Revegetation as a tool for risk containment of heavy metal polluted sites

Jan Japenga[1], Rafal Kucharski[2] & Ola Sas-Novosielska[2]

1: Soil Science Centre
ALTERRA Green World Research, Wageningen University and Research
P.O. Box 47, 6700 AA Wageningen, The Netherlands
e-mail: jan.japenga@wur.nl
2: Institute for Ecology of Industrial Areas (IETU),
Katowice, Poland
e-mail: sas@ietu.katowice.pl

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Background

- All over the world extended sites exist with extremely high heavy metal contents in the soil
- Many of these sites are unable to sustain vegetation
- The sites may cause direct effects on human health and ecosystems, through leaching, erosion etc.
- Complete clean-up of the sites is generally no viable option

IS REVEGETAION A SOLUTION ?

Objectives (I)

To assess the viability of revegetation of heavy metal polluted sites, focusing on verifiable "critical success factors"

Objectives (II)

To develop a Decision Support System to quantify revegetation benefits in comparison with other soil remediation options

Presentation outline

I Mesocosm and field experiments carried out in Katowice, Poland

Critical success factors
Research results
Conclusions

II The Decision Support System (DSS)

General structure
Revegetation in the DSS
Output

General conclusions

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- *a Critical success factors*
- *b Research results*
- *c Conclusions*

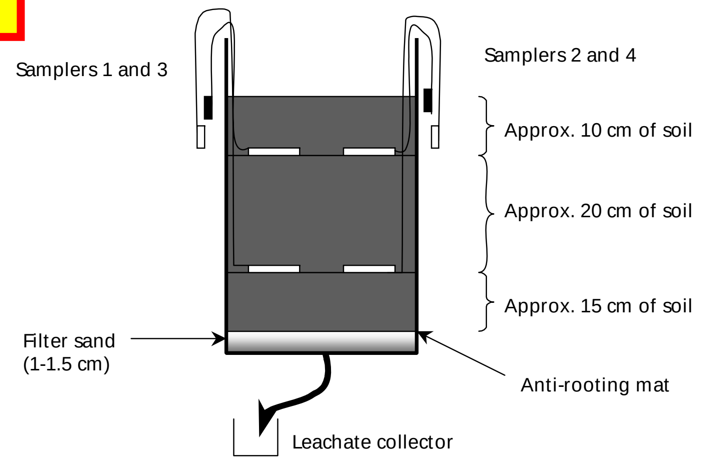
II The Decision Support System (DSS)

- *a General structure*
- *b Revegetation subroutines*
- *c Output*

General conclusions

Katowice- mesocosm experiments

Mesocosm set-up at Katowice



Monitored heavy metals:

Zinc	1.3%
Cadmium	0.05%
Lead	0.9%
Arsenic	0.02%

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Katowice – mesocosm experiments

Additives tested

- TSP 5%
- TSP 2.5% + lignite 10%

Plant species tested (focusing on **local wild species**)

- *Cardaminopsis arenosa* (marginally growing at the site)
- *Deschampsia cespitosa* (marginally growing at the site)
- Mixture of all three locally observed species in naturally found ratios (20% *Silene inflata*, 40% *Cardaminopsis arenosa*, 40% *Deschampsia cespitosa*).
- *Salix purpurea* (potential energy crop)

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Katowice – field tests

Additives tested

- TSP 5% in upper 20 cm
- TSP 2.5% + lignite 10% in upper 20 cm

Plant species tested

- *Deschampsia cespitosa* (marginally growing at the site)
- *Salix purpurea* (potential energy crop)

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Katowice – critical succes factors

- Effects on heavy metal <u>leaching</u> rates
- Effects on wind and water **<u>erosion</u>** rates; vegetation cover and root density
- Risks of food chain contamination and soil <u>ecosystem risks</u>

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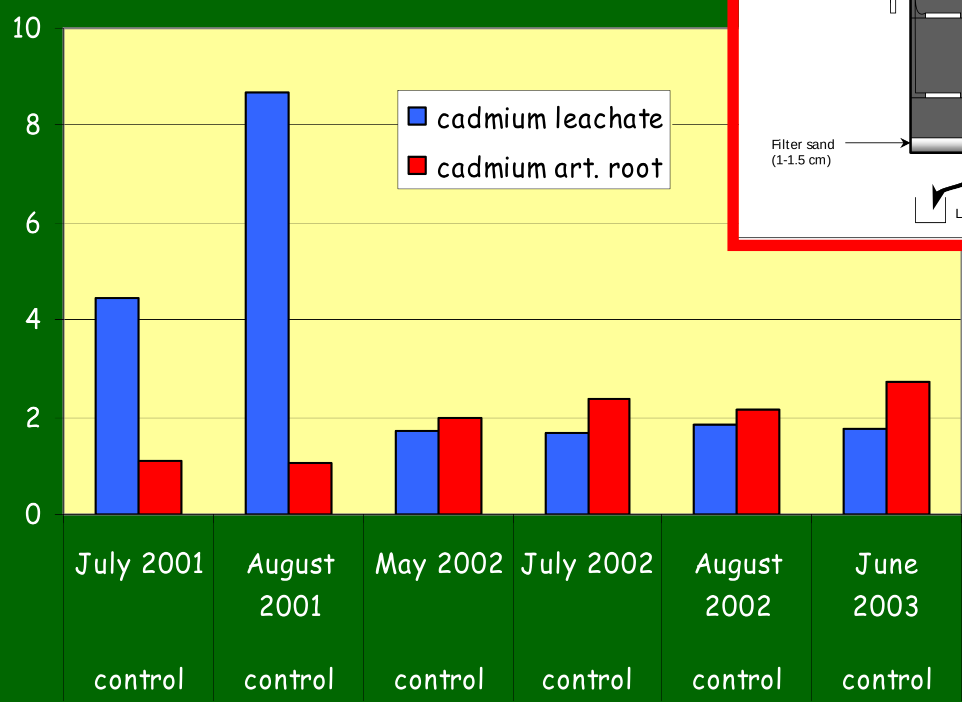
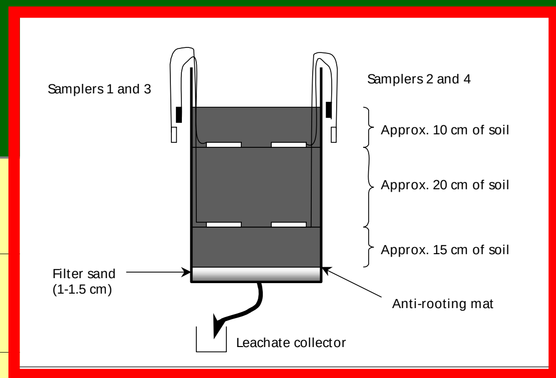
Katowice - mesocosm leaching

Leaching behaviour during 2 years of experiments





Stable after one year mesocosm functioning

Concentrations in leachates and pore water are the same

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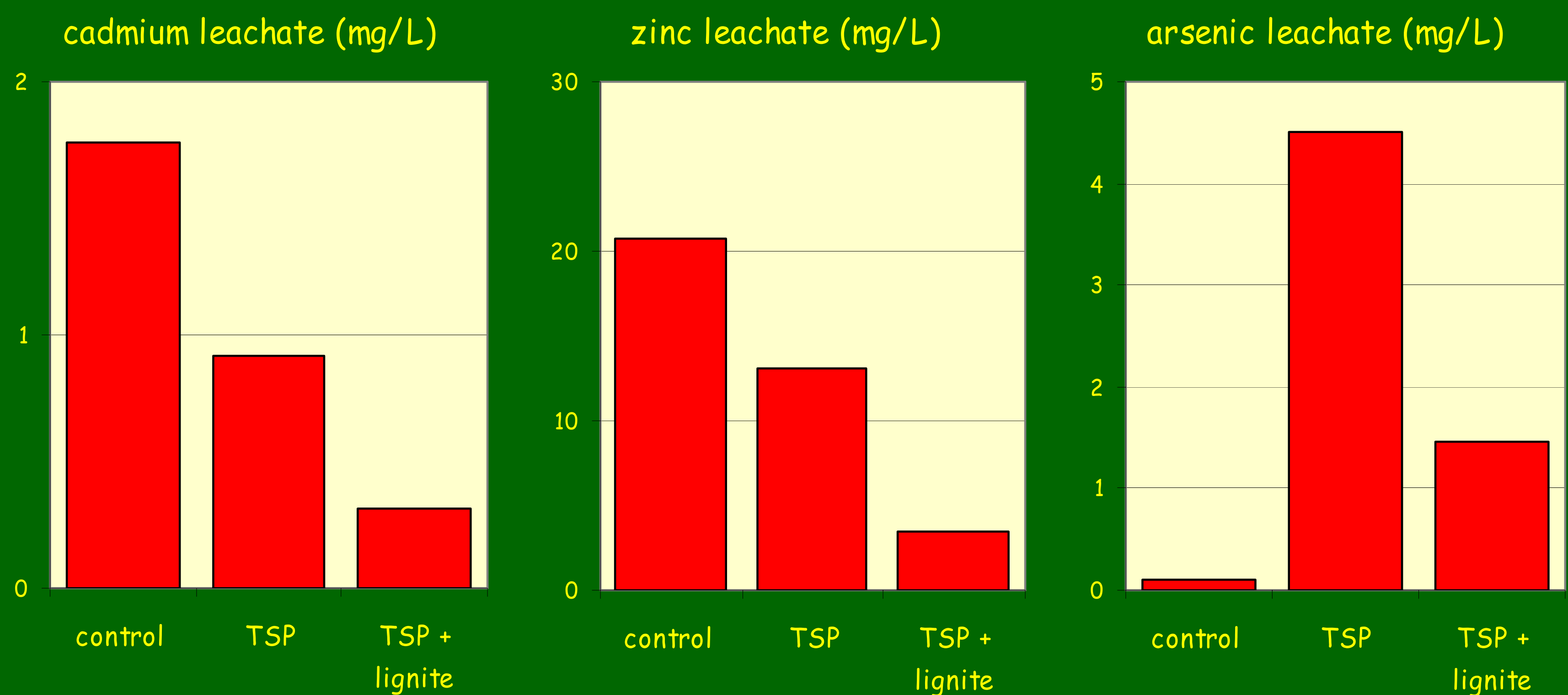
Katowice – mesocosm leaching



Additives reduce heavy metal concentrations in leachates for Cd and Zn, but not for As

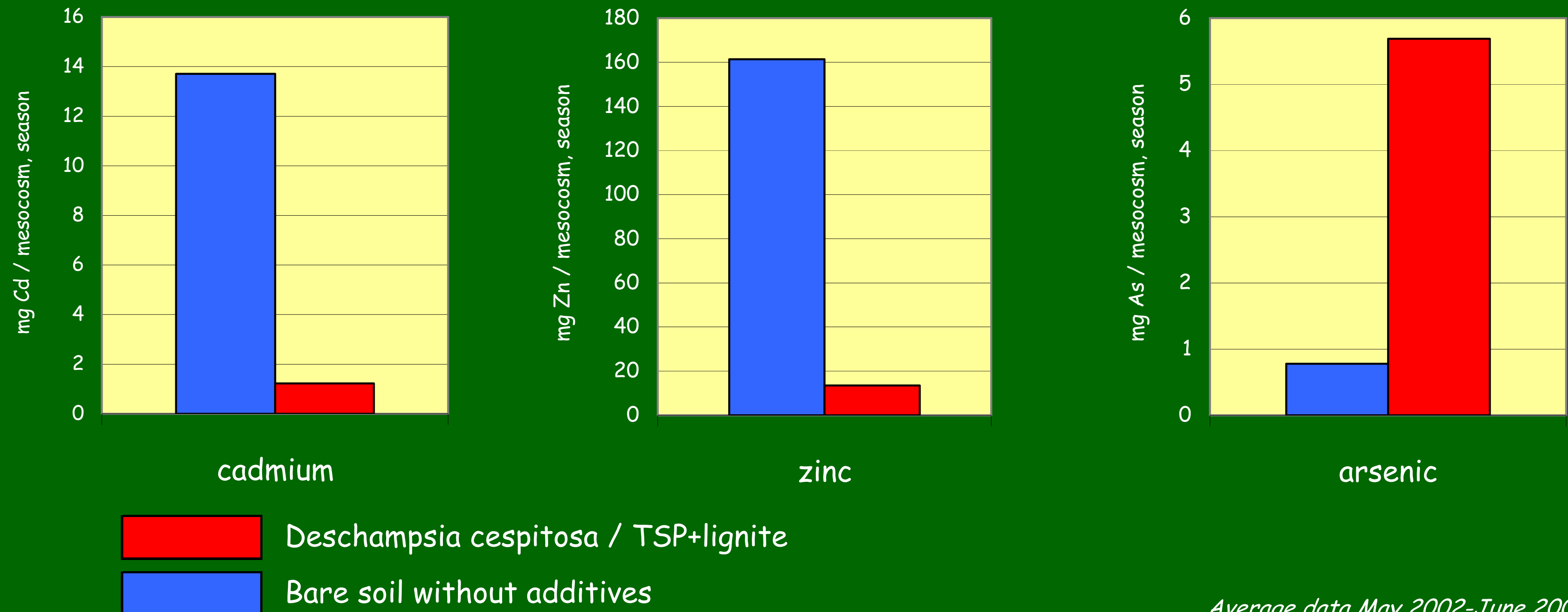
Average data May 2002-June 2003

Katowice – mesocosm leaching

Influence of vegetation cover on leaching rates

Leachate volumes:

Bare soil:	7.8 L/season
Deschampsia cespitosa	3.9 L/season



Average data May 2002-June 2003

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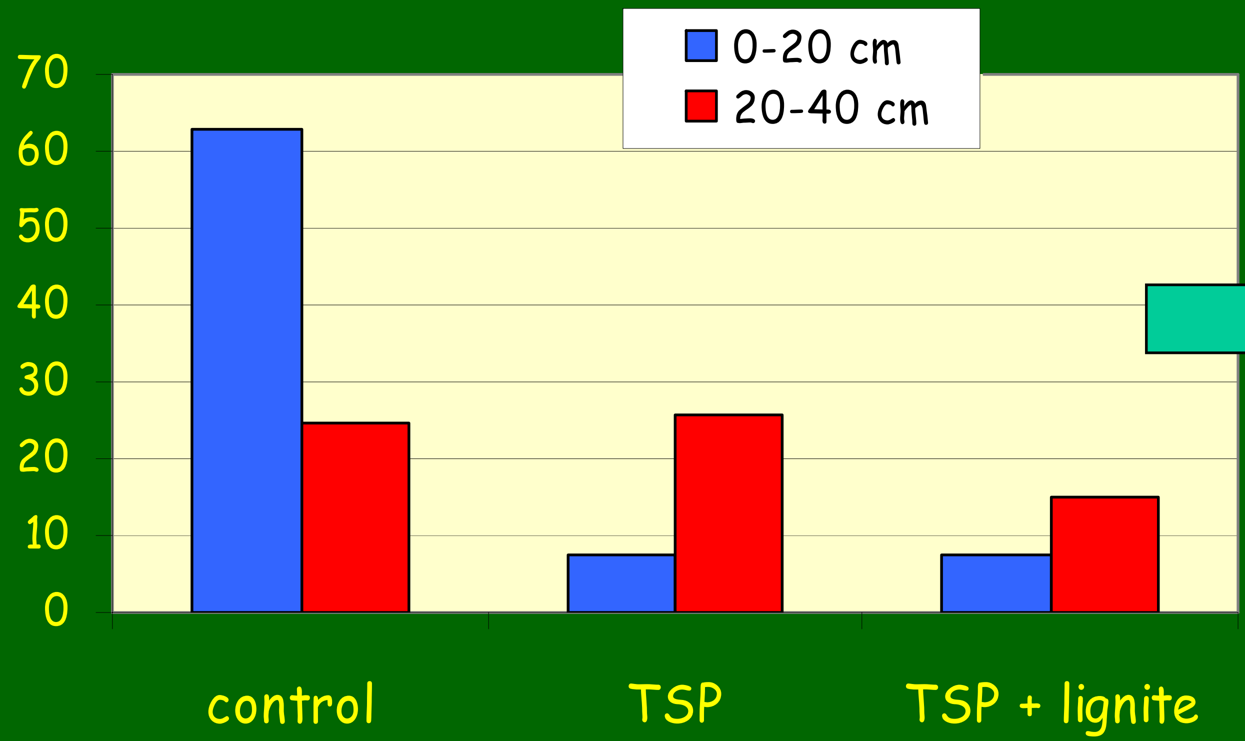
Katowice – field site leaching

Influence of vegetation cover on “available” cadmium concentration (0.01 M $CaCl_2$ extraction, mg/kg) at different depths



Leaching rates in the field higher than in the mesocosms

Data March 2004

Katowice – leaching conclusions

The combination of TSP (+ lignite) and vegetation reduces leaching rates for Cd, Zn & Pb by around 10 times.

Leaching rates of As are increased 5-fold due to P-As competition.

Katowice – critical succes factors

- Effects on heavy metal leaching rates
- Effects on wind and water **erosion** rates; vegetation cover and root density
- Risks of food chain contamination and soil ecosystem risks

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Katowice – critical succes factors

- Effects on wind and water erosion rates; vegetation cover and root density

  - ✓ Dry matter production
  - ✓ Root density/distribution

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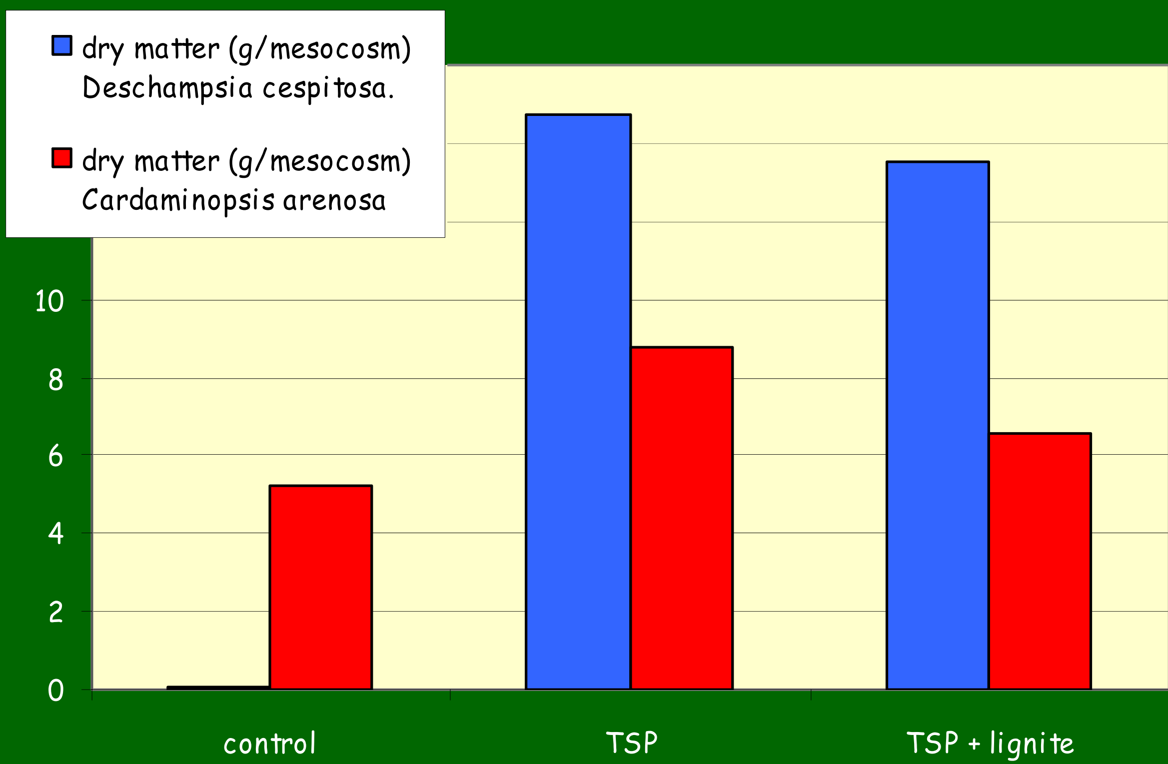
Katowice – mesocosm vegetation

Dry matter production after stabilisation of the mesocosms



Deschampsia c. favored over *Cardaminopsis a.* in additive-amended mesocosms

Additives increase vegetation cover.

Data summer 2003

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Katowice - field site vegetation

general overview summer 2003

Deschampsia grows well

Salix shows very marginal growth

Katowice – field site vegetation

Root density / distribution measurements

"Fakir bed" technique

healthy roots

deep rooting

Katowice –vegetation conclusion

Deschampsia cespitosa effectively revegetates the site, but only when immobilising agents are added.

Effects are proven sustainable for at least 2-3 years. Experiments continue.

Katowice - critical succes factors

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Katowice – critical succes factors

- Risks of food chain contamination and soil <u>ecosystem risks</u>
  - ✓ Heavy metals in vegetation
  - ✓ Soil life interaction

Katowice – food-chain contamination

Heavy metals in vegetation mg/kg dry matter

		As	Zn	Pb	Cd
Cardaminopsis mesocosm	control	5.1	10105	800	1086
	TSP	6.9	954	126	89
	TSP + lignite	11.5	1384	245	83

hyperaccumulator

		As	Zn	Pb	Cd
Deschampsia mesocosm	control	n.d.	n.d.	n.d.	n.d.
	TSP	4.8	295	98	16.2
	TSP + lignite	3.8	418	92	12.6

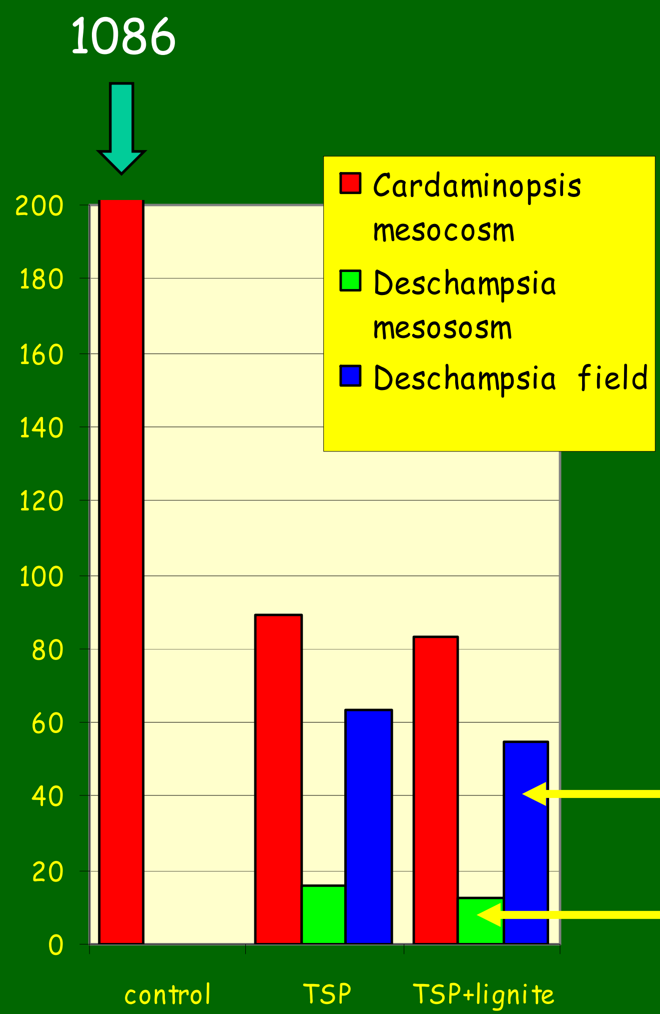
		As	Zn	Pb	Cd
Deschampsia field	control	n.d.	n.d.	n.d.	n.d.
	TSP	n.d.	1108	648	64
	TSP + lignite	n.d.	1077	564	55

Additive only in upper layer at field site

Data summer 2003

Katowice – food-chain contamination

Heavy metals in vegetation



Deschampsia:
Field site cadmium concentrations higher because roots penetrate unamended layers

field

mesocosm

Data summer 2003

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Katowice – food-chain contamination - conclusions

Deschampsia cespitosa in combination with soil additives gives good vegetation covers with low heavy metal contents in the plant shoot.

Arsenic contents in the vegetation are quite low.

Deschampsia cespitosa wins the competition with *Cardaminopsis arenosa*, which reduces the food-chain contamination.

Heavy metal uptake under field conditions is higher than in mesocosms (only upper soil layer treated with additives).

Katowice – soil life effects

Experimental set up

Pot experiments, comparing Katowice soil (+5% TSP) non-vegetated and vegetated (*Deschampsia cespitosa*).

Measurements after one year equilibration.

Katowice – soil life effects

Results:

- Bacterial numbers were low (around 2 million per gram soil) in both vegetated and non-vegetated soil
- Bacterial growth rates were 25-30 times higher in vegetated soils (both leucine and thymidine data)
- Nematode numbers increased 25-fold, but mainly rhizosphere bacterivores which did not colonize the bulk soil (verified by separate rhizosphere analysis)

Katowice – soil life effects conclusion

Effects of vegetation on soil life are restricted to the rhizosphere.

Data summer 2003

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DSS - decision making process

the soil pollution problem is detected

the need to solve the problem is recognised

site characteristics are determined

a set of potential solutions is defined

merits of potential solutions are quantified = **DSS**

output

stakeholder bargaining leads to decision

remediation project is carried out and evaluated

DSS - general aspects of the REC-approach

Site input data

Remediation technology input data

DSS

Factors:

- **Risk reduction**
- **Environmental merit**
- **Costs**

risk reduction index

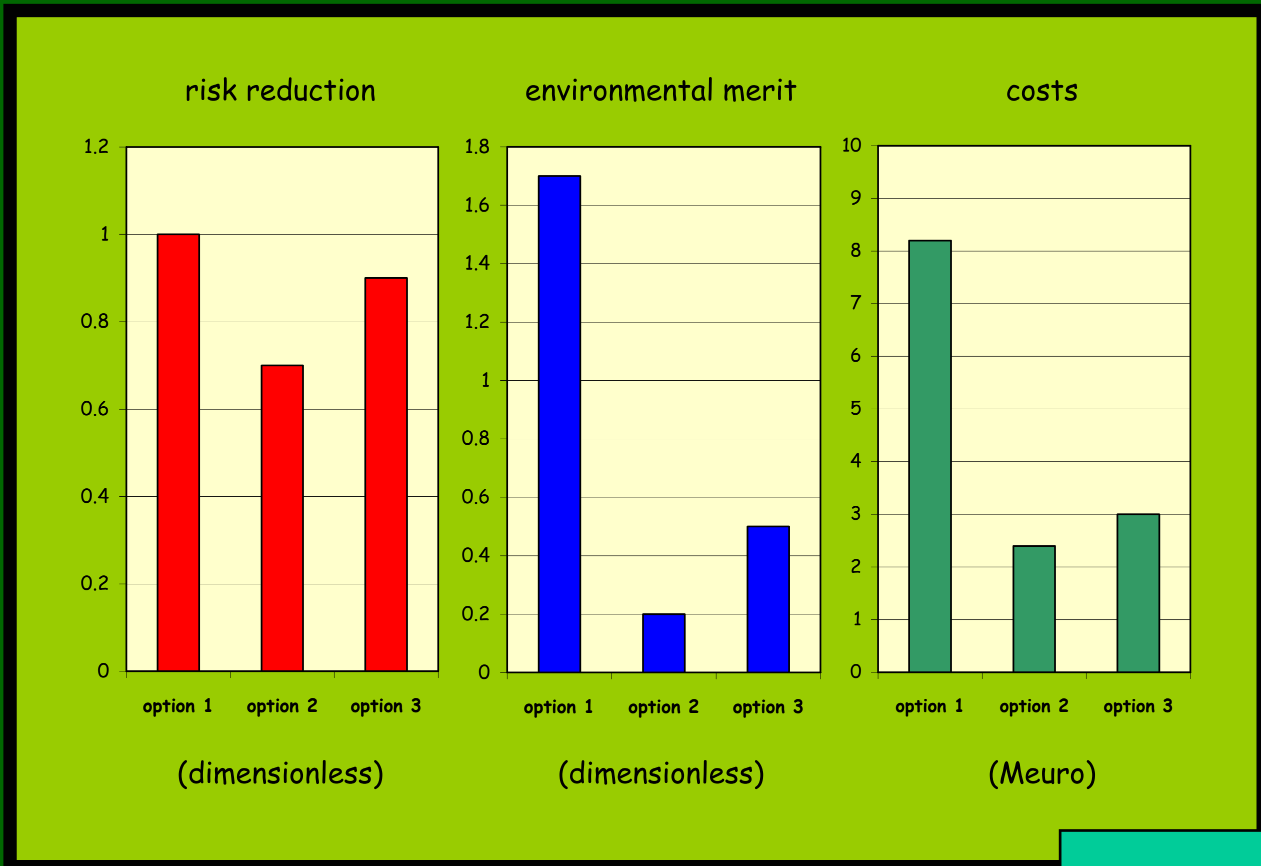
environmental merit index

costs index

general index

DECISION MAKING

DSS – comparison between scenarios



DECISION

Option 1: rich man's choice
Option 3: poor man's choice

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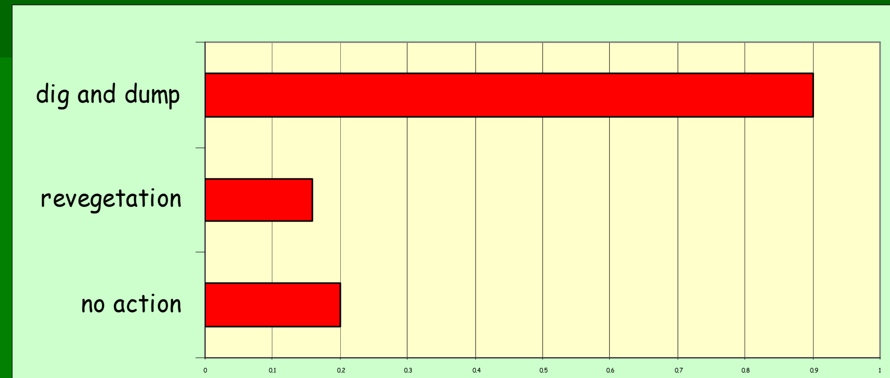
DSS – risk reduction

Comparison of remediation options:

1. dig and dump
2. no action
3. revegetation



- Leaching –
  lower leaching rates after revegetation
- Direct human uptake of polluted soil – decreased after revegetation
- Risks of “food-chain contamination” – increased (?) after revegetation

Land use important for risk estimation !

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DSS – environmental merits

Environmental merits (negative or positive) include:

- production of clean soil/water
- production of polluted soil/water
- energy use
- use of water

DSS - environmental merits

Comparison of remediation options:

1. dig and dump
2. no action
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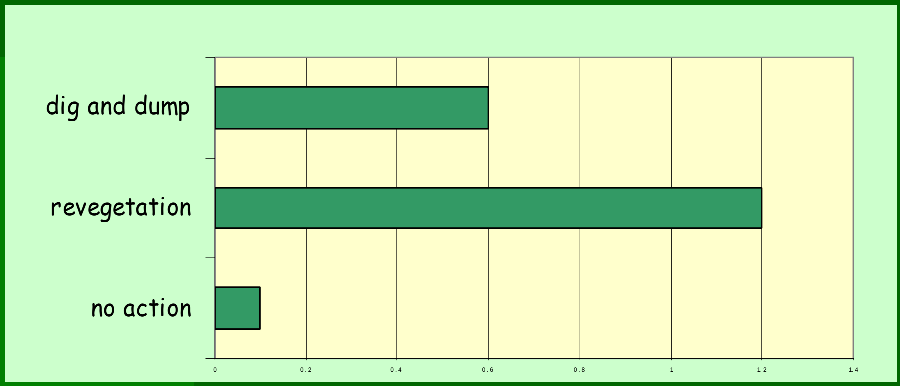

- Leaching/erosion - produced polluted soil and water reduced after revegetation

Leaching and erosion (wind/water) calculated by a simple erosion model

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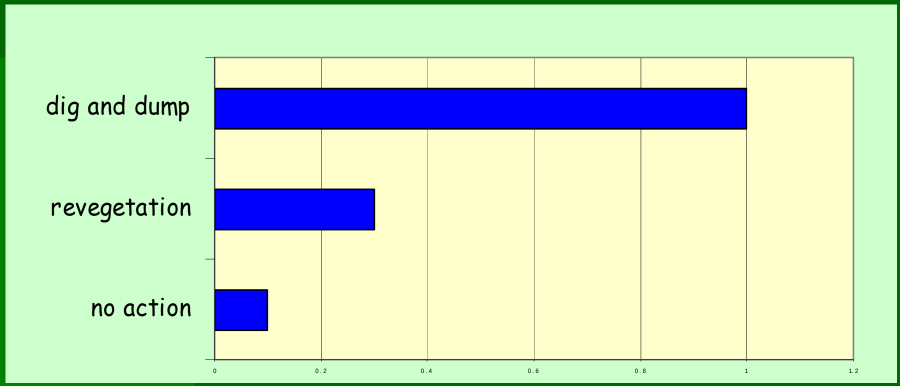
DSS – costs

Comparison of remediation options:

1. dig and dump
2. no action
3. revegetation



- ➢ Dig and dump by far the most expensive

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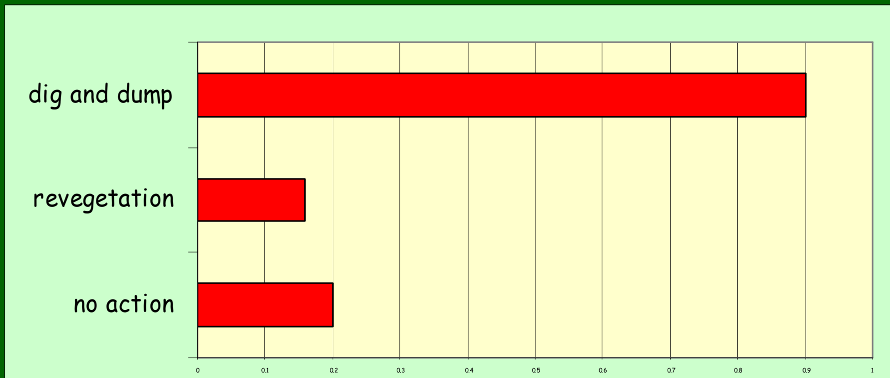
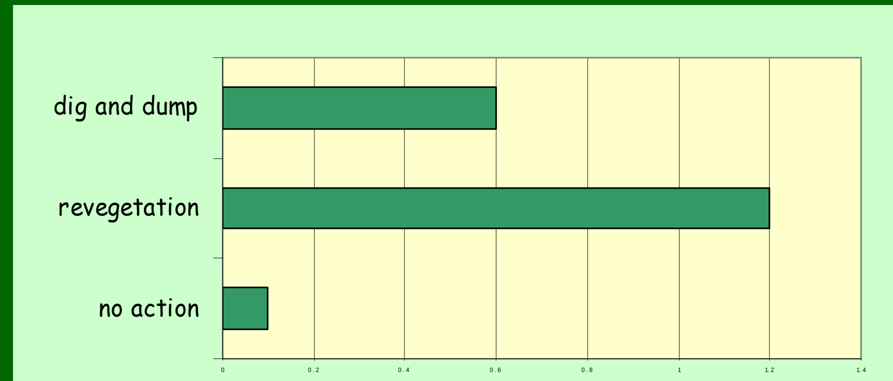
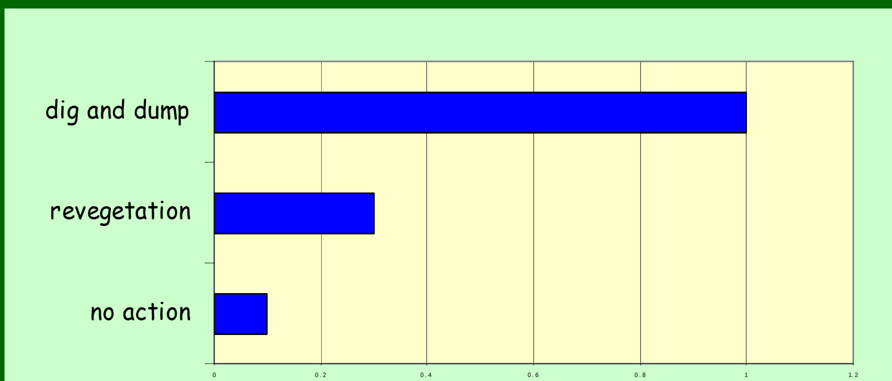
DSS - REC



Risk reduction



Environmental merits



Costs

Decision making depends on:

- Local exposure rates (land use)
- Vulnerability of adjacent areas
- Capital disponibility
- Soil economical value

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General conclusion

Revegetation is a viable option to decrease transport of heavy metals through wind/water erosion and leaching

Revegetation does not reduce the risks at the sites, but only at adjacent sites

Revegetation is a cost-effective option, whenever sustainability is assured

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