Actual risk assessment and in-situ remediation of Norwegian harbour sediments

Gerard Cornelissen[1,2], Dag Broman[1], Kristoffer Næs[3], Gijs Breedveld[2], Amy M. P. Oen[2], Anders Ruus[3]

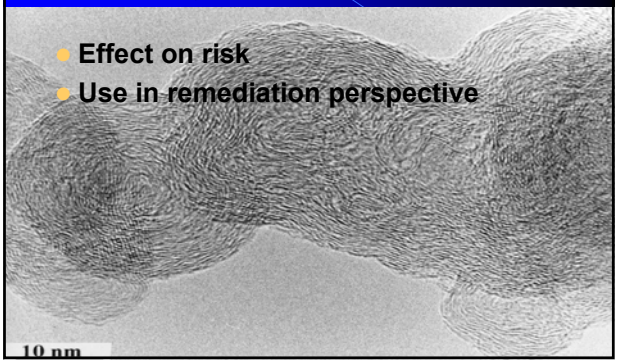
[1] Department of Applied Environmental Science (ITM), Stockholm University, Sweden.

[2] Department of Environmental Engineering, Norwegian Geotechnical Institute (NGI), Norway

[3] Norwegian Institute for Water Research (NIVA), Norway.

Soot, coal and charcoal

- **Effect on risk**
- **Use in remediation perspective**



Soot and charcoal

Biomass ..... ^{14}C dating ..... Fossil fuel

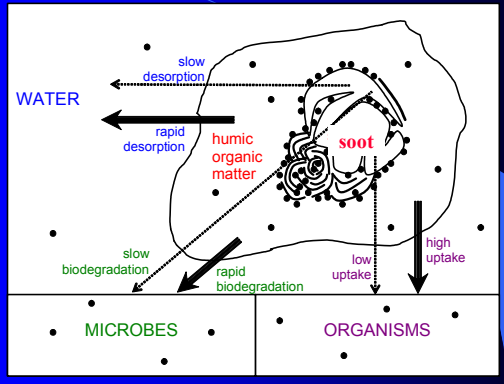
Incomplete combustion

Soot, Charcoal

PAH source → Health problems (air)

PAH sink → Lower uptake in organisms (sediment)

Strong binding to soot



Cornelissen Gustafsson Bucheli Jonker Koelmans Van Noort, critical review, Environ. Sci. Technol. 2005, 6881-6895

How much soot do we find in sediments?

Sediment literature:

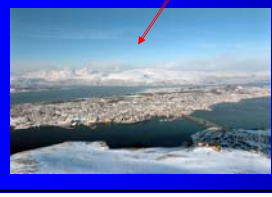
19 studies, 300 samples

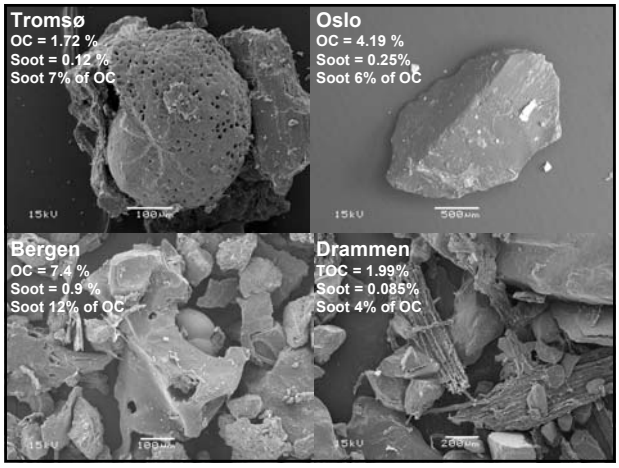
Median Soot/charcoal 10% of TOC, (2-30%)

Cornelissen Gustafsson Bucheli Jonker Koelmans Van Noort, critical review, Environ. Sci. Technol. 2005, 6881-6895.

Norwegian contaminated harbour sediments

Oslo (OS)
Bergen (BG)
Tromsø (TR)
Drammen (DR)





Soot binds PAHs factor of 50-1000 stronger than humic organic matter!

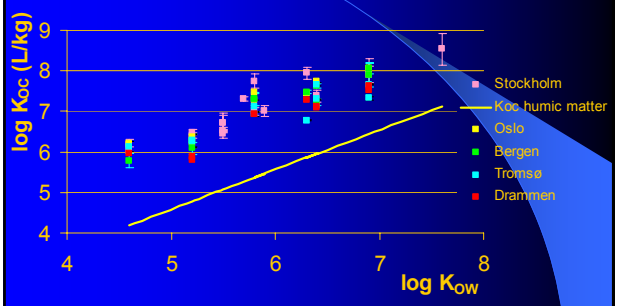
	Phe	BaP
OC-water distribution ratio:	$10^{4.2}$	$10^{5.7}$
Soot Oslo sediment	$10^{6.8}$	$10^{7.9}$
Soot Bergen sediment	$10^{6.3}$	$10^{7.8}$
Soot Tromsø sediment	$10^{6.8}$	$10^{7.1}$
Soot Drammen sediment	$10^{6.4}$	$10^{7.5}$

Cornelissen Breedveld Kalaitzidis Christanis Oen, Environ. Sci. Technol. 2006, 40, 1197-1203

Strong binding to soot/charcoal (and to activated carbon!) for many compound classes

- PAHs (Jonker and Koelmans 2002; Bucheli and Gustafsson 2003; Cornelissen et al. 2004)
- (planar) PCBs (Jonker and Koelmans 2002; Bucheli and Gustafsson 2003; Cornelissen et al. 2004)
- PCDDs (Barring et al. 2002)
- PCDFs (Barring et al. 2002)
- PBDEs (Barring et al. 2002)
- Chlorobenzenes (Kleineidam et al. 2002; Ran et al. 2004; Braida et al. 2001; Chun et al. 2004)
- Chloroalkanes (Grathwohl 1990; Cornelissen et al. 2005)
- Diuron, butylate (Yang and Sheng 2003a,b; Cornelissen et al. 2005)

Organic compounds in field: Binding 100 times stronger than humic materials!



Cornelissen Breedveld Kalaitzidis Christanis Oen, Environ. Sci. Technol. 2006, 40, 1197-1203

Measured uptake in worms and snails (BSAF for 16 PAHs)

	Worms	Snails
Oslo	0.004	0.01
Bergen	0.009	0.01
Tromsø	0.01	0.009

$BSAF = C_{lipid}/C_{OC}$

BSAF = 1 for humic organic matter!

Cornelissen Breedveld Næs Oen Ruus, Environ. Toxicol. Chem. 2006, 25, 2349-2355

Measured uptake in worms and snails (BSAF for 16 PAHs)

	Worms	Snails
Oslo	0.004	0.01
Bergen	0.009	0.01
Tromsø	0.01	0.009

$BSAF = C_{lipid}/C_{OC}$

BSAF = 1 for humic organic matter!

Uptake from sediments factor of 100 lower than uptake from humic organic matter!

Cornelissen Breedveld Næs Oen Ruus, Environ. Toxicol. Chem. 2006, 25, 2349-2355

Implications for risk assessment: Effect of strong binding to soot on actual risk

Binding stronger than assumed (factor 100)

↓

Freely dissolved porewater concentrations lower

↓

Uptake in organisms lower (factor 100)

↓

Actual risk factor 100 lower

Improved chemical risk assessment

Freely dissolved concentrations

↓

Use of existing aquatic quality criteria

↓

Risk assessment

Main conditions:

1. Reliable methods
2. Routine-like application
3. Field application

Risk assessment for sediment: total sediment contents

	Sediment Quality Guideline (µg/kg)	Sediment Content (µg/kg)
Phenanthrene	543	
Oslo		570
Drammen		70
Bergen		4,600
Tromsø		770
Benzo[*a*]pyrene	33	
Oslo		1,400
Drammen		260
Bergen		6,900
Tromsø		570

Risk assessment for sediment: free porewater concentrations

Sediment	Water Quality Guideline (ng/l)	Free concentration in porewater (ng/l)
Phenanthrene	3,200	
Oslo		16.8
Drammen		3.8
Bergen		128
Tromsø		59
Benzo[*a*]pyrene	5	
Oslo		3.3
Drammen		0.33
Bergen		9.8
Tromsø		2.8

Measuring free concentrations in sediment and water

- In **sediment porewater**: easy, take sediment to the lab and shake with passive sampler
- In **overlying water**: more difficult, has to be done in the field

Risk assessment of overlying water

POM 500 µm[a]

POM 55 µm

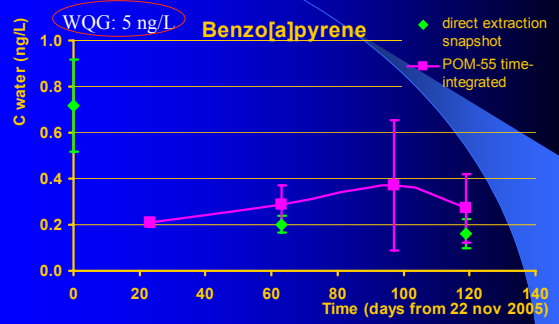
SPMDs: no equilibrium!

[a] Polyoxymethylene, Jonker and Koelmans, Environ. Sci. Technol 2001, 3742

Deployment in field (Oslo harbour)

- **Deployed 22 november until now**
- **Measured C_{water} (total extraction) at several times**
- **1 m over bottom, depth 9-65 m, current 2-10 cm/sec**

Deployment in field: POM 55 µm



Advantages of equilibrium passive samplers

- Time-integrated measurements
- Equilibrium in 3-6 weeks in the field
- Free concentrations
- Low detection limits (< 0.1 pg/L)
- No pumping for e.g. PCBs, dioxins

Advantages of equilibrium passive samplers

- Time-integrated measurements
- Equilibrium in 3-6 weeks in the field
- Free concentrations
- Low detection limits (< 0.1 pg/L)
- No pumping for e.g. PCBs, dioxins

Expose 10 g passive sampler

Advantages of equilibrium passive samplers

- Time-integrated measurements
- Equilibrium in 3-6 weeks in the field
- Free concentrations
- Low detection limits (< 0.1 pg/L)
- No pumping for e.g. PCBs, dioxins

Expose 10 g passive sampler

OR

Advantages of equilibrium passive samplers

- Time-integrated measurements
- Equilibrium in 3-6 weeks in the field
- Free concentrations
- Low detection limits (< 0.1 pg/L)
- No pumping for e.g. PCBs, dioxins

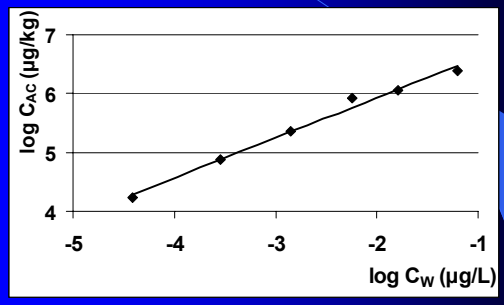
Expose 10 g passive sampler

OR

Extract 10.000-100.000 L water

Remediation perspective of charcoal: Activated Carbon (AC) amendment

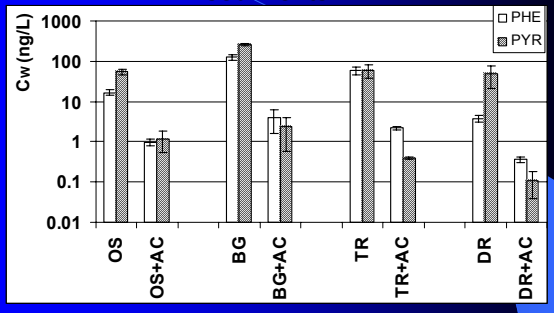
How strong is the binding to AC?



K_{AC} $10^{8.08}$ at 1 ng/L (K_{SOOT} 10^{7}, K_{OC} 10^{4}) (phenanthrene)

Cornelissen Breedveld Kalaitzidis Christanis Oen, Environ. Sci. Technol. 2006, 40, 1197.

2% AC very effective for Norwegian sediments!



Free concentrations in water reduced by 95-99.5%!

AC does not influence habitat quality

	Lipid contents (%)			
	No AC		**AC 2 %**	
	Worms	Snails	Worms	Snails
Clean sed.	0.7	0.8		
Oslo	1.3	1.3	0.5	1.2
Bergen	0.7	1.2	1.0	1.2
Tromsø	0.8	1.3	0.6	1.6
	No AC: 1.1 ± 0.3 %		**AC: 1.0 ± 0.4%**	

Cornelissen Breedveld Næs Oen Ruus, Environ. Toxicol. Chem. 2006, 25, 2349-2355

Effect of AC on uptake

	Reduction in PAH uptake	
	Worms	Snails
Oslo	85%	30%
Bergen	20%	10%
Tromsø	83%	~ 0%

- AC less effective than expected!
- Possible explanation: AC in foldings in snail skin (tested now)
- Promising technique for all other compound groups that sorb strongly to soot and coal