

Ecological risk assessment of contaminated sediments

Structure, experience,
and general applicability
of the Norwegian
system

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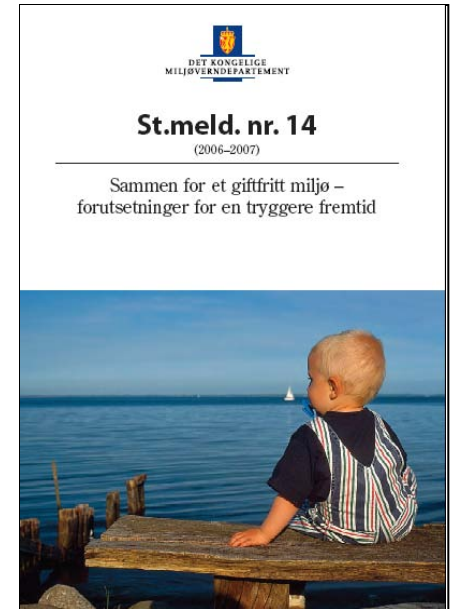
Background

- Restriction on food consumption imposed on 30 Norwegian fjords
- Legacy pollution in marine sediments from earlier discharges
- Sediments presently regarded as the prime contamination source
- Price tag for remediation 1-3 billion euro



Ambitions

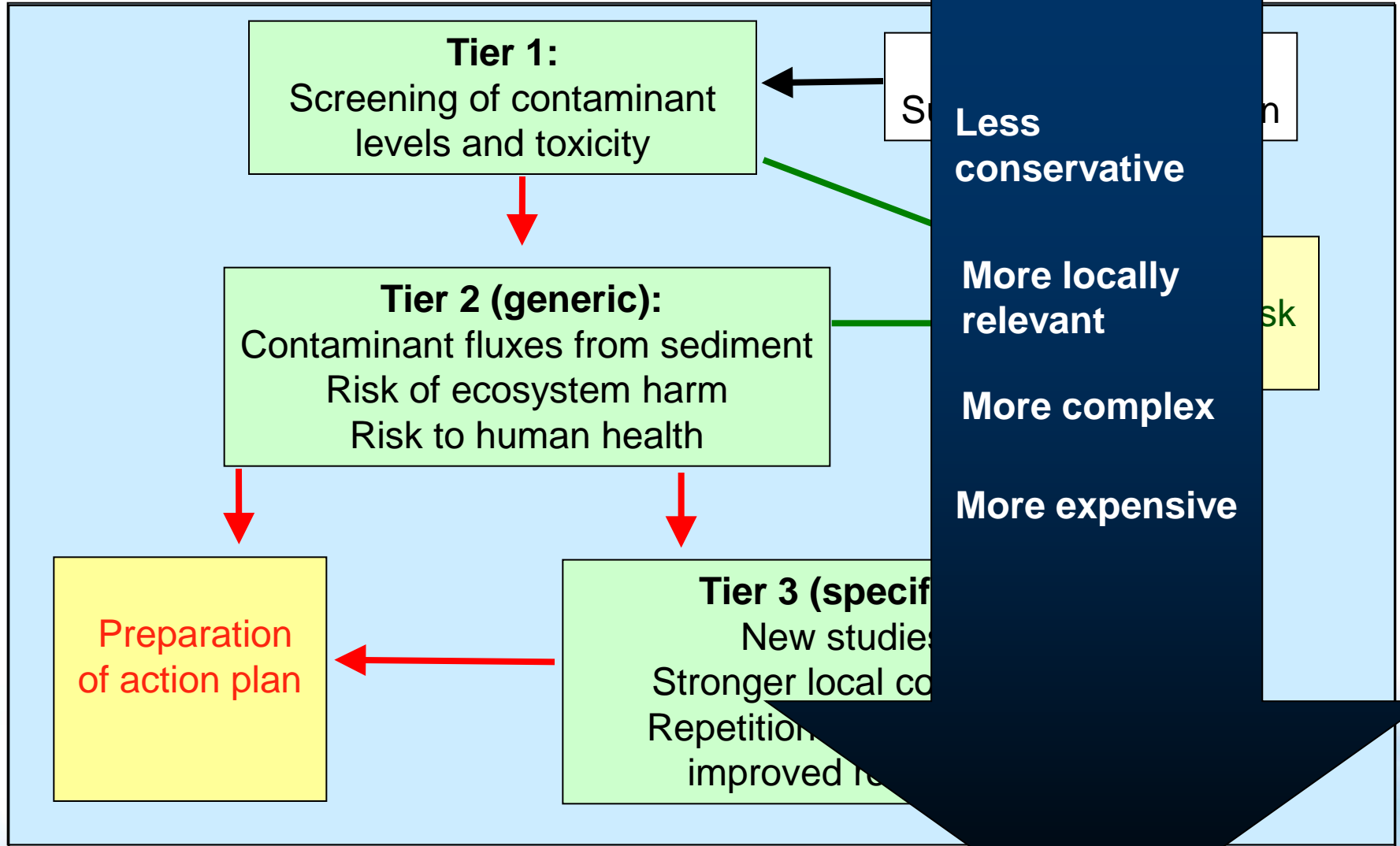
- Governmental White Paper #12. "Together for a non-toxic environment – conditions for a safer future" (2006-2007)
- Sediment contamination shall be reduced to no-effects levels
- A need to consider action plans for the sediments in
 - 17 major fjord regions
 - 10 large public harbours
 - 109 shipyards
- The plans shall be based on risk assessment of the sediments



A national risk assessment guideline for sediments (2007)

- To what extent are the present levels of contaminants in the sediments a risk to the marine environment and human health?
- Ensure harmonized risk assessment procedure for all sediment areas
- EU risk assessment principles adopted when relevant
- Focus on risk contribution from the sediments alone (no other risk sources included)
- Simple to use (spreadsheet basis)
- Regular revisions and improvements
- Close link to the Norwegian environmental quality classification system


Risk assessment guideline structure



Covers 40 contaminant compounds/groups

Tier 1

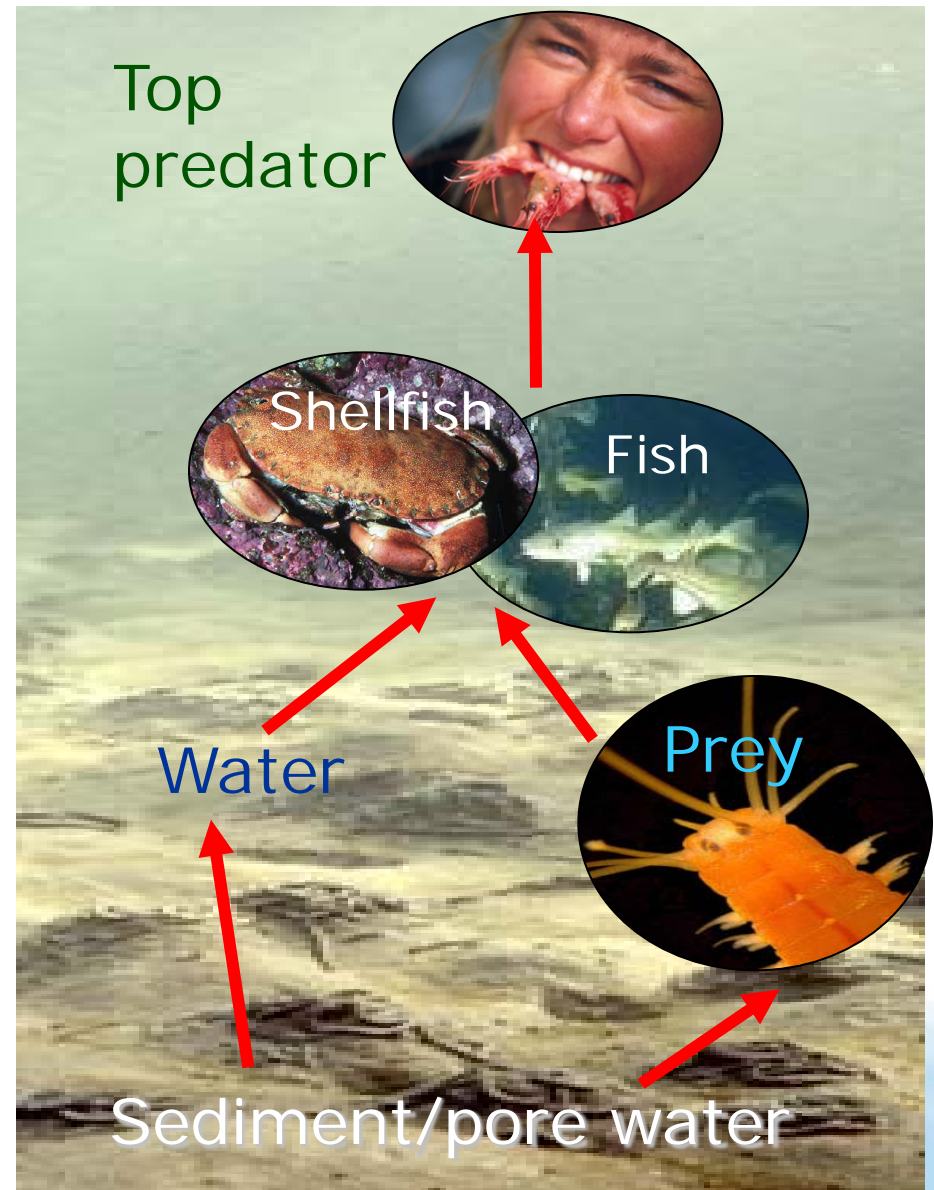
- Screening of contaminant concentrations
- Mandatory set of toxicity tests to account for combined toxicity and compounds not analysed



	Parameters	Classes				
		I Insignificantly polluted	II Moderately polluted	III Markedly polluted	IV Severely polluted	V Extremely polluted
Metals in water	Lead ($\mu\text{g Pb/l}$)	<0.05	0.05-0.15	0.15-0.5	0.5-1	>1
	Cadmium ($\mu\text{g Cd/l}$)	<0.03	0.03-0.07	0.07-0.2	0.2-0.5	>0.5
	Copper ($\mu\text{g Cu/l}$)	<0.3	0.3-0.7	0.7-1.5	1.5-3	>3
	Mercury ($\mu\text{g Hg/l}$)	<0.001*	0.001-0.005	0.005-0.015	0.015-0.03	>0.03
Contaminants in sediments (dry weight)	Lead (mg Pb/kg)	<30	30-120	120-600	600-1500	>1500
	Cadmium (mg Cd/kg)	<0.25	0.25-1	1-5	5-10	>10
	Copper (mg Cu/kg)	<35	35-150	150-700	700-1500	>1500
	Mercury (mg Hg/kg)	<0.15	0.15-0.6	0.6-3	3-5	>5
	Σ PAH ($\mu\text{g/kg}$) ²⁾	<300	300-2000	2000-6000	6000-20000	>20000
	Σ PCB ₇ ($\mu\text{g/kg}$) ⁵⁾	<5	5-25	25-100	100-300	>300

Tier 2

- Contaminants flux estimates
 - Diffusion and bioturbation
 - Resuspension
 - Food chain transfer
- Accepted criteria
 - PNECs/EQS in sediment and water
 - Limits on human intake of contaminants



Output Tier 1

Compound	Levels in sediments mg/kg			Tier 1 EQS (mg/kg)	Exceedance of EQS	
	Antall prøver	Max	Mean		Max	Mean
Arsen	0	mangler	mangler	52		
Bly	3	194	122	83	134 %	47 %
Kadmium	3	0,5	0,366666667	2,6	-81 %	-86 %
Kobber	3	347	238,3333333	51	580 %	367 %
Krom totalt (III + VI)	0	mangler	mangler	560		
Kvikksølv	3	0,67	0,446666667	0,63	6 %	-29 %
Nikkel	0	mangler	mangler	46		
Sink	3	619	396	360	72 %	10 %
Naftalen	3	0,27	0,129	0,29	-7 %	-56 %
Acenaftilen	3	0,03	0,017433333	0,033	-9 %	-47 %
Acenaften	3	0,19	0,096333333	0,16	19 %	-40 %
Fluoren	0	mangler	mangler	0,26		
Fenantren	3	0,87	0,58	0,50	74 %	16 %
Antracen	3	0,28	0,158	0,031	803 %	410 %
Fluoranten	3	1,5	1,016666667	0,17	782 %	498 %
Pyren	3	1,5	0,953333333	0,28	436 %	240 %
Benzo(a)antracen	3	0,77	0,516666667	0,06	1183 %	761 %
Krysen	3	1,1	0,65	0,28	293 %	132 %
Benzo(b)fluoranten	0	mangler	mangler	0,24		
Benzo(k)fluoranten	3	1,1	0,643333333	0,21	424 %	206 %
Benzo(a)pyren	3	0,97	0,616666667	0,42	131 %	47 %
Indeno(1,2,3-cd)pyren	3	0,67	0,486666667	0,047	1326 %	935 %
Dibenzo(a,h)antracen	3	0,23	0,15	0,59	-61 %	-75 %
Benzo(ghi)perylen	3	0,77	0,49	0,021	3567 %	2233 %
Tributyltinn (TBT-ion)	3	18	12,53333333	0,035	51329 %	35710 %

Output Tier 2 Human risk

Compound	Total lifetime exposure mg/kg/d			Limit to human exposure MTR/TDI	Exceedance of limits to human exposure	
	Antall prøver	Max	Mean		Max	Mean
Arsen	0	mangler	mangler	52		
Bly	3	194	122	83	134 %	47 %
Kadmium	3	0,5	0,366666667	2,6	-81 %	-86 %
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Output Tier 2 Ecological risk sediment

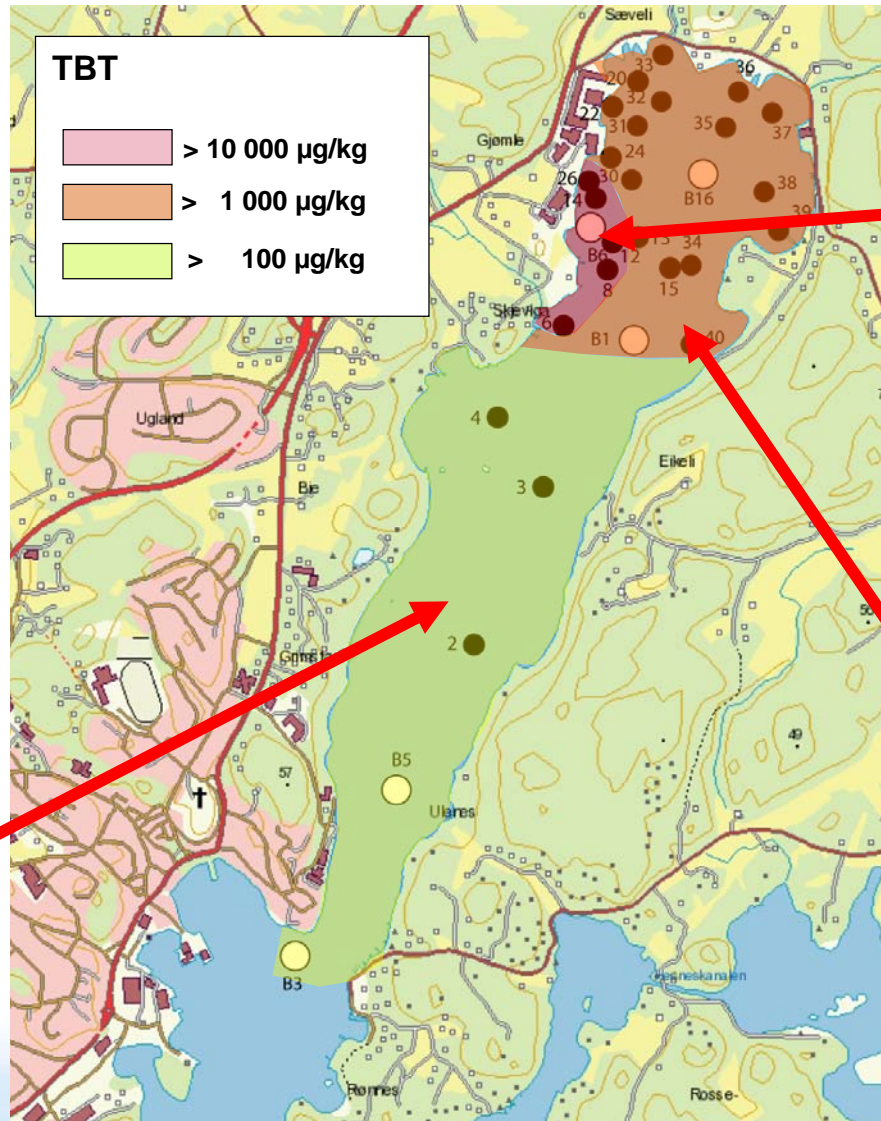
Compound	Pore water concentration mg/l			EQS for water exposure (HC5)	Exceedance of EQS in pore water	
	Antall prøver	Max	Mean		Max	Mean
Arsen	0	mangler	mangler	52		
Bly	3	194	122	83	134 %	47 %
Kadmium	3	0,5	0,366666667	2,6	-81 %	-86 %
Kobber	3	347	238,3333333	51	580 %	367 %
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Tributyltinn (TBT-ion)	3	18	12,53333333	0,035	51329 %	35710 %

Output Tier 2 Ecological risk seawater

Compound	Seawater concentration mg/l			EQS for water exposure (HC5)	Exceedance of EQS in seawater	
	Antall prøver	Max	Mean		Max	Mean
Arsen	0	mangler	mangler	52		
Bly	3	194	122	83	134 %	47 %
Kadmium	3	0,5	0,366666667	2,6	-81 %	-86 %
Kobber	3	347	238,3333333	51	580 %	367 %
Krom totalt (III + VI)	0	mangler	mangler	560		
Kvikksølv	3	0,67	0,446666667	0,63	6 %	-29 %
Nikkel	0	mangler	mangler	46		
Sink	3	619	396	360	72 %	10 %
Naftalen	3	0,27	0,129	0,29	-7 %	-56 %
Acenaftilen	3	0,03	0,017433333	0,033	-9 %	-47 %
Acenaften	3	0,19	0,096333333	0,16	19 %	-40 %
Fluoren	0	mangler	mangler	0,26		
Fenantren	3	0,87	0,58	0,50	74 %	16 %
Antracen	3	0,28	0,158	0,031	803 %	410 %
Fluoranten	3	1,5	1,016666667	0,17	782 %	498 %
Pyren	3	1,5	0,953333333	0,28	436 %	240 %
Benzo(a)antracen	3	0,77	0,516666667	0,06	1183 %	761 %
Krysen	3	1,1	0,65	0,28	293 %	132 %
Benzo(b)fluoranten	0	mangler	mangler	0,24		
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Risk assessment of sub-areas

Predicting risk reduction by selective sub-area remediation



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	Antall prøver	Mean		Max	Mean
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Bly	3	194	122	83	134 %
Kadmium	3	0,6	0,366666667	2,6	47 %
Kobber	3	347	238,3333333	511	387 %
Krom total (III + VI)	0	manngler	manngler	560	
Kvikkesiv	3	0,67	0,446666667	0,63	6 %
Nikkel	0	manngler	manngler	46	
Sink	3	619	386	360	72 %
Nitrosen	3	0,27	0,129	0,29	-7 %
Arsenathalen	3	0,03	0,017433333	0,033	-9 %
Kvinnathalen	3	0,19	0,096333333	0,18	-19 %
Fluoren	0	manngler	manngler	0,26	
Finanthen	3	0,87	0,59	0,50	74 %
Arsen	3	0,28	0,168	0,031	893 %
Fluoranten	3	1,5	1,016666667	0,17	782 %
Pyren	3	1,5	0,933333333	0,28	436 %
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Triakylten (TBT-sum)	3	18	12,53333333	0,036	81329 %

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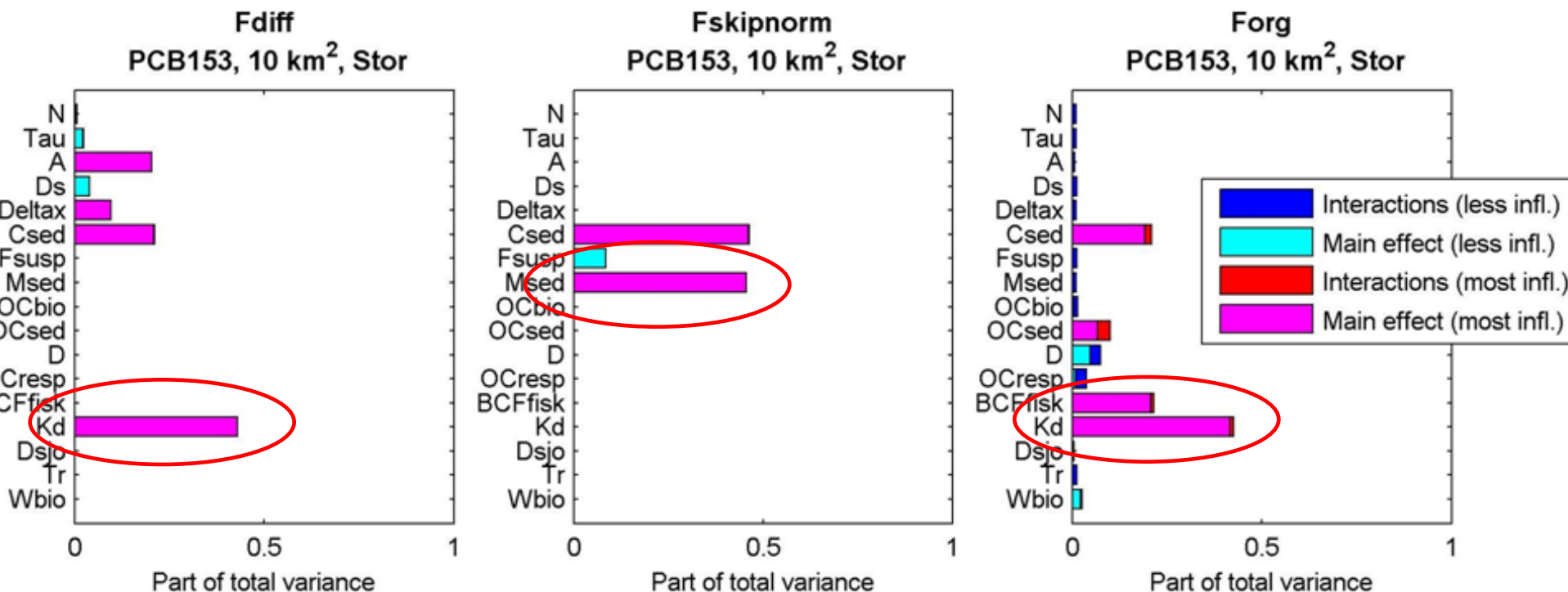
Tier 3

- Improve reliability of Tier 2 through local measurements
 - Replace generic flux estimate coefficients with locally measured values
 - Measurement of pore water contaminants
 - Contaminant flux measurements
 - Contamination in sediment fauna
 - Contaminants in local seafood
 - Harvest and typical consumption of local seafood
 - Ecological condition of the sediment fauna
 - Numerical modelling of food chain transport

Most influential parameters for Tier 2

- Sensitivity analysis on 27 scenarios
 - 3 contaminants x 3 sediment areas x 3 harbour types
- 100 000 model runs for each scenario varying all parameters within their likely range

Saloranta et al in press



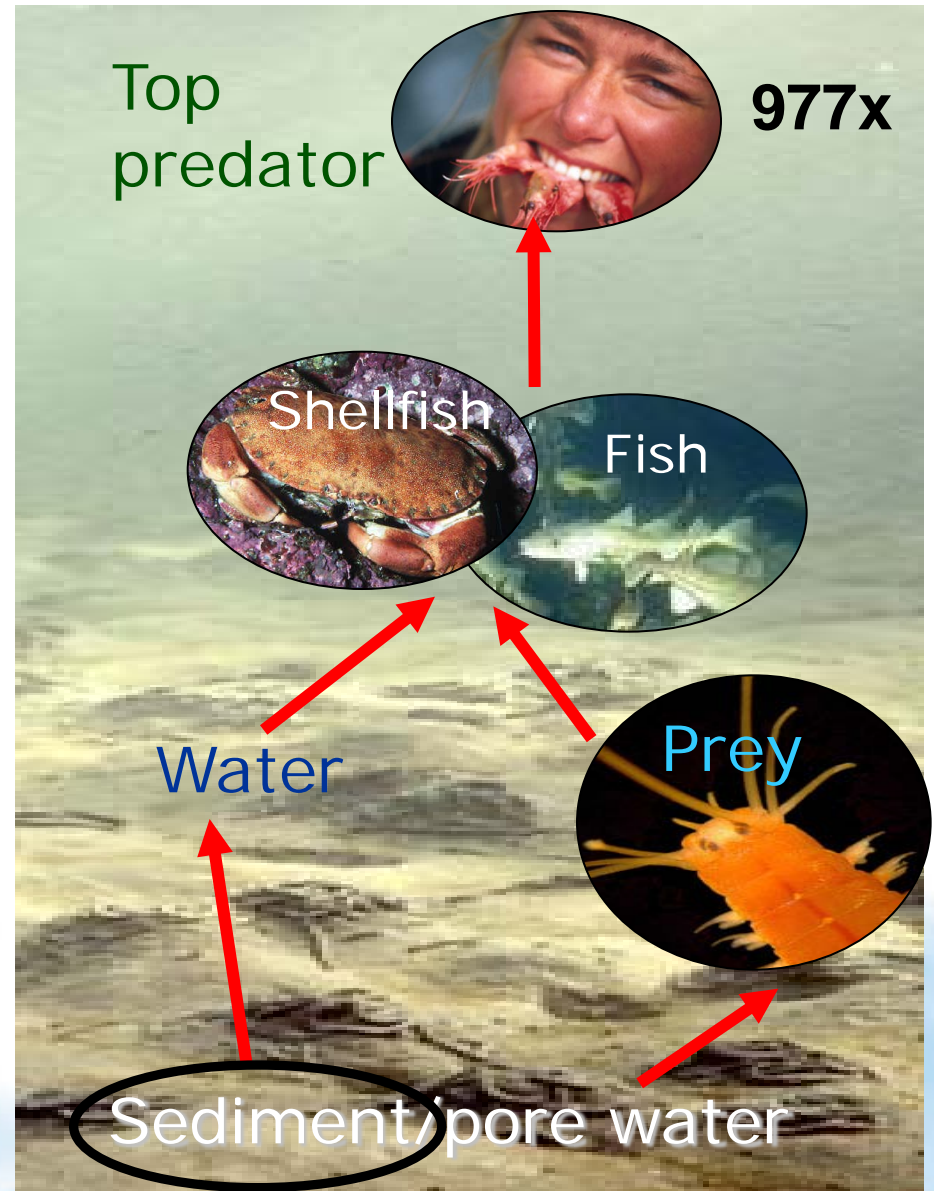
Most influential parameters

- These factors provide the largest uncertainty in the risk estimates:
 - Partitioning coefficients K_d :
sediment/pore water
 - Bioconcentration factors BCF:
water/organisms
 - Amount of sediment resuspended by ships
 - Bioturbation factor (how bioturbation facilitates diffusion)

Effect of Tier 3 – an example using TBT

Exceedance of human health MTR/DTI for TBT in a ship yard sediment

Tier 2: Generic estimate

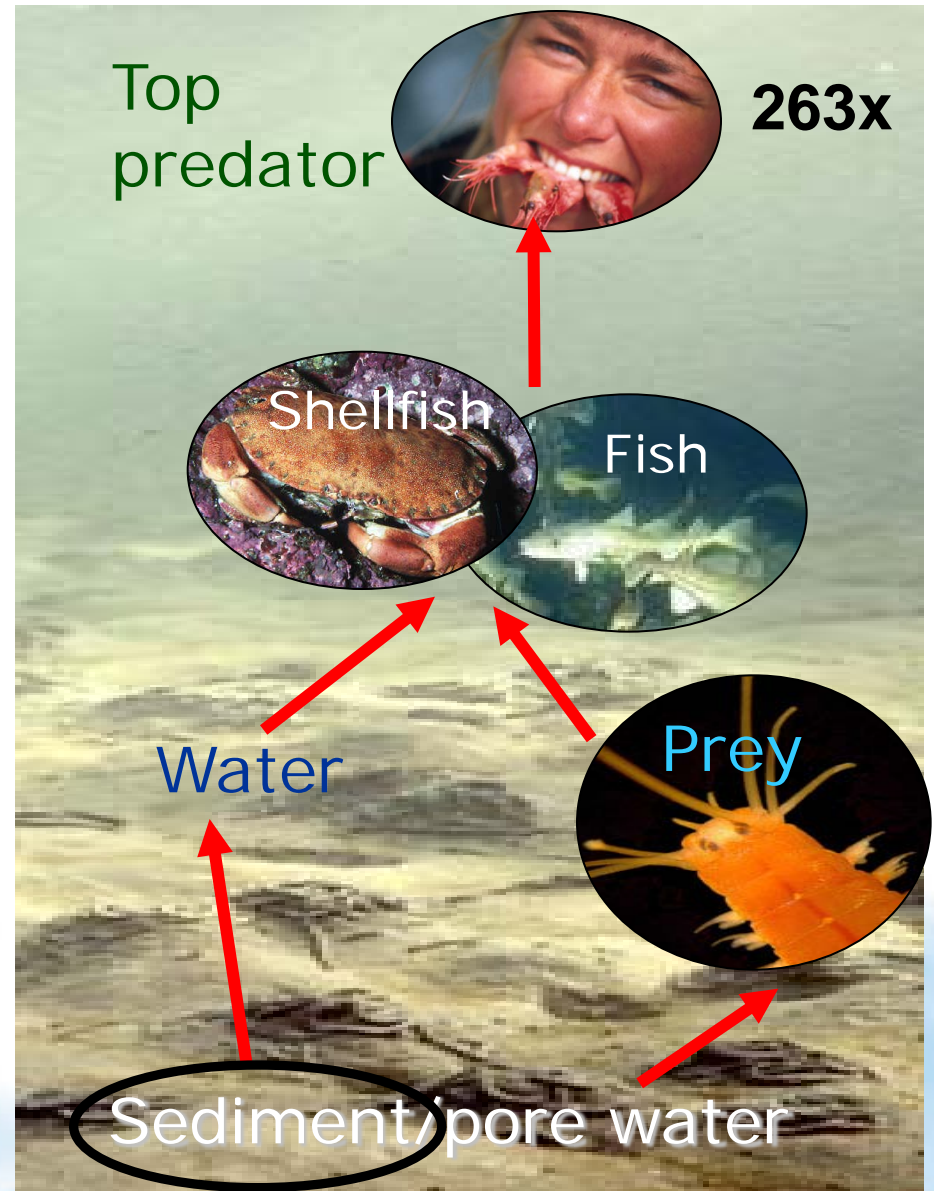


Effect of Tier 3 – an example using TBT

Exceedance of human health MTR/DTI for TBT in a ship yard sediment

Adjusted for local TOC

Tier 2: Generic estimate



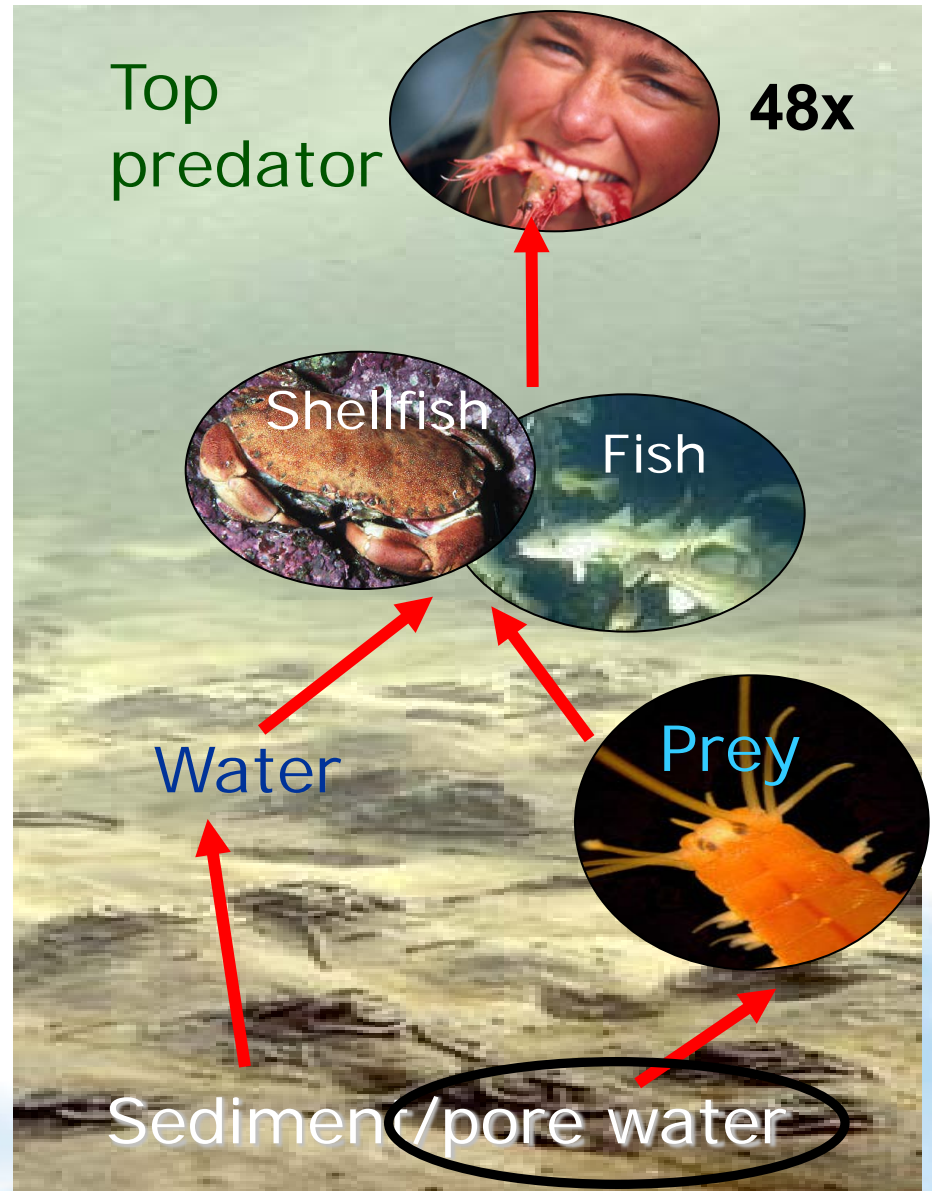
Effect of Tier 3 – an example using TBT

Exceedance of human health MTR/DTI for TBT in a ship yard sediment

TBT in porewater measured

Adjusted for local TOC

Tier 2: Generic estimate



Effect of Tier 3 – an example using TBT

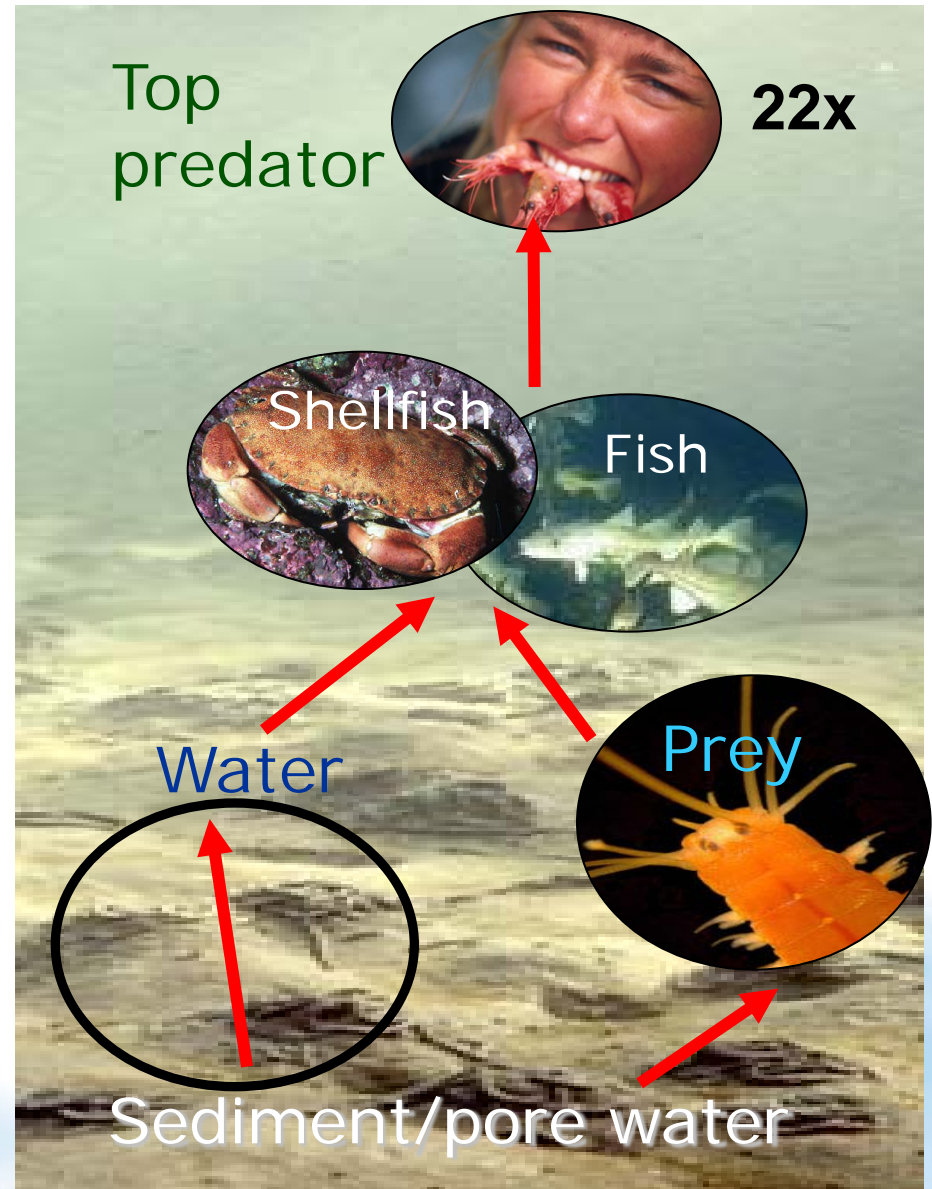
Exceedance of human health MTR/DTI for TBT in a ship yard sediment

Direct flux measurement

TBT in porewater measured

Adjusted for local TOC

Tier 2: Generic estimate



Effect of Tier 3 – an example using TBT

Exceedance of human health MTR/DTI for TBT in a ship yard sediment

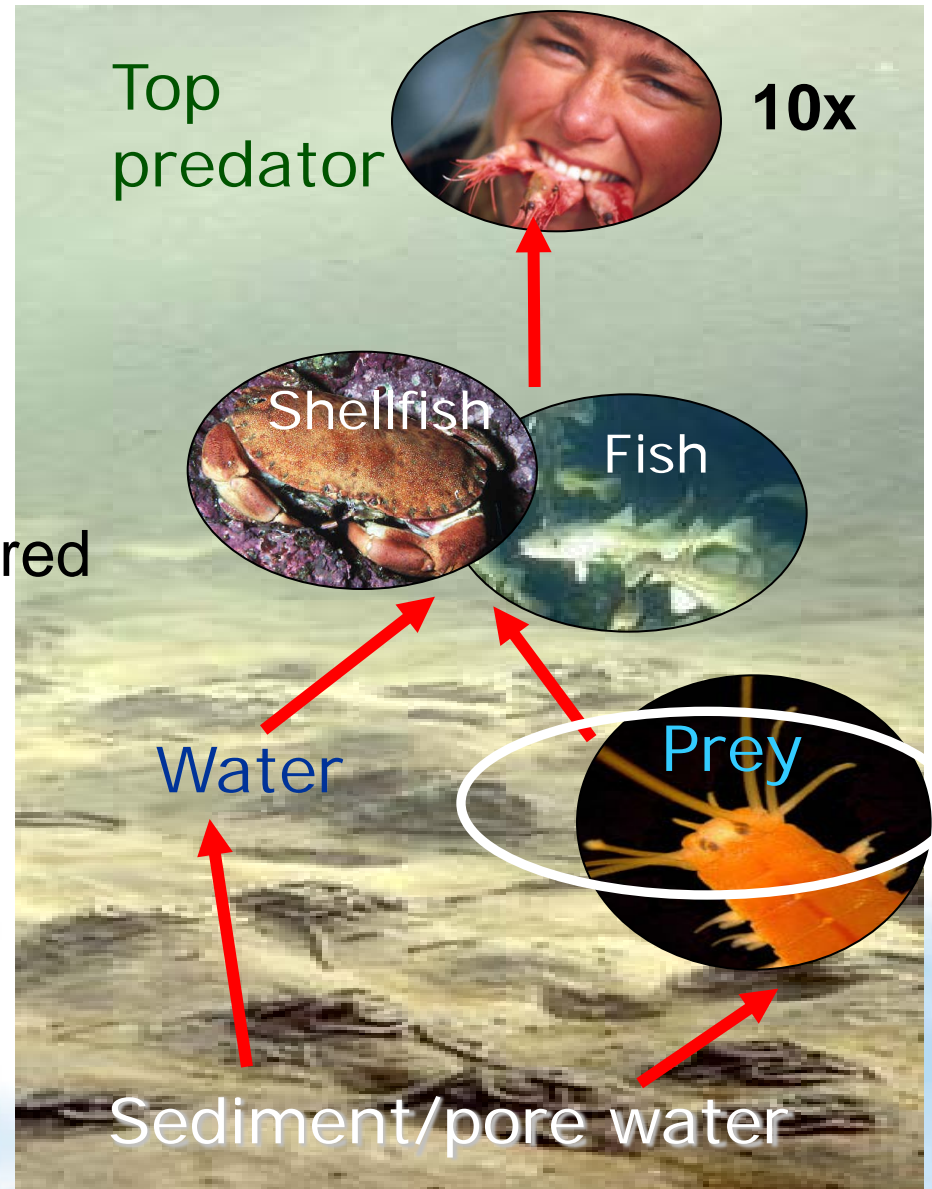
TBT in sediment fauna measured

Direct flux measurement

TBT in porewater measured

Adjusted for local TOC

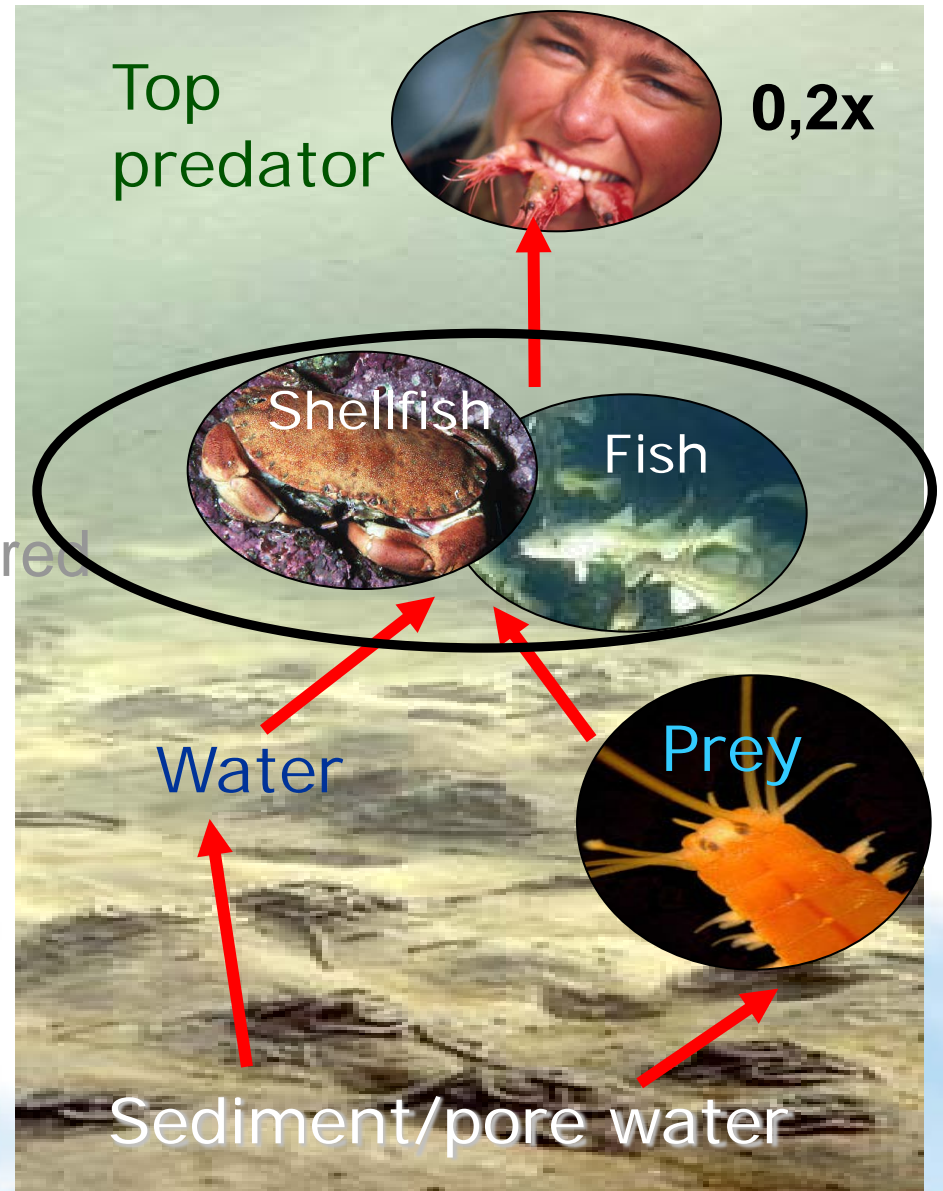
Tier 2: Generic estimate



Effect of Tier 3 – an example using TBT

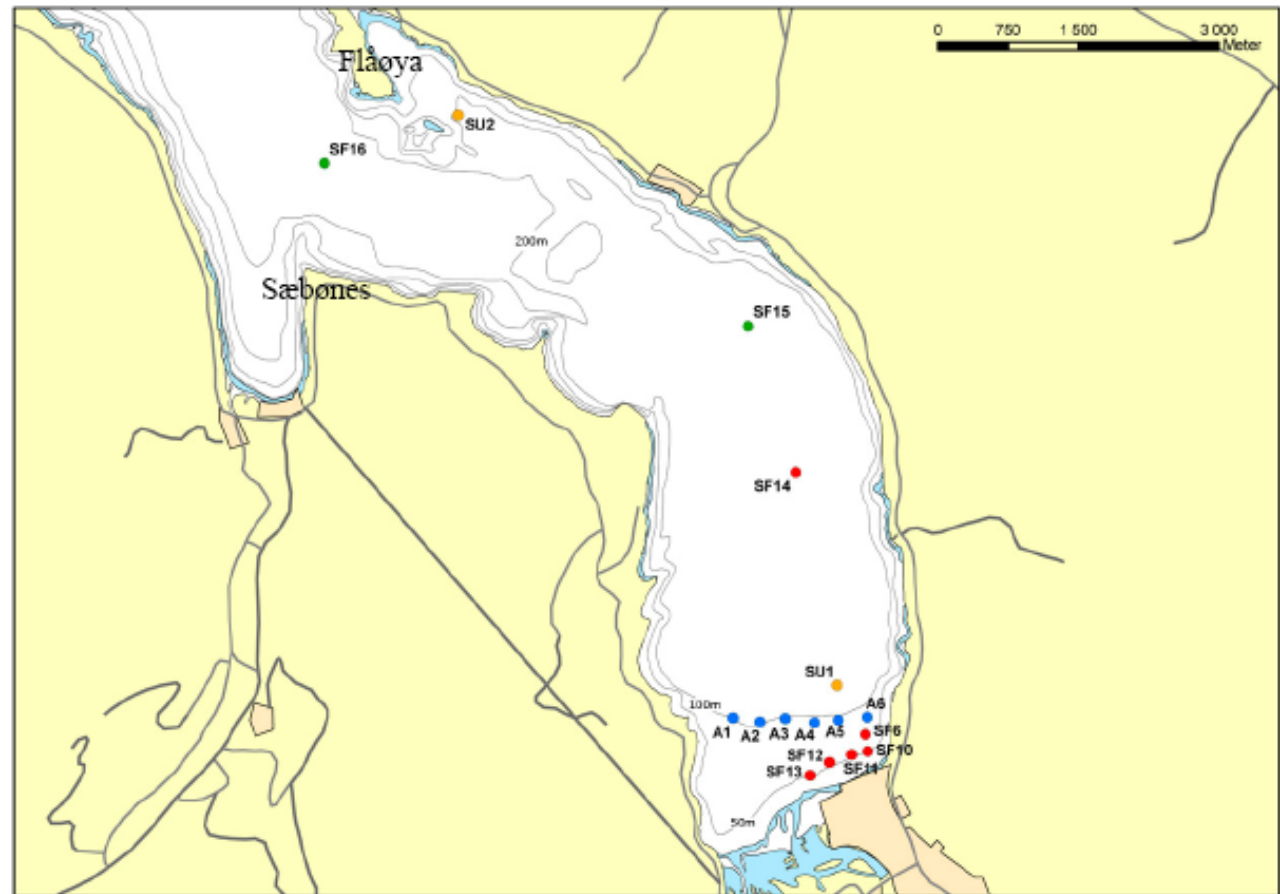
Exceedance of human health MTR/DTI for TBT in a ship yard sediment

- TBT in seafood measured
- TBT in sediment fauna measured
- Direct flux measurement
- TBT in porewater measured
- Adjusted for local TOC
- Tier 2: Generic estimate



Most important future improvements

- Resuspension of propellers
 - Estimate of resuspension
 - Function of movement
- Definition of parameters to be assessed
- Effect of bioturbation and diffusive flux
- How to account for resedimentation



Figur 1. Kart som viser stasjonsplassering og stasjonsnummer for sedimentprøvetakingen ved Hydro Aluminium Sunndal. Stasjoner merket A er ikke prøvetatt for sedimenter.