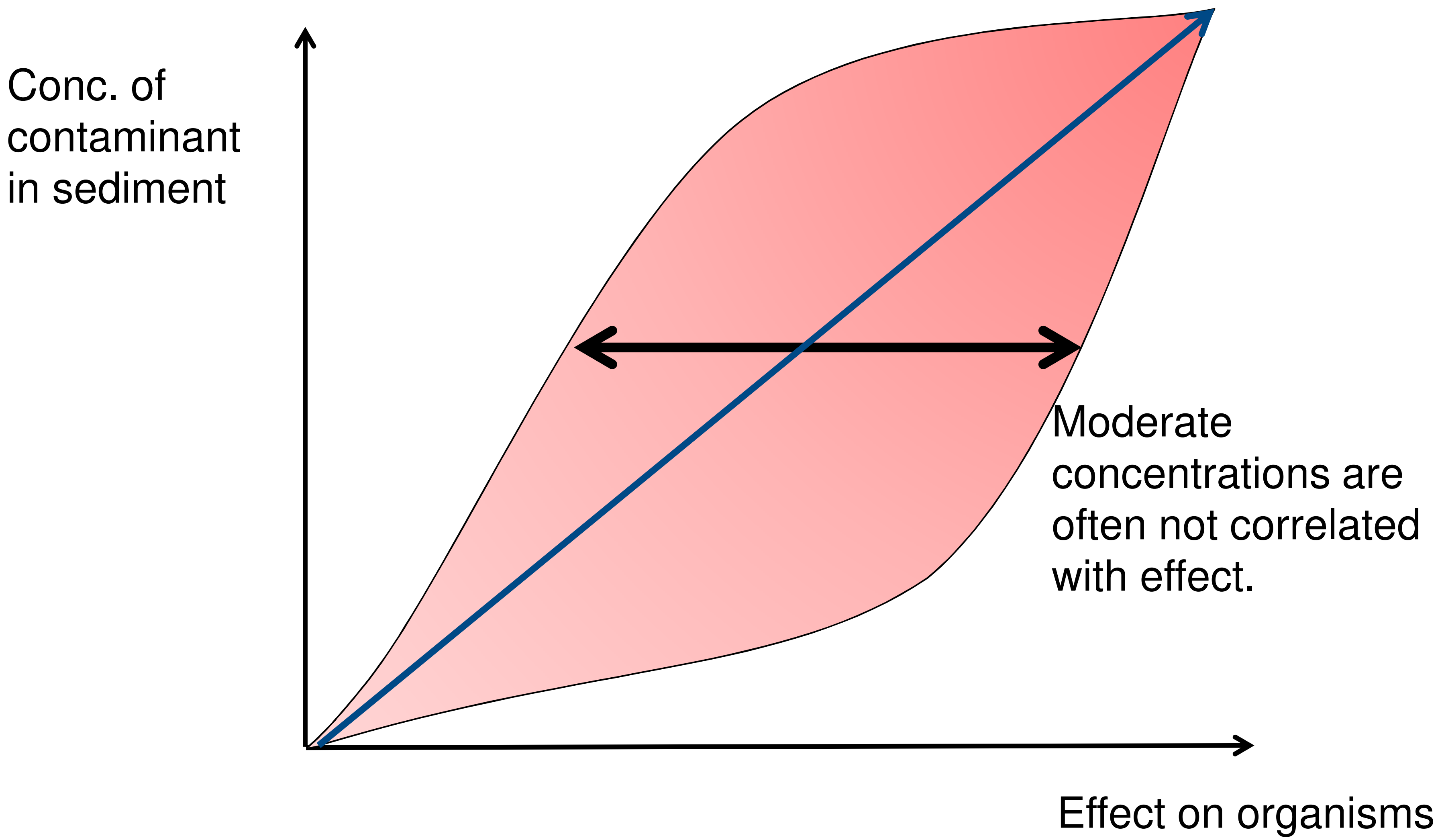
The "Toxic Iceberg"



"Toxicologists know a great deal about a few chemicals, a little about many, and next to nothing about most." (Rodricks, JV, 1992: 146)

(slide: Vanderlinden, Toronto Public Health)

Another problem: the bioavailability



Why is the effect of sediment bound contaminants particularly difficult to predict?

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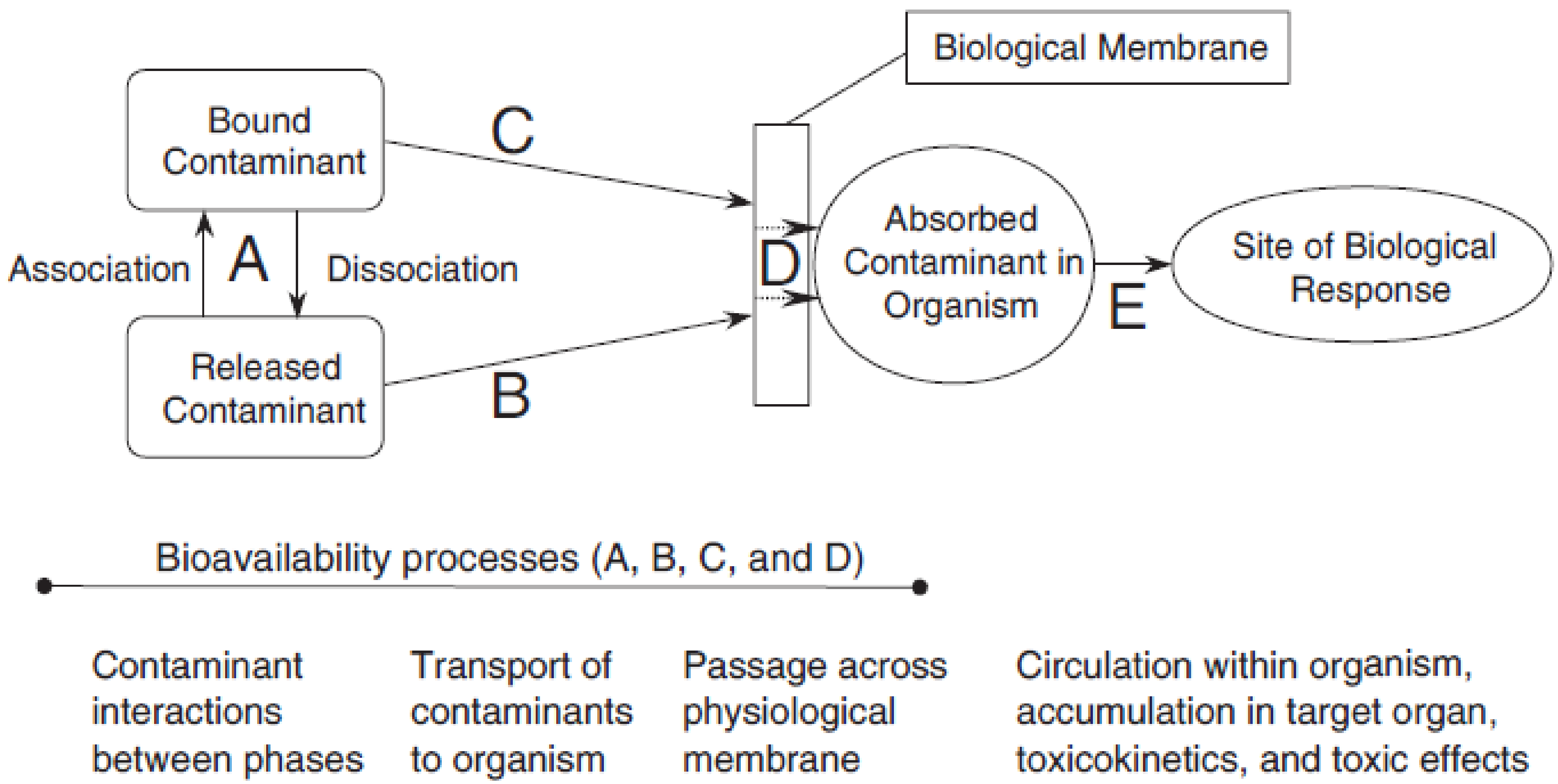
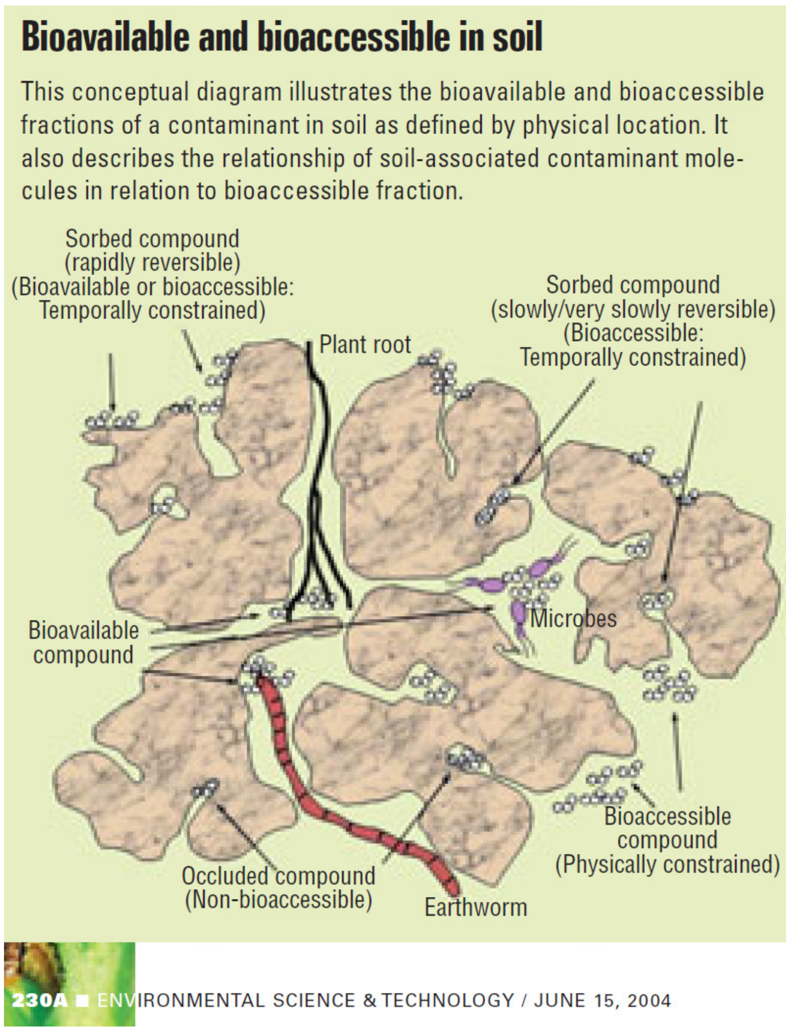


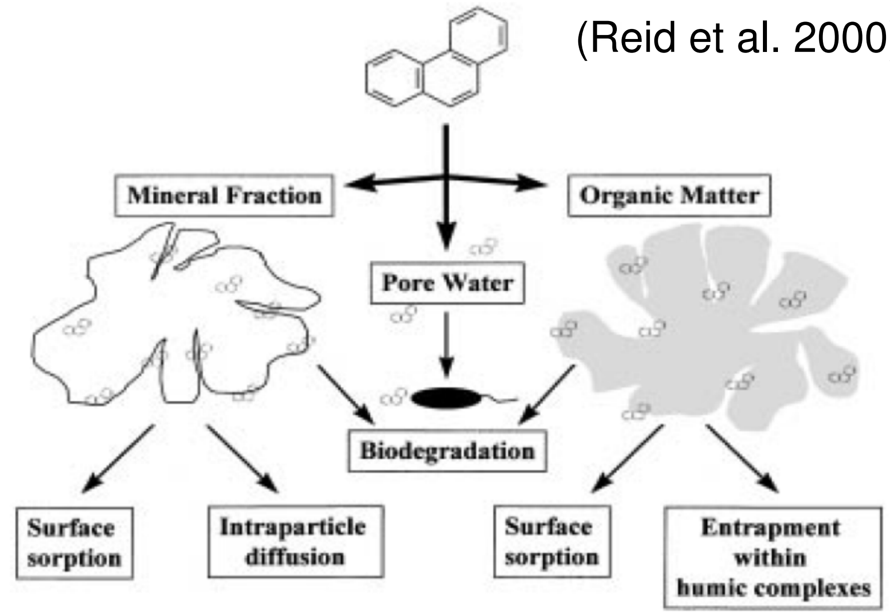
(NRC, 2003)

Often no correlation between concentration of pollutants and biological effect



(Semple, 2004)

(Reid et al. 2000)



In many cases, there is little correlation between chemically measured concentrations in environmental samples and toxic effect. The bioavailability of substances changes with time, varies with substrate and organisms.

What to do?

- Too many chemicals to measure
- Mostly unknown toxic effects
- Little information on bioavailability
- Often unknown interaction of contaminants (synergic, additive effects?)

➔ Measurement of ecotoxicity of sediments

To determine the impact of chemicals or mixture of chemicals on organisms with the aim to assess an impact on the environment.

Ecological evaluation of stressors in sediments

Benthic community structure:

- of ecological relevance
- important on the way to risk assessment

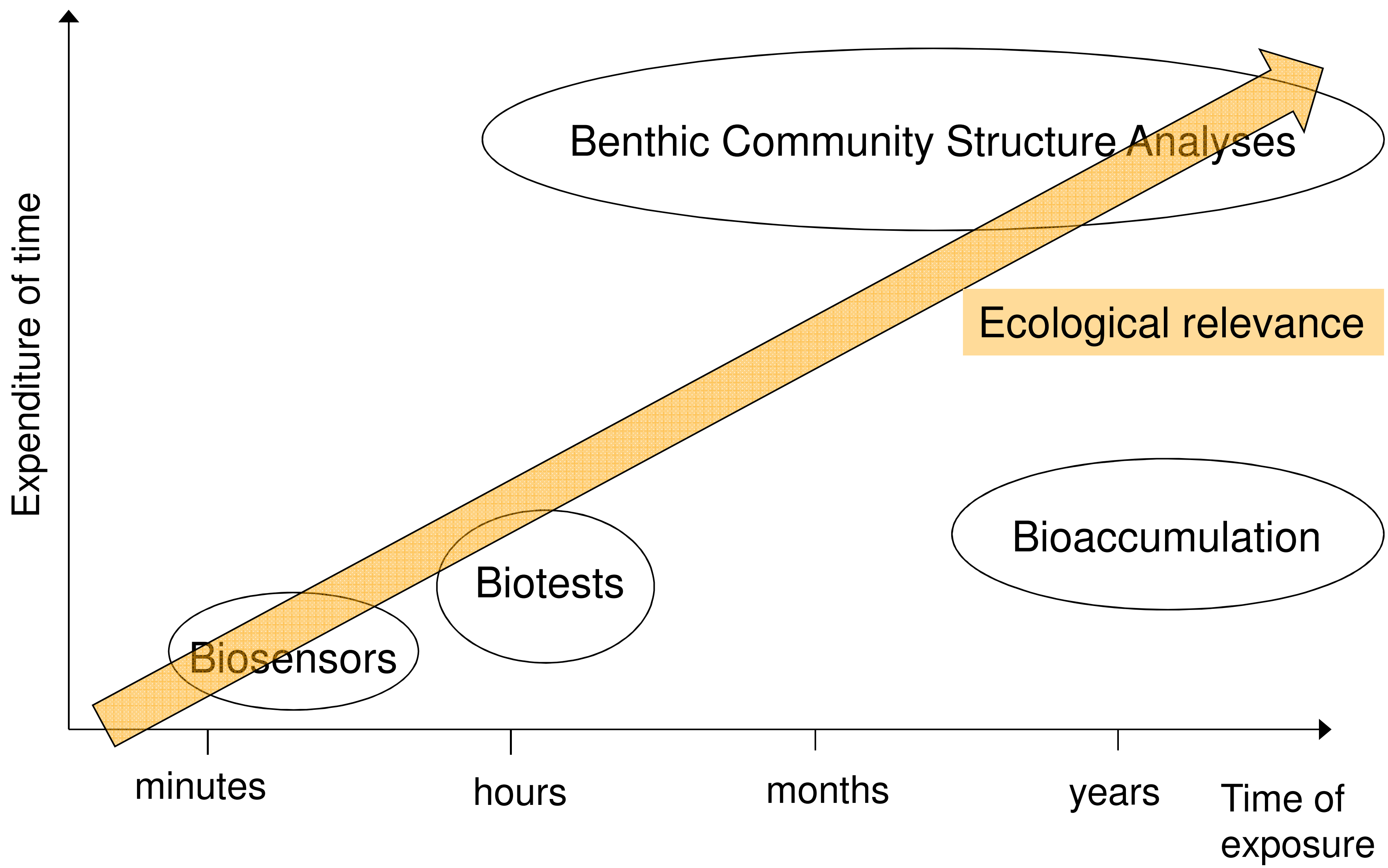
Bioassays:

- points out possible hazards -
effects on single species

Bioaccumulation:

- points to transfer in the food web -
effects otherwise unobserved

Time of exposure vs. test duration



How can ecotoxicological tests inform us about sediment quality?

Performance of ecotoxicity test

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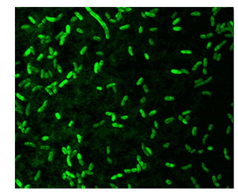
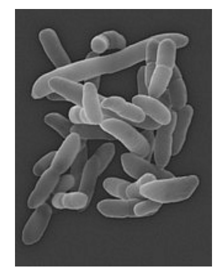
Environmental sample	+ Test organisms	***Incubation*** →	„Endpoint“	**Comparison**
Optimal growth medium	+ Test organisms	***Incubation*** →	„Endpoint“	e.g. % inhibition

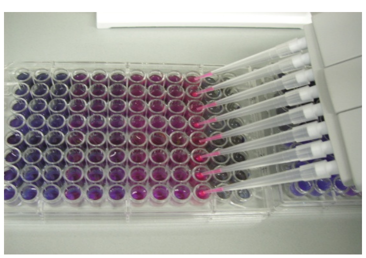




Endpoints:
Growth
Mortality
Movement
Reproduction
Metabolic activiy

Biotests with
Nematodes
Crustacea
Bacteria
Algae
Plants ……

Environmental sample:
Water
Sediment
Elutriate (water extract)



Standardizations acc. to ISO

Is application of one test enough? NO!

Sediments contain mixtures of contaminants

Different modes of action

Acting by different exposure pathways (water, direct contact etc)

Organisms are differently sensitive

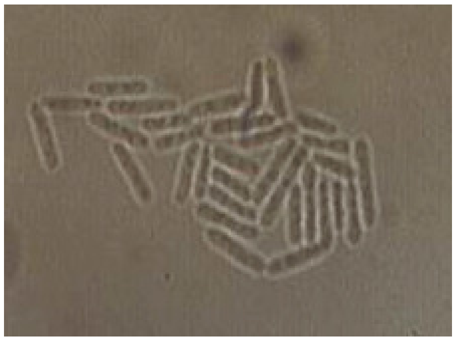
↓

Biotest combinations are necessary in order to detect all (?) potential effects

→ Often 3, better 5 bioassays
→ Different exposure pathways
→ Different sensitivities
→ Acute and chronic tests.

Application of a biotest-battery (Example)

Sediment bacteria



Bacillus cereus

Nematodes

Caenorhabditis elegans

Sediment Contact

Biotestbattery

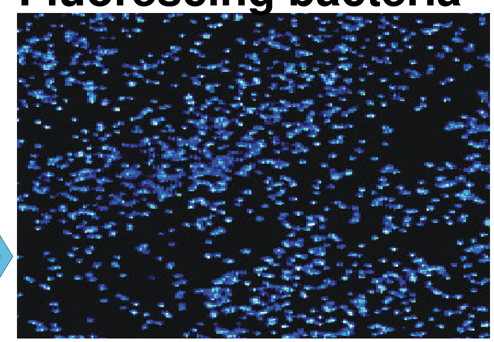
Elutriate

Elutriate
and Methanol-
extract

Green algae

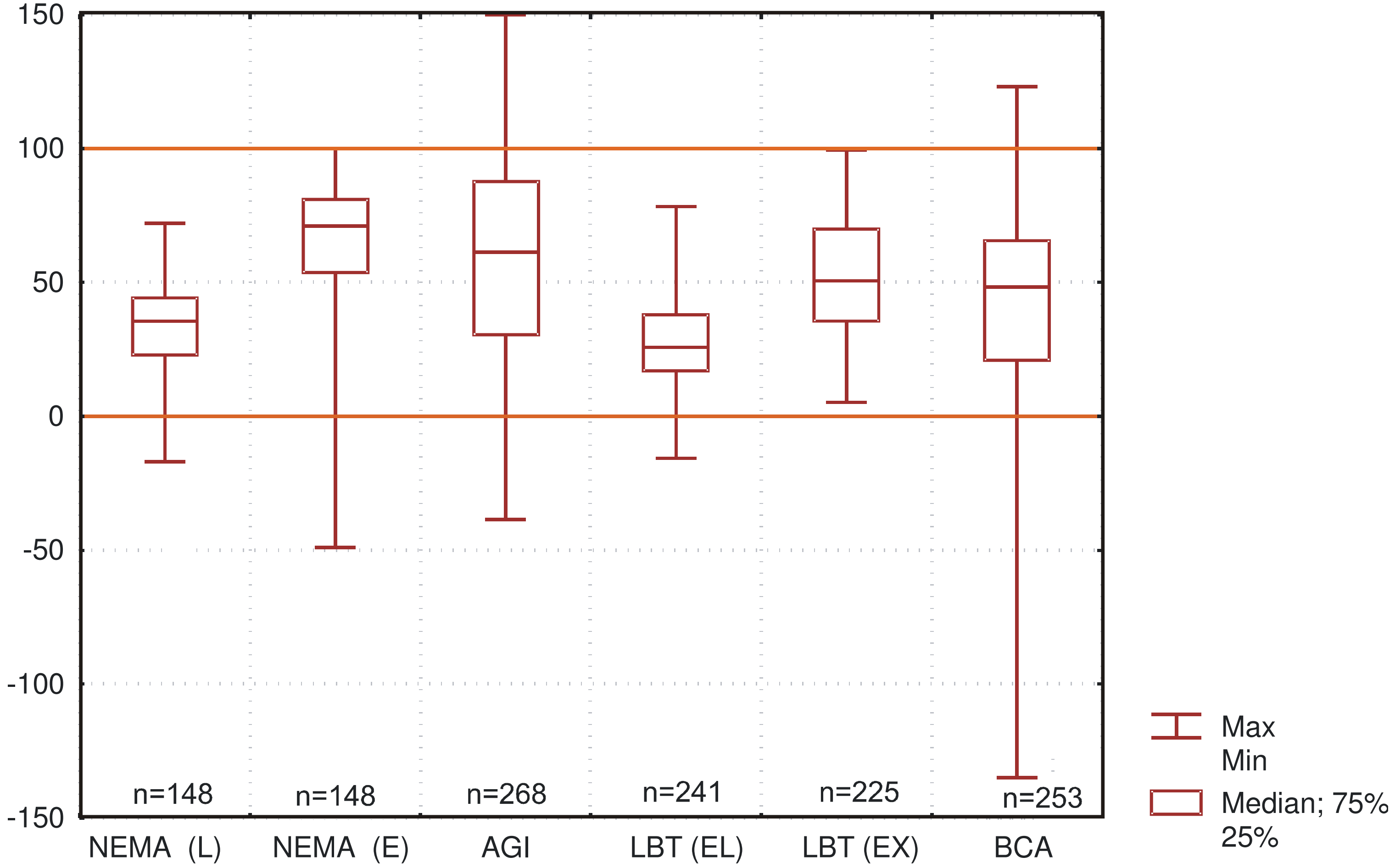
Pseudokirchneriella subcapitata

Fluorescing bacteria



Vibrio fischeri

Variation of test responses



Tests and endpoints respond differently to the same environmental stress pattern → classification of results from a battery?

There is no uniform biotest classification

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Single tests:

Test batteries:

Determination of the most sensitive organism

Fixed thresholds: e.g. the first dilution step that results in a toxicity lower than 20%. → the most sensitive biotest indicates the toxicity

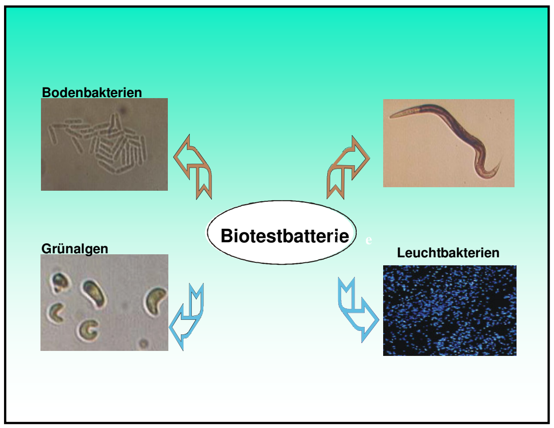
Addition of inhibition values

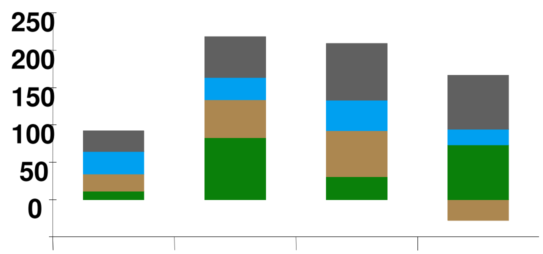
Inhibition value of undiluted sample → Adding up all inhibitions

Integrative assessment of tests

Characterization of test responses
On the basis of test characterization → Combination of biotest results
On the basis of pattern recognition

Evaluation of Ecotoxicological Data





Detection of patterns

Goal-oriented

e.g. -Monitoring

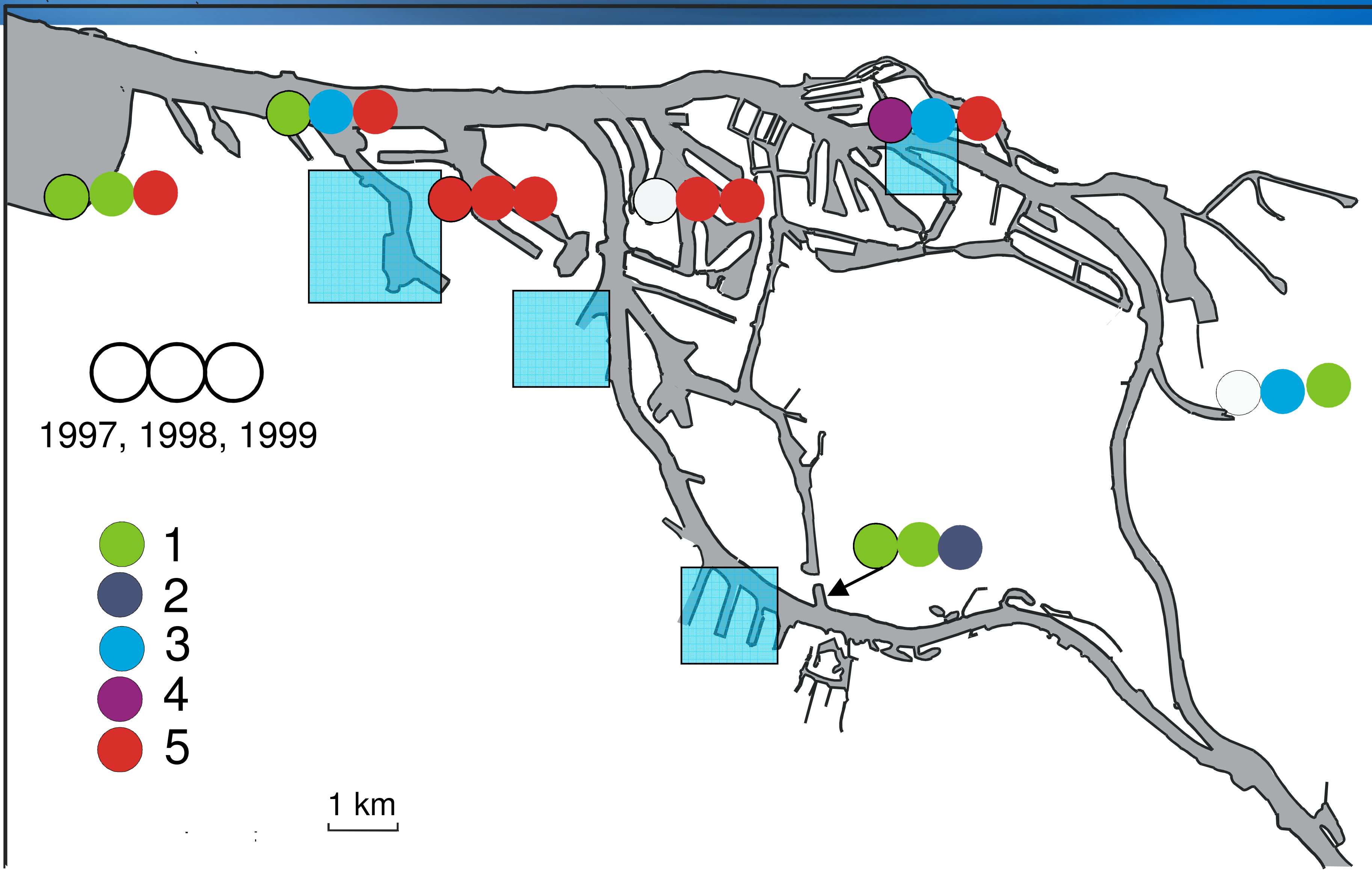
-Sediment management

Interpretation

absolute toxicities

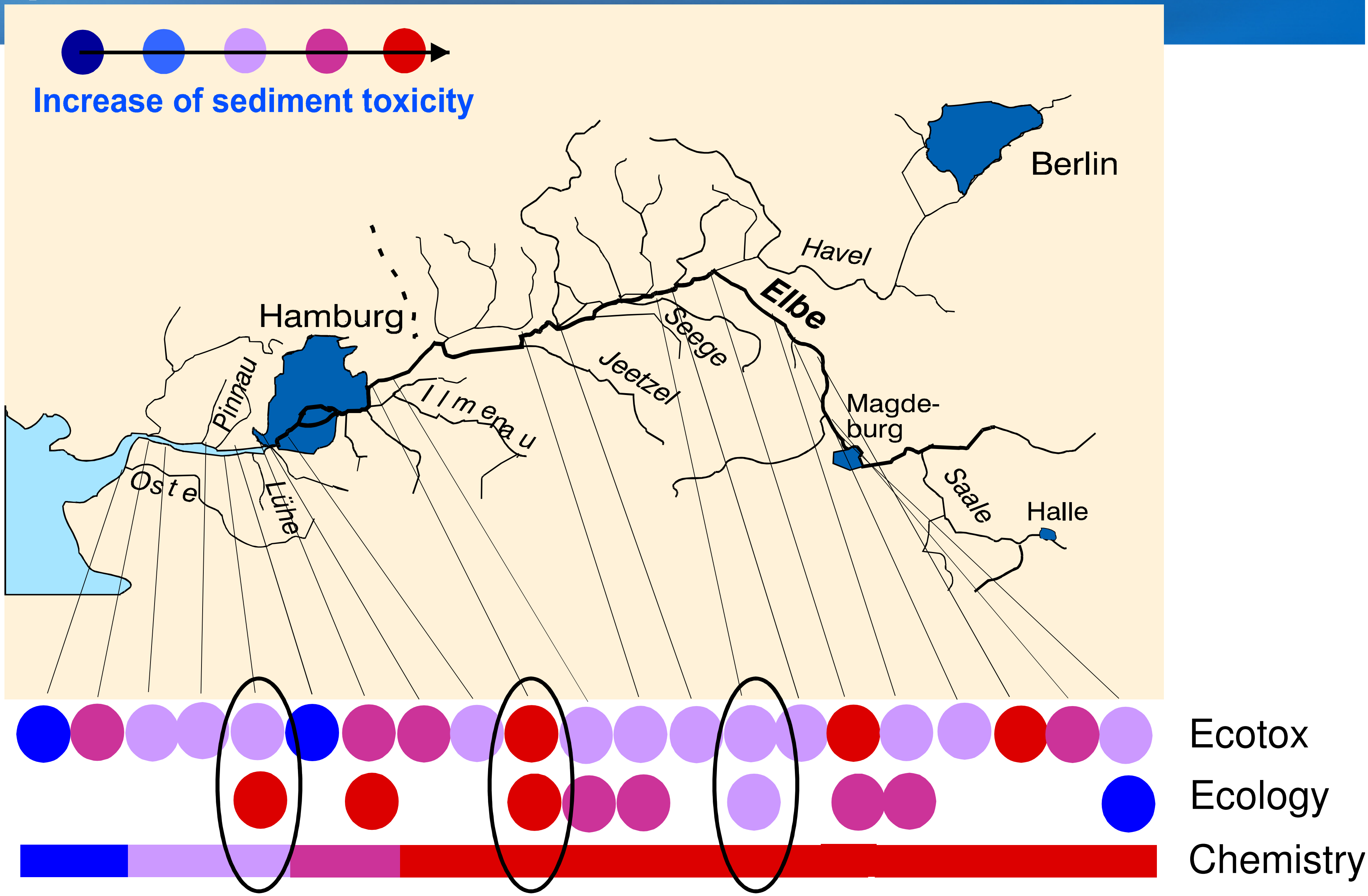
depending on issues

Changes with time: Hamburg Harbour

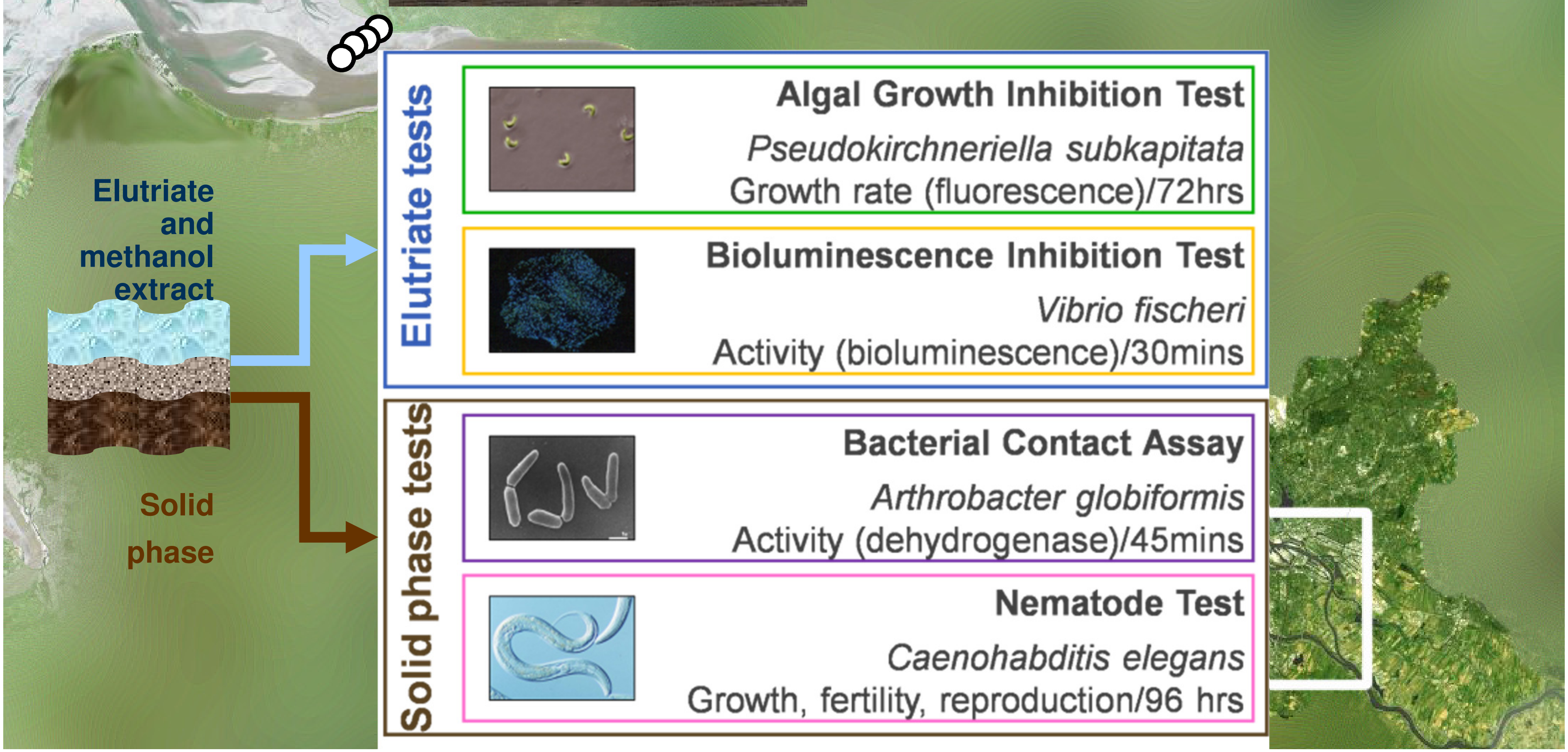


(Daten: TUHH)

Spatial variation: Elbe River



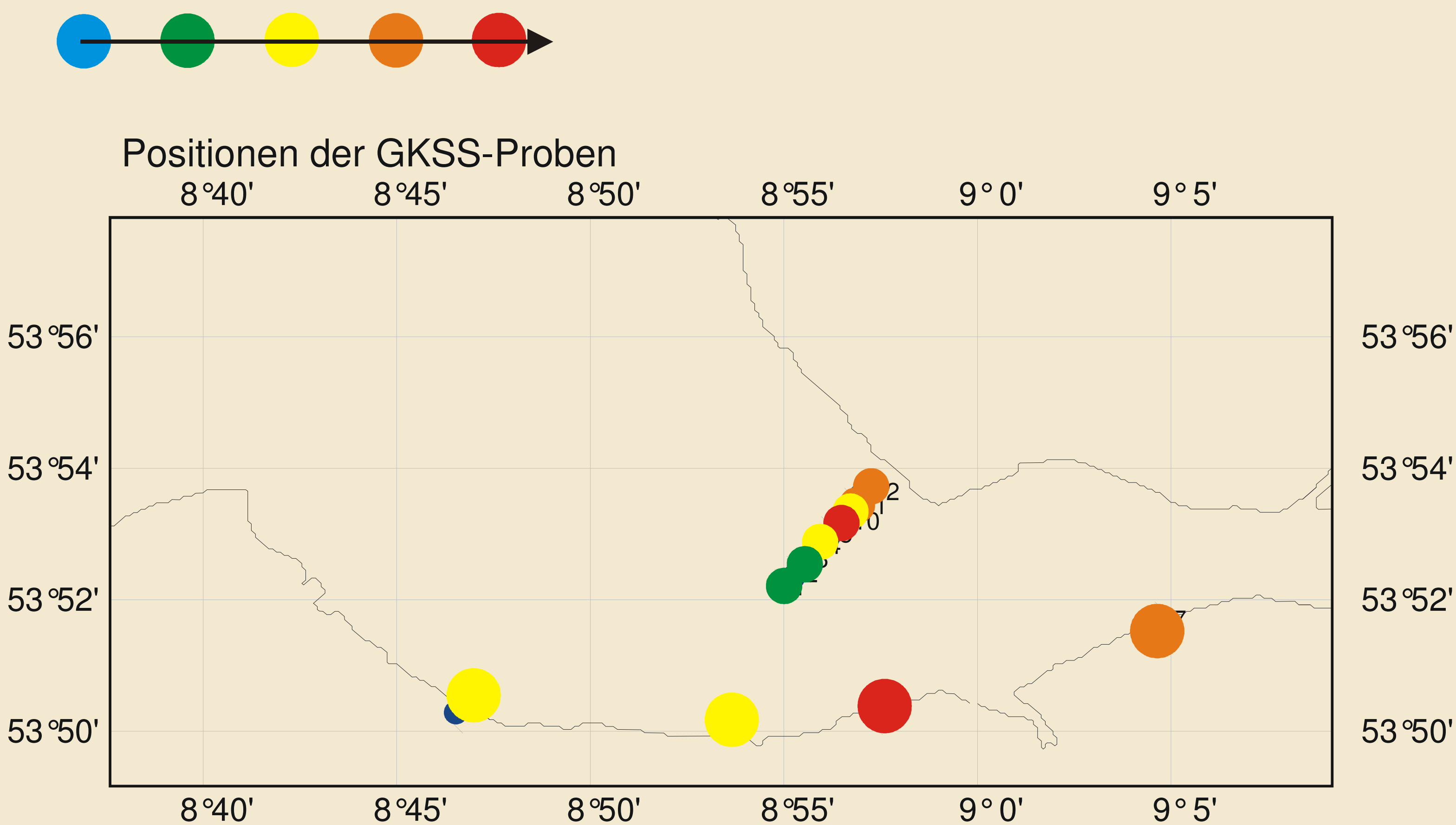
Effects of the events e.g. Elbe-flood 2002 on brackish mudflats?



E.g. Impact of the Elbe flood 2002

before the flood

23/24.8.02



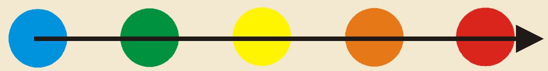
Scale: 1:366554 at Latitude 0°

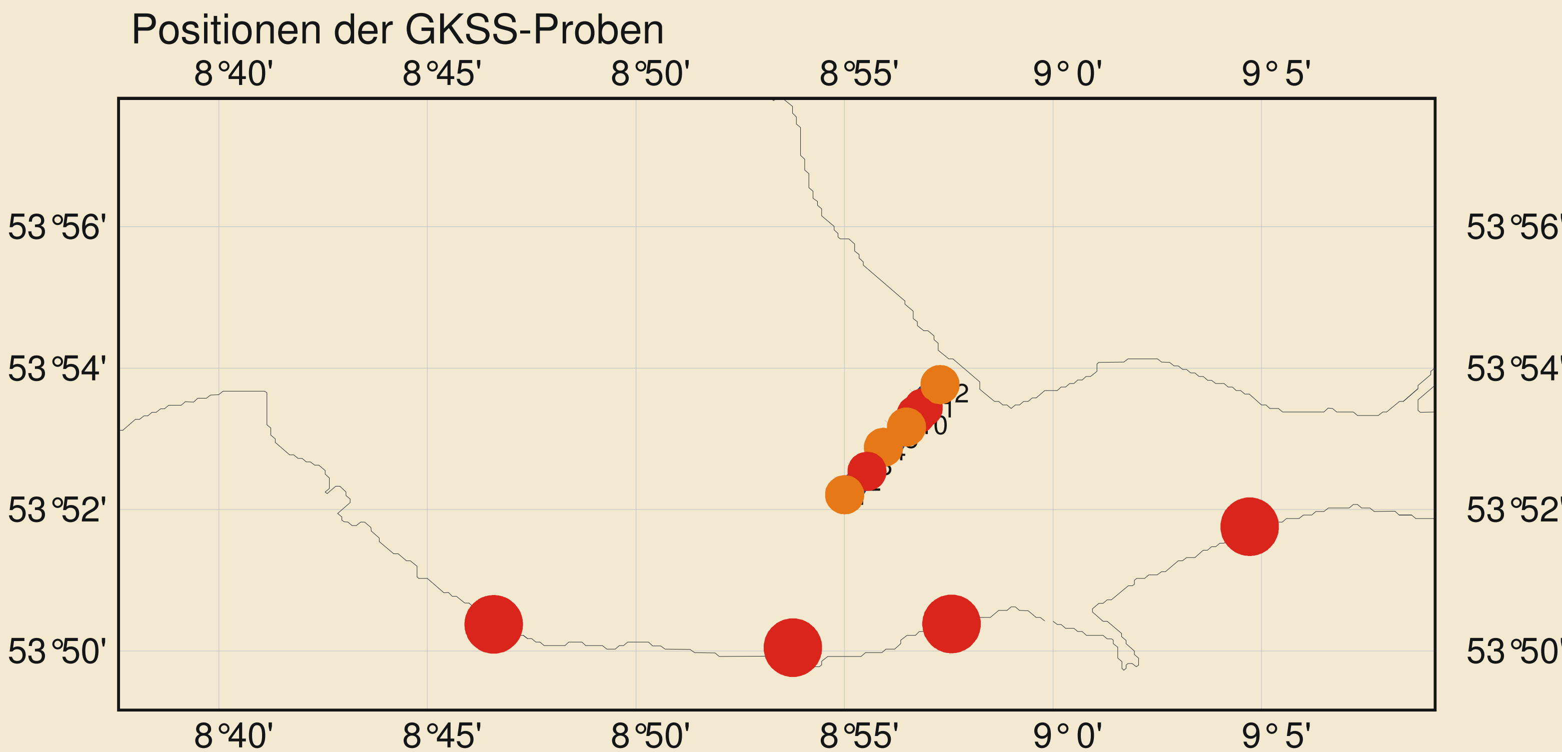
öko/toxikologie

E.g. Impact of the Elbe flood 2002

after the flood

30.9./2.10.02



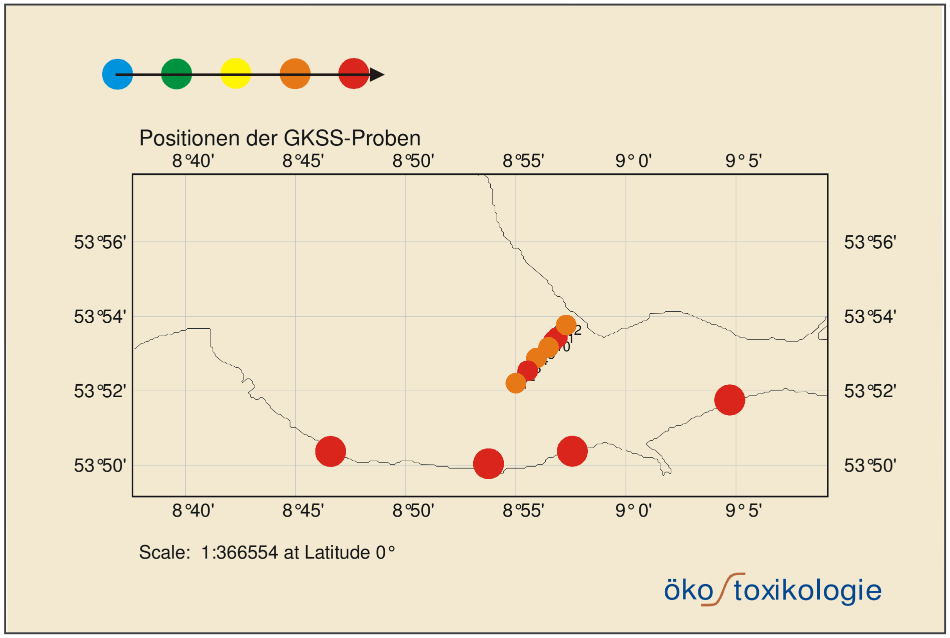


Scale: 1:366554 at Latitude 0°

(Heise et al. 2003)

öko/toxikologie

Other results?



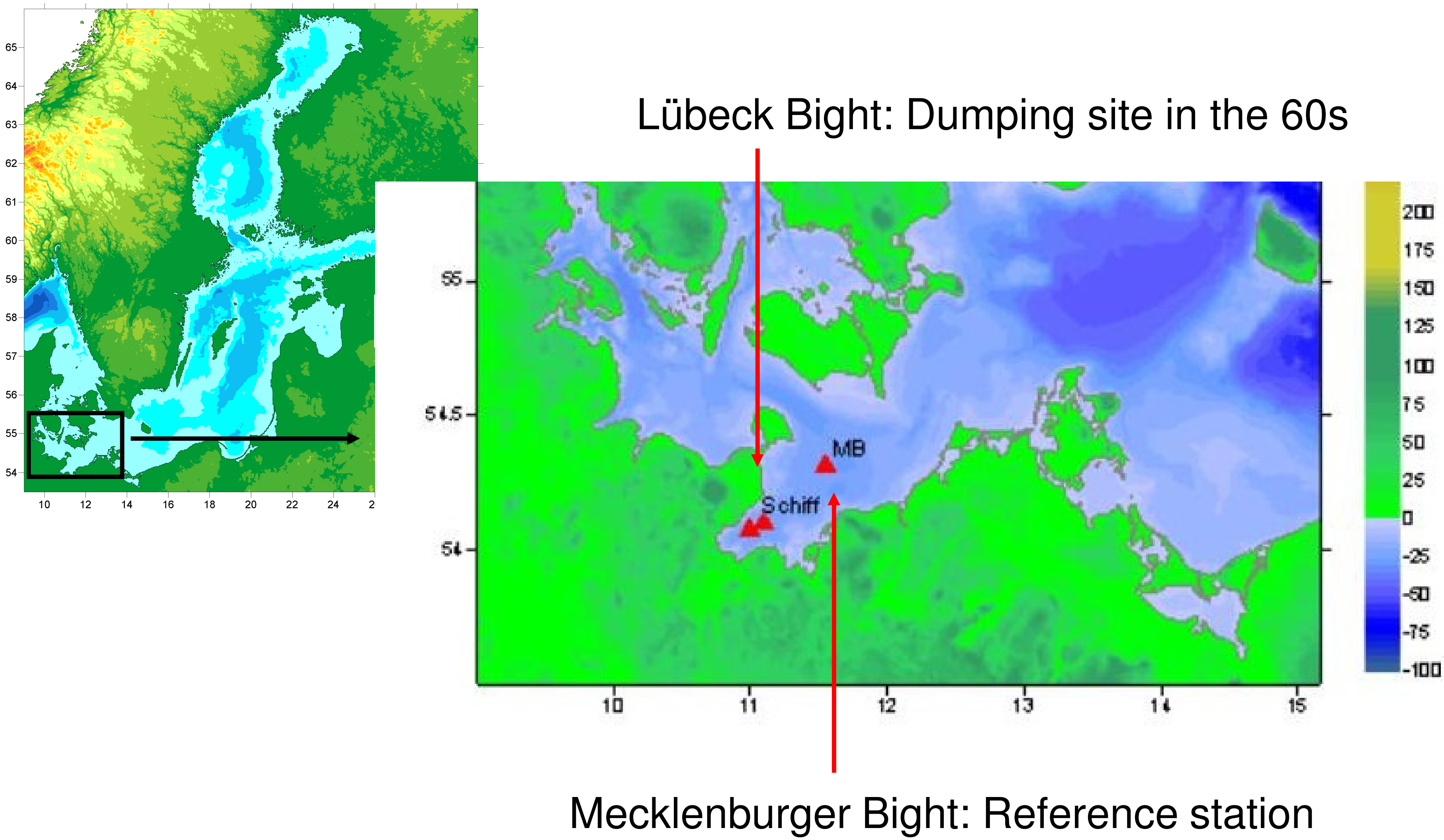
Increased toxicity with algae (elutriate), bacteria and nematodes (sediment)

(*Heise et al. 2003*)

Ötken et al. 2005: No effects of estuarine sediments after the flood on *Chironomus riparius* (insecta) and *Potamopyrgus antipoda*rum (gastropoda)

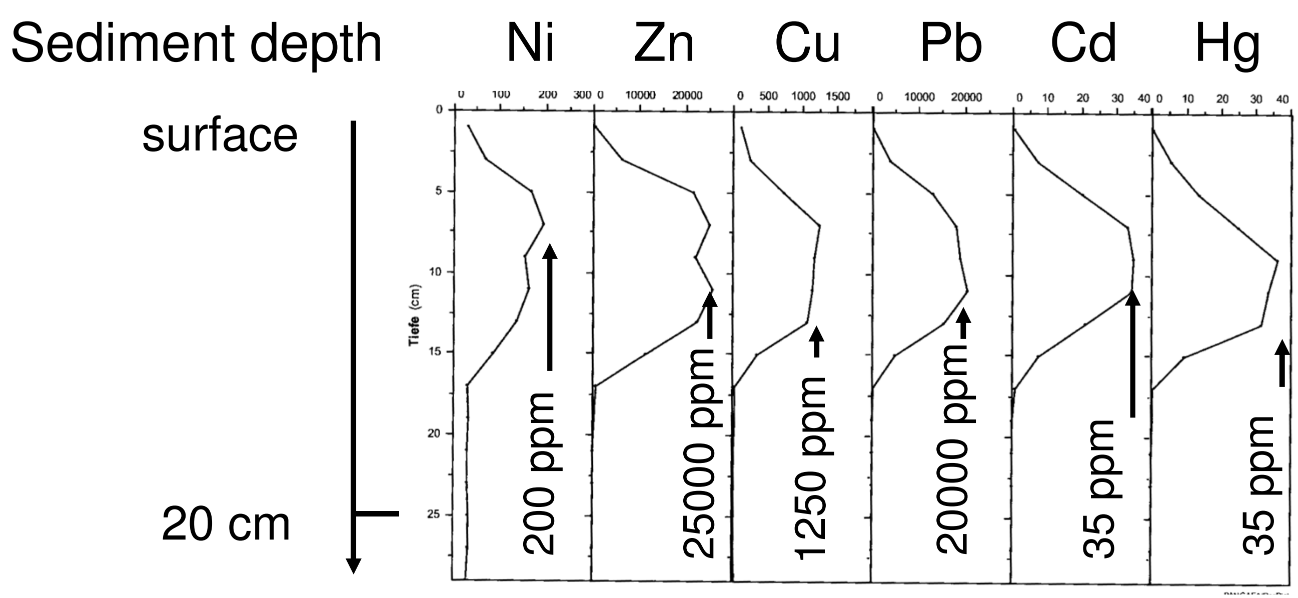
Einsporn et al. (2005): toxic effects in flatfish and mussels after the flood. Flatfish were most affected in the Elbe estuary and near Helgoland. High levels of organic contaminants in fish liver and mussels.

Lübeck Bight: Assessment of old dumping site/ or „Success of mitigation measures“



Chemical Analysis

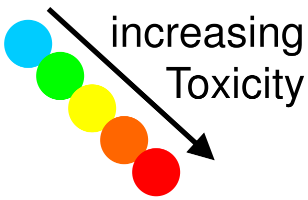
Heavy metals
In ppm



(Leipe et al. 2002)

Lead and Zn: up to 2 % of the sediment layers 3-18 cm

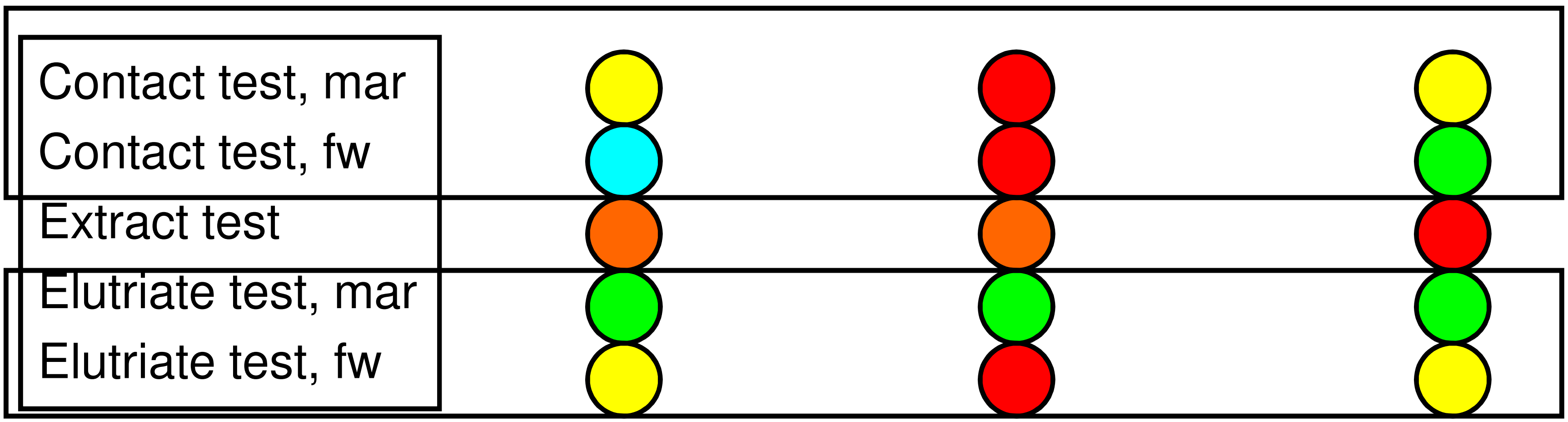
Effects measurements: Exposure pathways



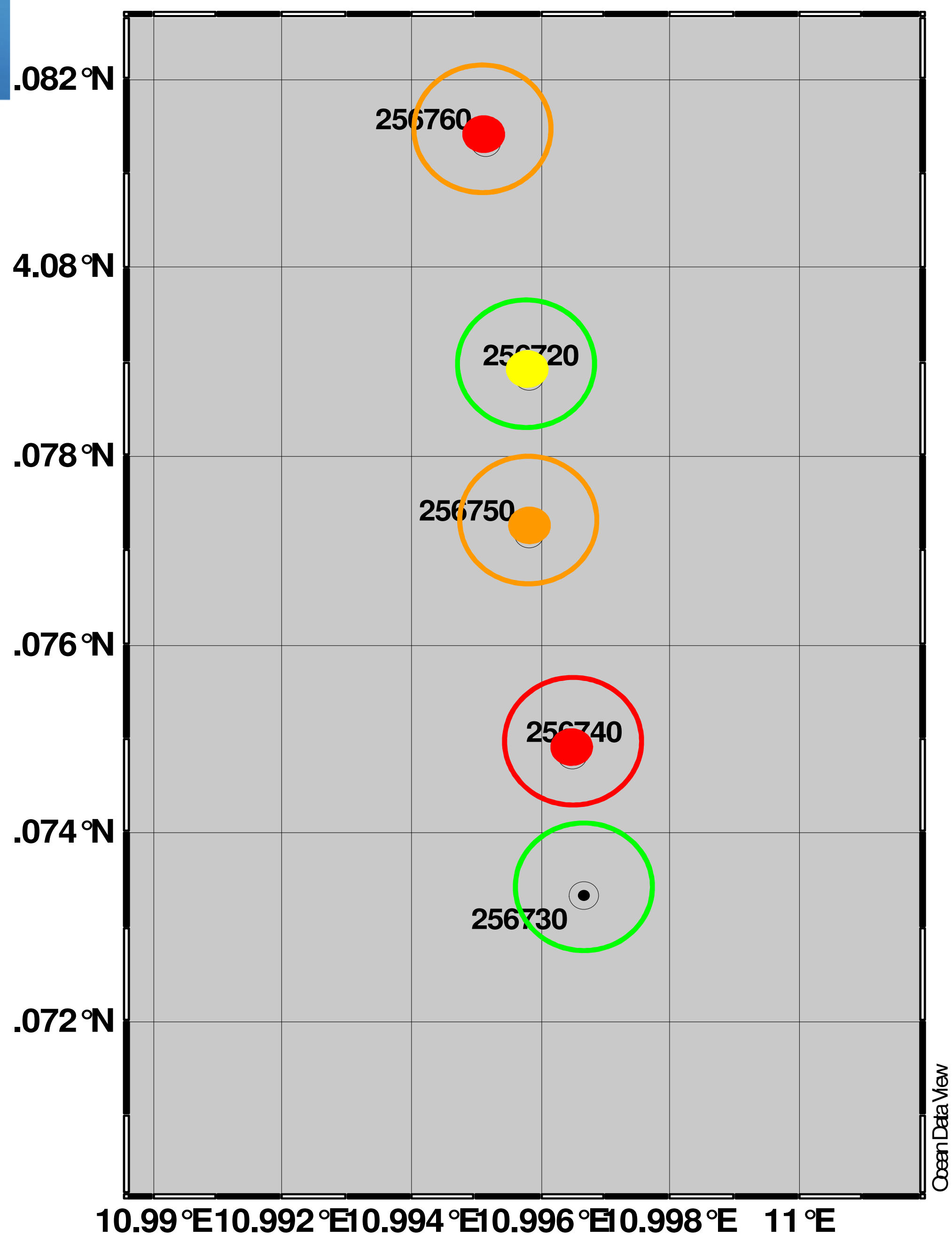
Surface material (low toxicity) (0-2)

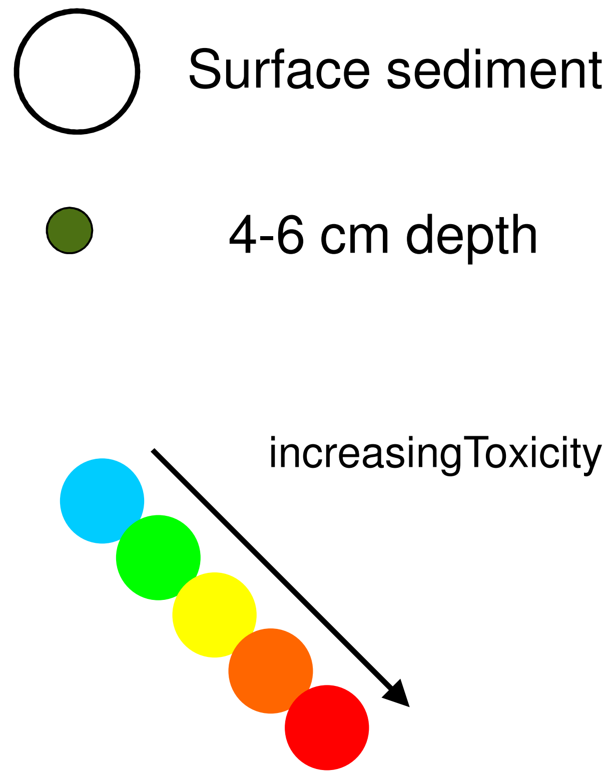
Below surface (4-6)

16-18 cm depth



Investigation of the contaminated site in detail





Dumping of „clean“ material in the region as a capping measure

Disadvantage of „only“ biotests

Lack of knowledge on relevant stressors!

No source control!

Transferability to other trophical levels / to the ecosystem?

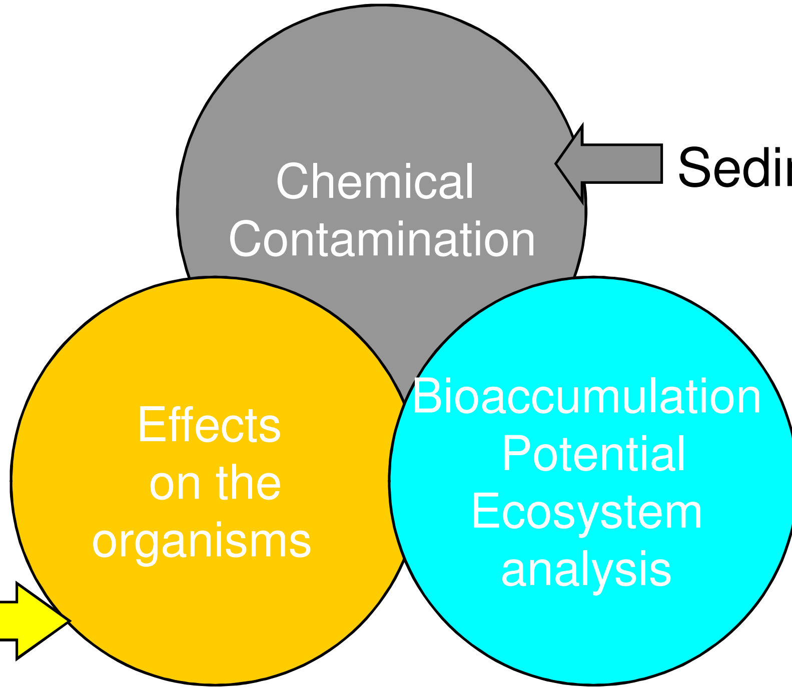
Weight of evidence approaches and tiered approaches are necessary:

Combination of

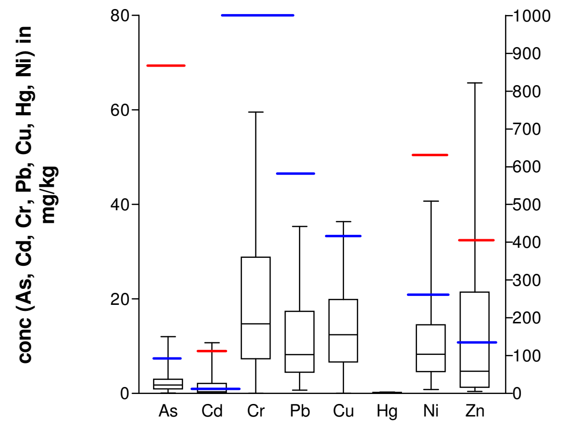
- *in vitro*-biotests (on e.g. celluar level): → modes of action, fingerprinting
- *In vivo* biotests → exposure pathways, bioavailability
- Ecological community modelling → from organism level to population level
- and TIE – Toxicity Idenfitication Profiling

are necessary for an efficient environmental assessment.

Risk Assessment: Application of a Sediment Triad



Sediment Quality Criteria



Ecotoxicological
Test Systems

Acute test
Chronic test with Elutriates

Modelling of
Biomagnification
Ecosystem analysis
(diversity of benthos organisms

Thank you for your attention!

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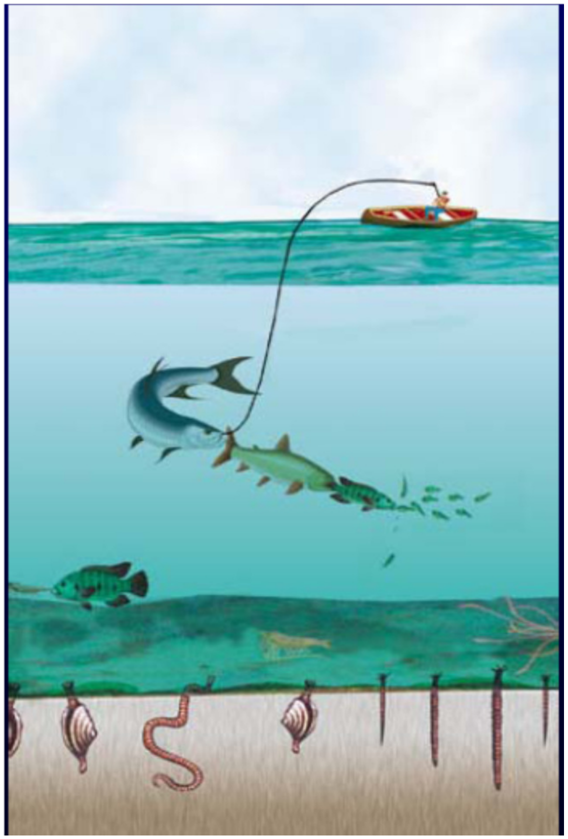
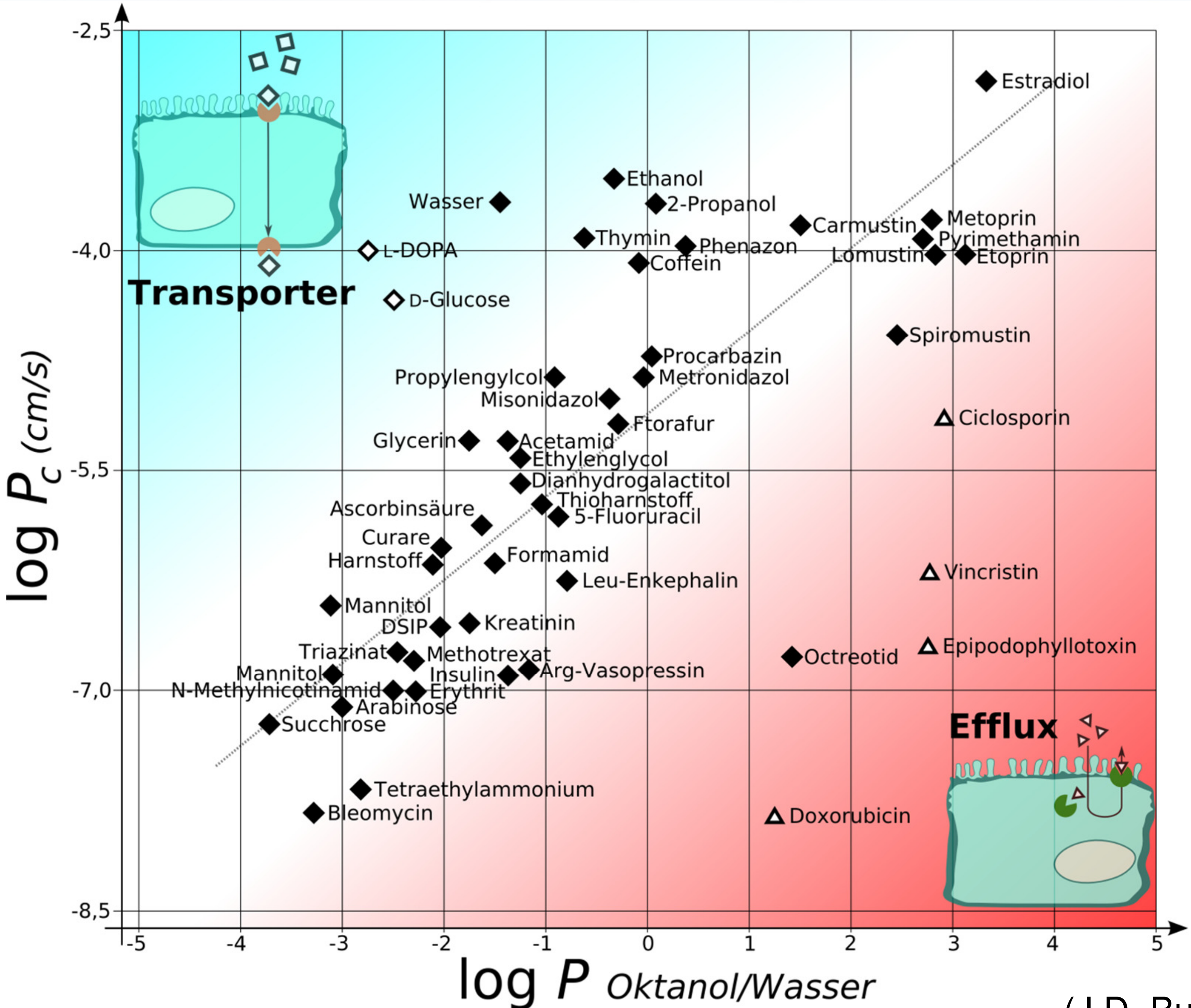
Bioconcentration / Biomagnification

Bioconcentration: A process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination.



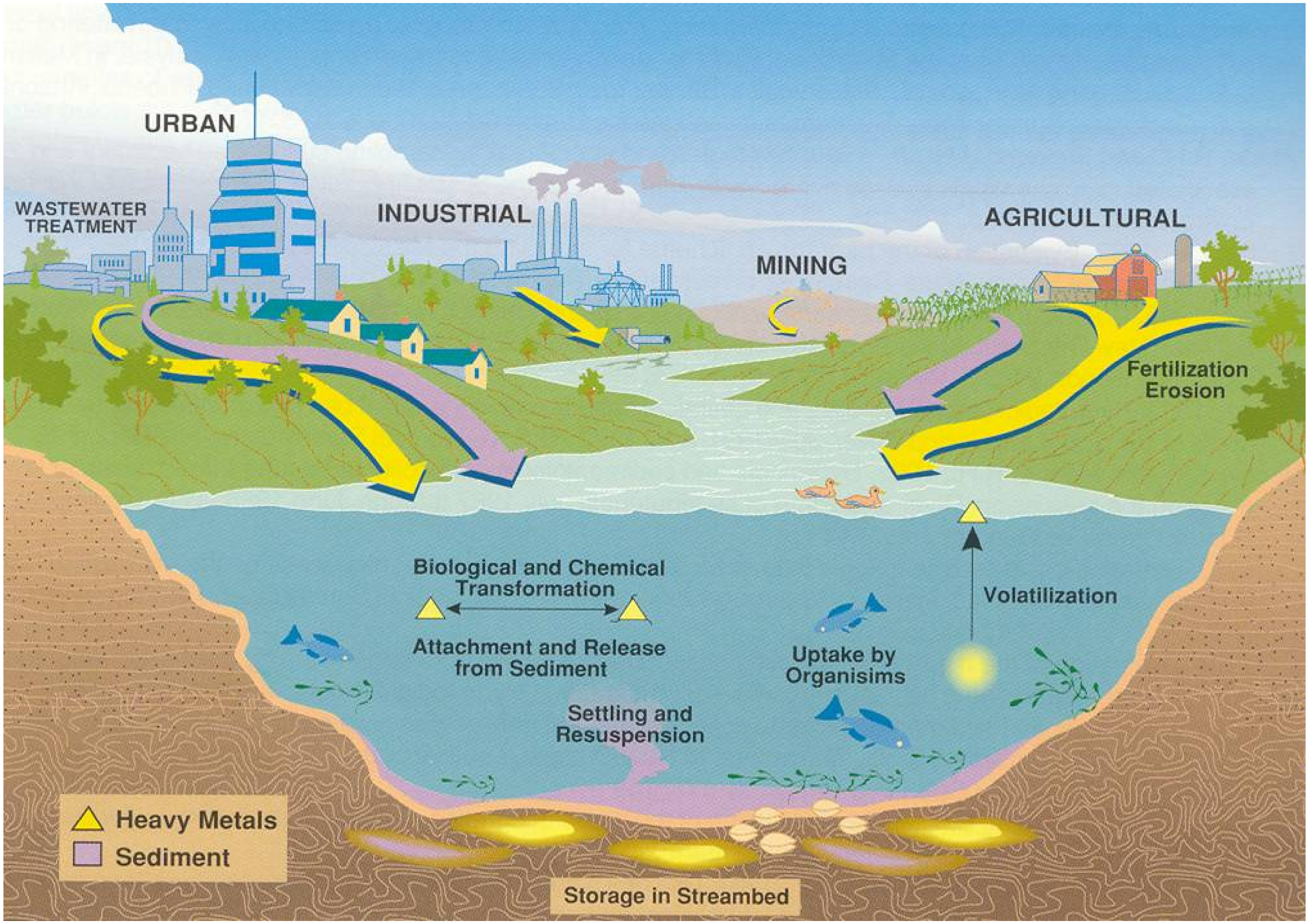
Bioaccumulation: accumulation of contaminants in tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, pore water, or dredged material.

Biomagnification: Tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels.



(J.D. Buynak, 2011)

Contamination sources for sediments



Ecotoxicology Versus Toxicology

HAW Hamburg
Fakultät LS
Life Sciences

Toxicology	Ecotoxicology
Protection of humans	**Protection of the ecosystem**
Target organism is well known	**Often, sensitive species are not known**
Models using mammals	**Experiments with / direct studies of indicator species / test species**
Model organisms are homeothermic	**Many organisms are heterothermic, various physiologies**
Exposure can be determined precisely (oral doses)	**Identity of stressor, concentration and exposure time theoretically known, availability by various potential exposure pathways often is not.**
Basic research: Understanding of processes	**Basic research regarding availability, environmental exposure; also empirical studies to determine threshold levels for legislation**
Methods are mostly established	**Many methods are relatively new, often being in the process of standardization**