Ecological Risk Assessment in the United States

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Purpose of this presentation,

• Describe current approaches to ecological risk assessment in the United States
• Identify several key issues for advancing ecological risk assessment
• Suggest an environmental context for ecological risk management
A formal definition of risk...
\[ R = \sum_{k} \sum_{i} \sum_{j} C_k (A_k) \sum_{i} P(A_k \setminus E_{ji} \cap S_i) P(E_{ji} \setminus S_i) P(S_i) \]

where,

- \( C_k \) = consequences of adverse affect \( k \)
- \( A_k \) = adverse affect \( k \)
- \( P(A_k \setminus E_{ji} \cap S_i) \) = probability of \( A_k \) given exposure \( j \) and stressor \( i \)
- \( P(E_{ji} \setminus S_i) \) = probability of exposure \( j \) given stressor \( i \)
- \( P(S_i) \) = probability of stressor \( i \)
Consider a simple model of risk

\[ \text{Risk} = F\{x_i, p_i, s_i\} \]

\(x_i = \text{what is at risk}\)

\(p_i = \text{probability of } x_i\)

\(s_i = \text{consequences of } x_i\)

Kaplan and Garrick (1981)
Defining “ecological risk”

an *ecological risk* is the conditional probability of a specified ecological event occurring, along with an evaluation of its consequences...
Adverse ecological event might include,

<table>
<thead>
<tr>
<th>• Local extinction</th>
<th>• Physiological process (e.g., photosynthesis)</th>
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<tbody>
<tr>
<td>• Population change</td>
<td>• Energy flow</td>
</tr>
<tr>
<td>• Community structure</td>
<td>• Nutrient cycling</td>
</tr>
<tr>
<td>• Growth and reproduction</td>
<td>• Ecosystem stability</td>
</tr>
<tr>
<td>• Individual loss</td>
<td></td>
</tr>
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</table>
National Research Council

Committee on Risk Assessment Methods
Water Environment Research Foundation (WERF)

Risk Assessment Methods
A Sequential or “Tiered” Approach

- Tier 1: Screening-level assessment
- Tier 2: Detailed assessment using existing data and information
- Tier 3: Detailed assessment involving new data
Each “tier” consists of

- Problem definition
- Source characterization
- Exposure assessment
- Ecological receptor characterization

- Ecological effects characterization
- Risk characterization
- Risk management
Other frameworks and approaches

- American Society for Testing and Materials Committee E.47
- OECD
- The Netherlands
- Environment Canada
U.S. Environmental Protection Agency (USEPA)

Proposed Guidelines for Ecological Risk Assessment
1996
Problem Formulation

Data Acquisition Verification and Monitoring

Problem Formulation

Problem Formulation

Exposure
Ecological Effects

Data Acquisition Verification and Monitoring

Problem Formulation

- Integrate available information
- Select what to protect
- Construct a conceptual model
- Develop a plan for analysis
Integrate available information

- Foundation of problem formulation
- Stressors, exposure, effects, ecosystems
- Influenced by reason for the assessment
- Scoping process
Selecting what to protect

- Ecological relevance
- Sensitive or susceptible to stressor(s)
- Likelihood of exposure
- Relevance to risk management
Conceptual model

• Blueprint for the entire assessment
• Two principal products:
  – Set of risk hypotheses
  – Diagram illustrating the conceptual model
Hazardous Waste Storage Sites
Plan for analysis

- Final stage of problem formulation
- Detail the methods for analysis phase
- Synopsis of measures to evaluate risk hypotheses
- Anticipate uncertainties, their impacts
- Entering results into decision-making
Exposure Analysis

- Source of the stressor(s)
- Scale and distribution of the stressor
- Pathways of exposure

Product: Exposure Profile
Exposure Profile

- Identify receptors
- Describe relevant pathways
- Frequency, intensity, extent, duration
- Address variability

The profile synthesizes above information in a report or model....
Deer Exposure to Mercury

\[ E = \frac{(C_w I_w) + (C_s I_v \cdot B_v + C_s I_s) \cdot H}{B_w} \]
Model parameter values

Accumulation pathways for deer

<table>
<thead>
<tr>
<th>Model Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Cw, concentration of chemical in water</td>
<td>(mg/kg)</td>
<td>0.10</td>
</tr>
<tr>
<td>lw, water ingestion rate for deer</td>
<td>(L/d)</td>
<td>1.10</td>
</tr>
<tr>
<td>Cs, concentration of chemical in soil</td>
<td>(mg/kg)</td>
<td>1.20</td>
</tr>
<tr>
<td>Iv, rate of ingestion of vegetation</td>
<td>(kg/d)</td>
<td>1.60</td>
</tr>
<tr>
<td>Bv, soil-to-plant transfer factor</td>
<td>(unitless)</td>
<td>200</td>
</tr>
<tr>
<td>Is, incidental soil ingestion</td>
<td>(kg/d)</td>
<td>0.02</td>
</tr>
<tr>
<td>H, ratio of home range area to site area</td>
<td>(unitless)</td>
<td>0.50</td>
</tr>
<tr>
<td>BW, body weight of deer</td>
<td>(kg)</td>
<td>45.40</td>
</tr>
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</table>
# Total Exposure to Deer

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<tr>
<th>Parameter</th>
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<tr>
<td>E, total exposure to deer</td>
<td>(mg/kg/d)</td>
<td>2.96</td>
</tr>
<tr>
<td>B, toxicity benchmark: mercury LD50</td>
<td>(mg/kg/d)</td>
<td>17.80</td>
</tr>
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</table>

\[
\text{Quotient} = \frac{E}{B}
\]

\[
\text{Quotient} = \frac{2.96}{17.80} = 0.17
\]
Forecast: Exposure rate

5,000 Trials

5,000 Trials

68 Outliers

Probability

0.00
0.008
0.017
0.025
0.033

Frequency

0
41.7
83.5
125
167

mg/kg/d

0.00
3.75
7.50
11.25
15.00
Effects Analysis

- Stressor-response analysis
- Establish cause and effect relationships
- Linking measures to assessment endpoints

**Product:** Stressor-response profile
Adverse ecological event might include,

- Local extinction
- Population change
- Community structure
- Growth and reproduction
- Individual loss

- Physiological process (e.g., photosynthesis)
- Energy flow
- Nutrient cycling
- Ecosystem stability
Stressor-response profile

- Identify effects of concern
- Establish causal linkage to stressor
- Estimate severity of effects in relation to intensity of exposure
- Characterize uncertainties

Profile may be a report or model...
Risk Characterization

- Estimating risks
- Describing risks
- Reporting risks
Estimating risks

- Qualitative estimates
- Single-value estimates
- Entire stress-response relationships
- Address variability in exposure and/or effects
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Quotient = E/B | (unitless) | 0.17   |
Sensitivity Chart

Target Forecast: Screening Index = E/B

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<th>Variable</th>
<th>Contribution</th>
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<tr>
<td>B, toxicity benchmark (mg/kg/d)</td>
<td>67.1%</td>
</tr>
<tr>
<td>Cs, concentration of chemical in soil</td>
<td>21.7%</td>
</tr>
<tr>
<td>BW, body weight of deer</td>
<td>9.4%</td>
</tr>
<tr>
<td>H, ratio of home range area to site area</td>
<td>1.1%</td>
</tr>
<tr>
<td>Bv, soil-to-plant transfer factor</td>
<td>0.3%</td>
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Measured by Contribution to Variance
Population models

- Structured population models
- Demographics
- Bioenergetics
- Collections of modeled individuals
FRESHWATER DRUM

Aplodinotus grunniens Rafinesque
Freshwater Drum: Proportional Mortality Risk vs Tows/day
Community models

- **Empirical models**
  - diversity indices (alpha, beta)
  - biotic integrity (Karr)
  - multivariate analyses (e.g., Landis)
- **Gradient models**
- **Community assembly models (Post)**
Ecosystem models

- Emphasize biotic-abiotic interactions in defining $x_i$’s
- Explicit representation of detailed system structure and function
- Dynamic in space and time
- Scale, aggregation, parameter estimation
- Accuracy, precision
Examples of ecosystem models for risk assessment

• AQUATOX
• LERAM
• SWACOM, CASM, IFEM
• Other models (Suter and Bartell 1993)
Landscape and larger scale models

- Characterize pattern on the landscape
  - Land use patterns
  - Indices: dominance, contagion, fractals
- Understand processes that determine pattern
  - Hydrology, geochemistry
  - Vegetation (ecology, dynamics)
  - Human activities
Problem Formulation

Risk Characterization

Exposure
Ecological Effects

Data Acquisition Verification and Monitoring

Risk Management

Risk Planning, Risk Management
Risk-based remediation: costs and decisions
Critical Issues in Advancing Ecological Risk Assessment
Technical and policy issues that need to be successfully addressed in order to advance the process of ecological risk assessment and provide for meaningful risk management....
Several Critical Issues in Ecological Risk Assessment

- Endpoint selection
- Multiple stressors
- Stress-response functions
- Ecological scale and complexity
- Decision criteria and ecological significance
Landscape

Ecosystem

Community

Population

Individual
Fundamental Ecological Views of Nature

• what environment?
• ecological frame of reference
• reference site selection

* a key component needed for meaningful assessments... *
Three metaphors of nature (Holling 1986)

- An environment in equilibrium
- A dynamic environment
- An evolutionary environment
A Context for Managing Ecological Risks
Human demography

- Root cause of environmental problems
- 170 people/minute added to Earth
- 250,000 people/day
Maslow’s Hierarchy of Needs

- Physiology
- Safety
- Belonging
- Esteem
- Inner self
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Third law of human ecology

\[
\text{total impact} = \text{population} \times \text{per capita impact}
\]

Hardin (1991)
I = P x A x T

P = Population
A = Affluence
T = Technology

Holdren and Erlich (1974)
The ecological footprints of individual regions are much larger than the land areas they physically occupy.
“ECOLOGICAL FOOTPRINTS”

- Natural capital requirements of human economy
- Total land area required to maintain a given population
- Appropriated carrying capacity
SUSTAINABLE ENVIRONMENTAL MANAGEMENT

A subset of sustainable development
“...improving the quality of human life while living within the carrying capacity of supporting ecosystems.”

WORLD CONSERVATION UNION, 1991
Precedence for Planning

- 10Th Century Native Americans
- Laws of the Indies (1573)
- Early English Settlements
- Regional Planning Association of America (1920’s)
Law of the Indies (Spain)

- Settlement Directives ca. 1573
- 148 Separate Ordinances
- Site Selection Referenced to Local Resources
- Main Square With Public Buildings
SUSTAINABLE ENVIRONMENTAL MANAGEMENT

- Stabilizing population
- Sustaining agriculture
- Conserving biological diversity
- Reducing wastes, pollution

... ALL TOWARD A STEADY-STATE
In summary,

• Frameworks for assessing ecological risk continue to evolve in the United States
• Essentially parallel efforts with USEPA Framework as the major guideline
• Important technical and policy issues remain to be addressed
• Require a management context for meaningful ecological risk assessment
Thank you very much!