Methods for and aspects of ecological risk assessment

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Risk assessment process

Problem formulation

- Hazard analysis
- Object(s) of protection
- Site description (ecology)
- Boundary definition

Contamination situation:
- which contaminants
- amounts
- concentration
- leachability

Analysis

- Transport in the environment
  - flows to recipients
  - concentrations in recipients

- Exposure assessment
  - uptake
  - bioavailability

- Effects assessment
  - individuals
  - populations
  - communities/ecosystems

Risk evaluation

- What are the environmental effects?
- Are the effects acceptable?
- Type and severity of risk
- Distribution of risk (time and space)

POLICY

- e.g. level of protection
Level of detail

What is the problem?

Can some parts of the problem be ‘written off’?

About the problem?

Exactly how big is the problem?
Potential Receptors and Exposure Pathways of Contaminated Soil

Decomposers

1° consumers

2° consumers
Aquatic ecosystems
Contaminated land and recipients

Direct

Surface water
What are we trying to protect?

Depends on the aim of the assessment

Endpoints

- **Assessment:** Quantitative or quantifiable expression of the environmental value considered to be at risk in a risk assessment.

- **Measurement:** A change in an attribute of an assessment endpoint or its surrogate in response to a stressor to which it is exposed.

Two approaches – which determine how the risk assessment is structured
Ecosystems are not more complex than we think

They are more complex than we can think*

*Egler 1979
Approach 1

It is difficult to identify “critical” effects for an ecosystem **BUT**:

- A serious risk to the environment = a serious risk to ecosystem function(s)
- If most of the species of organisms in the ecosystem are protected, the ecosystem functions will also be protected (Conversley, ecosystem functions are threatened if the species composition is seriously disturbed)
- Risk to the environment can be described as the probability that more than a certain fraction of the species in the environment are harmed by contaminants
- Protection of species at the population level
- Data from ecotoxicological effects tests - statistical distribution
Approach 1 - SSD

Ecotox tests
NOEC
LOEC

Statistical model

Tolerable risk

Hazardous Concentration
Approach 1 - “special cases”

Bioaccumulating contaminants
- Toxic reference value (intake in mg/kg body weight)
- Exposure model with BCF, eg. soil, plant, herbivore, carnivore

Process data (carbon and nutrient turnover, enzymes)
- As a “check” on SSD
- Integrated with other data into one SSD
Approach 2

- Identify critical organism (e.g., threatened species)
- Assess exposure
- Assess exposure/effect relationship
- Evaluate effects
- Advantage – easier to communicate

Lab tests

Effects matrix

Ecosystem model

Monte-Carlo simulations

Environmental concentration of toxin

Frequency distribution of effects

Risk

Concentration
Choice of endpoint

"SSD" approach – Data requirements:

- Effect important at population level (e.g., growth, reproduction, survival)
- Sublethal effects
- Chronic exposure (depends on length of life of organism)
- Representative of ecosystem:
  - Range of ecological functions (e.g., trophic level)
  - Range of taxonomic groups
  - Different exposure pathways
- Statistics

"Critical" organism approach - criteria for choice:

- Important to structure and function of community
- High degree of exposure expected (distribution of contaminant in environment and organism)
- High degree of sensitivity (taking into account stage of life cycle)
- (Relevant to management goals, e.g., value)
Effects assessment
Type of toxicity data

- NOEC
- LOEC
- L(E)C50
- L(E)C20

Threshold
Level of detail

Problem formulation

Remediation

No action

Screening assessment

Remediation

No action

Detailed assessment

Remediation

No action

Complete assessment

Remediation

No action

What is the problem?

Can some parts of the problem be ‘written off’?

About How big is the problem?

Exactly How big is the problem?
Increasing the level of detail

<table>
<thead>
<tr>
<th>Screening level</th>
<th>Generic guideline values</th>
<th>Screening with generic guideline values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 2</strong></td>
<td>Increase site specificity</td>
<td>Development of site specific guideline values, eg modify concentration - bioavailability toxicity data for <em>relevant</em> species</td>
</tr>
<tr>
<td>Increase site specificity</td>
<td>Increase site specificity of guideline values</td>
<td></td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td>Site specific investigations And/Or Probabilistic analysis</td>
<td>Use of measured data and investigations And/Or Distributions of concentrations and toxicity data</td>
</tr>
<tr>
<td>Treatment of uncertainties</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Main areas of development

Use of guideline values

- What kind of toxic effect data?
  - High requirement for ecosystem – NOEC data
  - Lower requirement for ecosystem – effects data (L(E)Cx)
- What level of protection?
  - High requirement for ecosystem – HC5
  - Low requirement for ecosystem – HC50
- What does it mean ecologically??
- What to do when data are lacking?

Increasing the degree of site-specificity
Risk assessment process and level of detail

Problem formulation
- Hazard analysis
  - Object(s) of protection
  - Site description (ecology)
  - Boundary definition
- Contamination situation:
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  - concentration
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Risk evaluation
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Guideline values
- Soil Guidelines
- Recipient Guidelines

Risk assessment
- TRV
- TRV
"Different lines of evidence"
TRI AD (Liberation)

1. Chemistry (soil, groundwater)
   - Concentrations
   - Mobility (leachability)
   - Bioavailability

2. Ecotoxicology
   - Toxicity tests;
     - Species
     - Functions
     - Biomarkers
   - Biouptake

3. Ecology
   - Biological studies (e.g., benthic fauna studies, composition of invertebrate communities)

- Scaling av results (0-1) wrt control/benchmark for each study
- Evaluation of results from different lines of evidence
Chemistry

- Use of SSDs to calculate potentially affected fraction of species (Processes separate? Bioaccumulation separate?)
- Use of guideline/benchmark values (based on SSDs)

- Adjust for bioavailability?
- SSDs for bioaccumulation
Chemistry data, scaling method.
Guideline: 50th percentile av NOEC data
Guideline values

- **Screening assessment:**
  - NOEC data consistent with aims of screening assessment

- **Site specific assessment:**
  - Effects data correlate with ecotoxicity??
  - Effects data (eg EC20) consistent with aims of reducing degree of conservatism when site specific information becomes available
Ecotoxicology

- Tests indicate the combined toxicity of all contaminants
- Package of tests required (different functions, trophic levels, taxonomic groups, behaviour)
- Preferably test on whole soil, not on extracts
- *In vivo*
  - *In vitro*, test tests on hormonal effects. (Sensitive tests, avoid false negatives, but difficult to interpret)
- Standardise existing tests, develop new ones
- Adapt tests existing in other areas
Reproduction in nematodes

The diagram shows the relationship between the concentration of different metals in soil and reproduction in nematodes. The graph includes data for Arsenic, Copper, Chromium, and Nickel. The correlation coefficients for each metal are as follows:

- Arsenic: $R^2 = 0.4238$
- Copper: $R^2 = 0.4323$
- Chromium: $R^2 = 0.7166$
- Nickel: $R^2 = 0.7343$

The concentration of metals is measured in mg/kg dw (dry weight).
Ecotoxicity, scaling method.
(Tests: 2 plants, 2 invertebrates, growth, reproduction)
Correlation between chemistry data and ecotoxicity

\[
R^2 = 0.8504 \\
R^2 = 0.9276
\]
Ecological investigations

- Often in aquatic environments (e.g. benthic fauna) – part of environmental monitoring programmes
- Community species composition, individual density
- Soil invertebrates, microorganisms
- Indicator species, indices (e.g. nematodes, springtails, mites, microorganisms (e.g. CLPP in soil)
- Observed effects, tex mouth parts in *Chironimid* larver
- Databases with background information?
Correlation with contaminant concentrations - number of mites

Number of oribatid mites m^{-2}

Pb (mg kg^{-1} TS)

Zn (mg kg^{-1} TS)
Evaluation.

No known dose response relationship

Results nematode analyses.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Parameter 1</th>
<th>Parameter 2</th>
<th>Parameter 3</th>
<th>Parameter 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nematode numbers</td>
<td>Per 100 g soil</td>
<td>3,737</td>
<td>6,653</td>
<td>2,680</td>
<td>1,585</td>
</tr>
<tr>
<td>cp=1</td>
<td>%</td>
<td>14.3</td>
<td>25.6</td>
<td>12.5</td>
<td>2</td>
</tr>
<tr>
<td>cp=2</td>
<td>%</td>
<td>35.7</td>
<td>69.5</td>
<td>50</td>
<td>74</td>
</tr>
<tr>
<td>cp=3-5</td>
<td>%</td>
<td>50</td>
<td>4.9</td>
<td>37.1</td>
<td>24</td>
</tr>
<tr>
<td>MI (1-5)</td>
<td>-</td>
<td>2.90</td>
<td>1.83</td>
<td>2.64</td>
<td>2.48</td>
</tr>
<tr>
<td>MI (2-5)</td>
<td>-</td>
<td>3.22</td>
<td>2.11</td>
<td>2.88</td>
<td>2.51</td>
</tr>
</tbody>
</table>

Criteria for the evaluation of results

<table>
<thead>
<tr>
<th>parameter</th>
<th>No effect</th>
<th>Moderate effect</th>
<th>Highly negative effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nematode numbers</td>
<td>100-75 %</td>
<td>75-50 %</td>
<td>&lt; 50 %</td>
</tr>
<tr>
<td>Nematode MI</td>
<td>&lt; 5 %</td>
<td>5-10 %</td>
<td>&gt; 10 %</td>
</tr>
</tbody>
</table>

1. compared to reference
## Integration of results

### Summary of quantified effect parameters, topsoil and subsurface soil

<table>
<thead>
<tr>
<th>Component</th>
<th>SP9</th>
<th>SP8</th>
<th>SP6</th>
<th>SP5</th>
<th>SP1</th>
<th>SP10</th>
<th>SP3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal environmental chemistry</td>
<td>0</td>
<td>0.14</td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal ecology</td>
<td>0</td>
<td>0.19</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL Integrated Risk topsoil</td>
<td>0</td>
<td>0.17</td>
<td>0.14</td>
<td>0.67</td>
<td>0.53</td>
<td>0.13</td>
<td>0.85</td>
</tr>
<tr>
<td>Deviation</td>
<td>0</td>
<td>0.06</td>
<td>0.15</td>
<td>0.61</td>
<td>0.70</td>
<td>0.20</td>
<td>0.36</td>
</tr>
<tr>
<td><strong>Subsurface</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal environmental chemistry</td>
<td>0</td>
<td>0</td>
<td>0.02</td>
<td>0.05</td>
<td>0.09</td>
<td>0.23</td>
<td>0.30</td>
</tr>
<tr>
<td>Subtotal toxicology</td>
<td>0</td>
<td>0.19</td>
<td>0.01</td>
<td>0</td>
<td>0.16</td>
<td>0</td>
<td>0.13</td>
</tr>
<tr>
<td>TOTAL Integrated risk subsurface</td>
<td>0</td>
<td>0.09</td>
<td>0.02</td>
<td>0.02</td>
<td>0.12</td>
<td>0.11</td>
<td>0.21</td>
</tr>
<tr>
<td>Deviation</td>
<td>0</td>
<td>0.23</td>
<td>0.01</td>
<td>0.06</td>
<td>0.08</td>
<td>0.28</td>
<td>0.21</td>
</tr>
</tbody>
</table>

- **No risk (< 0,2)**
- **Low risk (0,21 – 0,5)**
- **Moderate risk (0,51-0,75)**
- **High risk (> 0,75)**
"Control" site?
Gradient in contaminant concentration?

As (mg/kg TS)

(n=164)  (n=198)

MKM

KM
# Lines of evidence/ Level of detail

<table>
<thead>
<tr>
<th></th>
<th>Chemistry</th>
<th>Ekotoxicology</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Screening</strong></td>
<td>Site specific benchmarks (soil and groundwater/leachate Combined toxic pressure PAF</td>
<td>Screening tests, eg Microtox, PAM on soil and groundwater/leachate</td>
<td>Survey - floristic</td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>Selective extractions TIES Bioavailability - modelling or tests</td>
<td>Germination test - plants Acute toxicity test, earthworm</td>
<td>C- and N-mineralisation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substrate induced respiration</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bait lamina</td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td>Selective extractions Bioaccumulation - modelling or uptake tests</td>
<td>Plant growth Invertebrates - growth, reproduction and survival Aquatic tests (algae, daphnia)</td>
<td>Microorganisms Invertebrates Decomposition tests Fauna survey</td>
</tr>
</tbody>
</table>
Further work

- Screening level: Guideline values/benchmarks important. Data for SSDs

- Important issues for derivation of benchmarks, eg.
  - Grouping of data or all datapoints equal?
  - Which data
  - Acceptable degree of effect

- Other “chemistry” issues; mobility and bioavailability of contaminants. Tests, models and validation

- Toolbox of toxicity tests – for site specific investigations and for providing data for SSDs

- Indices for ecological studies. Databank – background conditions

- Development of criteria for evaluation – when can we say we have enough information?

- Substances which don’t fit the system? (Persistent organics?) Alternative approach?