December 8, 2003

Lecture 24: Ecological Risk Characterization—Probabilistic Perspectives

I. Probabilistic Ecological Risk Characterization

A. One major conundrum with characterizing risk to ecosystems (or populations, communities, etc. within) is that there is a tremendous diversity of species to protect. Thus ERA has challenges not faced by assessment of risk for human health (which can rely on "simple" animal models—i.e., rats and dogs).

B. To characterize risk, there are essentially two methods—deterministic and probabilistic

1. Quick review of deterministic risk characterization
    a. Divide the level of exposure (a point estimate) by a toxicological endpoint (NOEL or LC_{50}) for the most sensitive species tested.
    b. The ratio is judged acceptable (or as EPA says, below their Level of Concern, LOC) or not; i.e., whether the deterministic risk characterization is acceptable or not is risk management.
    c. For ex., with an assessment of pesticide risk for causing adverse effects in an endangered species, the ratio of exposure to LC_{50} should be 0.05 (i.e., a 20-fold safety factor).

C. Probabilistic Techniques

1. Combine the <u>distribution of possible exposures</u> (modeled environmental concentrations and from real environmental measurements) with the distribution of acute and chronic effects endpoints for various individual species (= species sensitivity distributions).

D. <u>Species sensitivity distributions</u> are databases of how different species and/or taxa respond to a contaminant.

1. The distributions usually represent the fraction of all the known tested species responding to a given toxicity endpoint (i.e., the dose-response point estimate, LC50 or NOEC).
2. The species sensitivity distributions (SSD) for responses to chlorpyrifos are shown below in Figures 1, 2, and 3(data from van den Brink et al. 2002, in Species Sensitivity Distributions in Ecotoxicology, Posthuma et al. (ed.), CRC Press, pp. 155-193).
3. The SSD curves are derived from logistic regression modeling.
4. Note that the y axis is the proportion of all the animals or plants tested in any group that exceed a given toxicity endpoint (in the case of Figure 1 and 2, the endpoint is the EC50 or LC50).

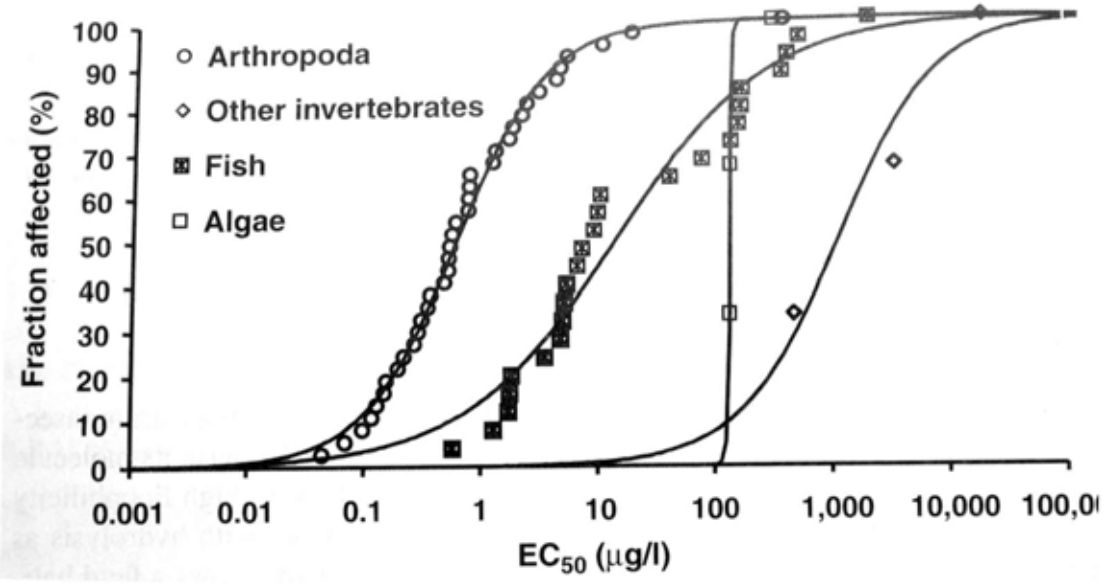

Figure 1: Lab-based SSD curves for chlorpyrifos by groups of aquatic organisms.

5. Note in Figure 2 below that the logistic curve for lab-based EC50's is predictive of the field-based EC50's.
   a. Note that the experiment that generated the field data were an outdoor ditch microcosm rather than a natural aquatic system.
6. Also note that the distribution of field and lab based EC50's were only comparable when Arthropods, rather than all invertebrates were compared.
7. Arthropods are extraordinarily sensitive to chlorpyrifos, which is an organophosphate insecticide.

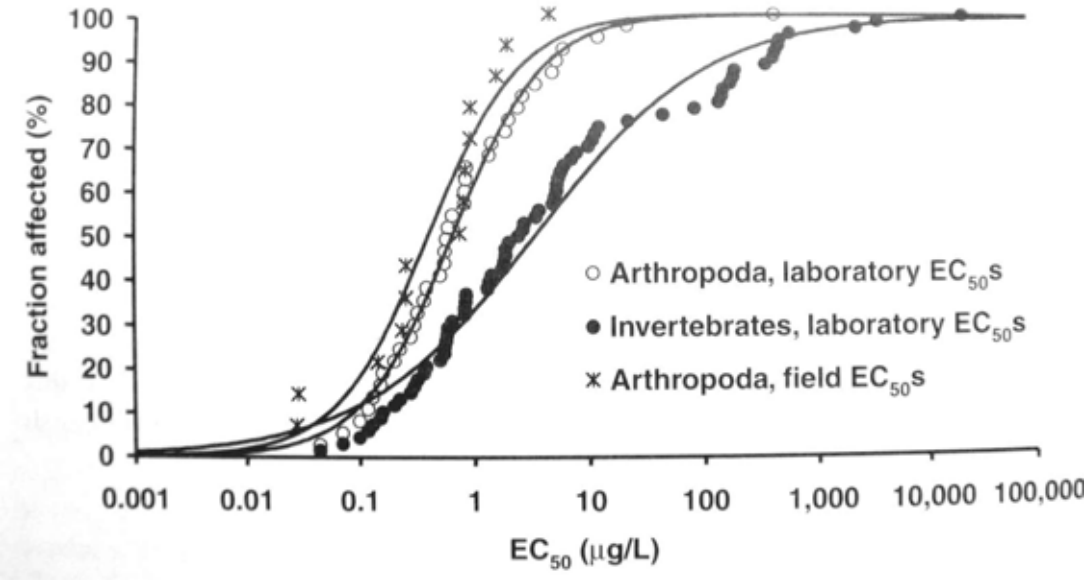

Figure 2. SSD curves for chlorpyrifos; comparison of laboratory based EC50 determinations and a semi-field exposure.

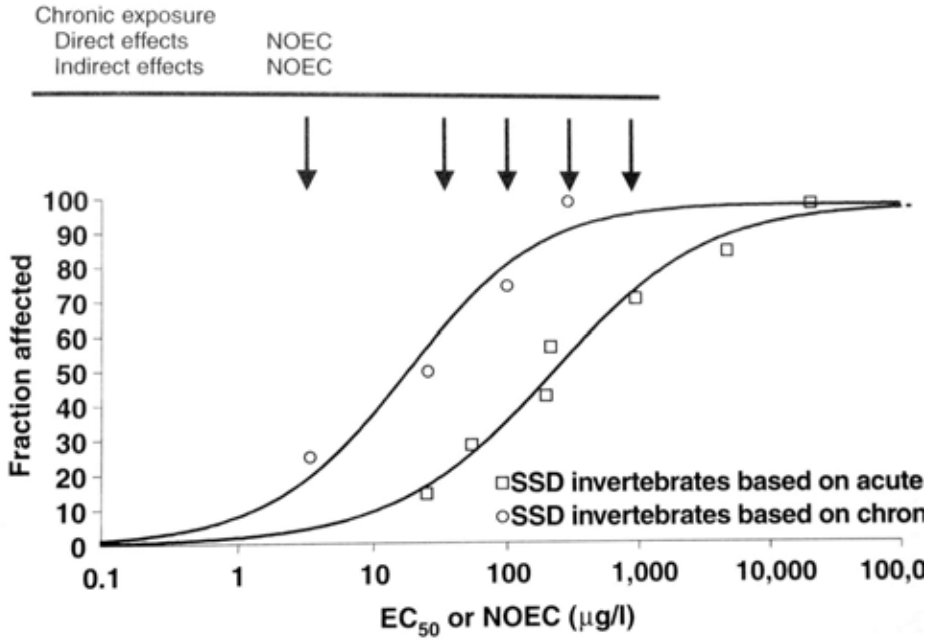

Figure 3. SSD curves for the acute toxicity and chronic toxicity of the fungicide carbendazim. The arrow lines indicate concentrations actually tested in a microcosm test 3.3 μg/L (first line, left to right), 33 (2nd line), 100 (3rd line), 330 (4th line), and 1000 (5th line). The NOEC for chronic exposure by direct and indirect effects was 3.3 μg/L, corresponding to a fraction affected of about 25%.

E. The distribution of concentrations can be superimposed on the SSD.
   1. In Figure 4 below, I've illustrated such an imposition, but instead of showing the SSD as a logistic curve, I've plotted it as a normal distribution.
   2. The distribution of hypothetical data illustrated in Figure 4 can be changed to a cumulative frequency distribution as shown in Figure 5.
   3. The cumulative frequency distribution can be linearized as shown in Figure 6 from Solomon et al. 2000. Probabilistic risk assessment of agrochemicals in the environment. Crop Protection 19:649-655.))
      a. An example of this probabilistic ecological risk characterization is illustrated for atrazine. (Figure 7)
      b. Using the log distribution of residues measured for the herbicide atrazine, and the log distribution of the LC_5 (as well as the LC_{50}), probabilistic ecorisk of atrazine was characterized by Solomon et al (1996) [Solomon, K. R., D. B. Baker, R. P. Richards, K. r. Dixon, S. J. Klaine, T. W. LaPoint, R. J. Kendall, C. P. Weisskopf, J. M. Giddings, J. P. Giesy, L. W. Jr. Hall, and W. M. Williams. 1996. Ecological risk assessment of atrazine in North American surface waters. Environ. Toxicol. Chem. 15(1):31-76.]
      c. This method enabled a calculation of the margin of safety given the distribution of environmental residues of atrazine and the distribution of species responses.

F. What is acceptable risk?
   1. One benchmark that the EPA is considering for acceptable ecological risk is that no more than the 10th percentile of species would be exposed to contaminant residue levels exceeding the LC_5 (lethal concentration to 5% of the test population).
   2. In the graph represented in Figure 4, the overlapped area would have to be smaller than a certain guideline to be acceptable.
   3. Remember, however, what is acceptable is a risk management decision, not a testable hypothesis. However, Figure 9 below illustrates an approach to using a joint probability curve (aka exceedance frequency curve) to determine what is acceptable. Figure 8 illustrates how the joint probability curve is derived from the logarithmic plots of the cumulative frequency distributions for exposure and toxicity endpoints.

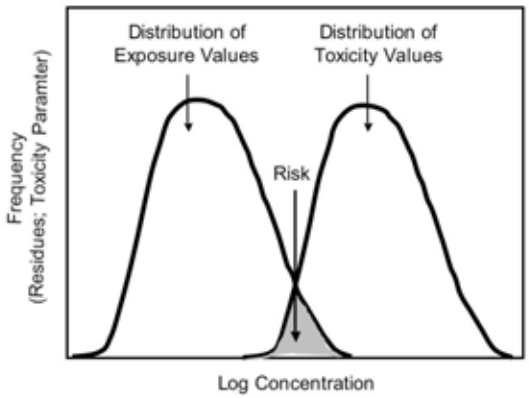

Figure 4. Overlap of distribution of exposure values (i.e., concentrations or doses) and distribution of toxicity values (suitable toxicological endpoint such as LC50, LC5, or NOAEC).

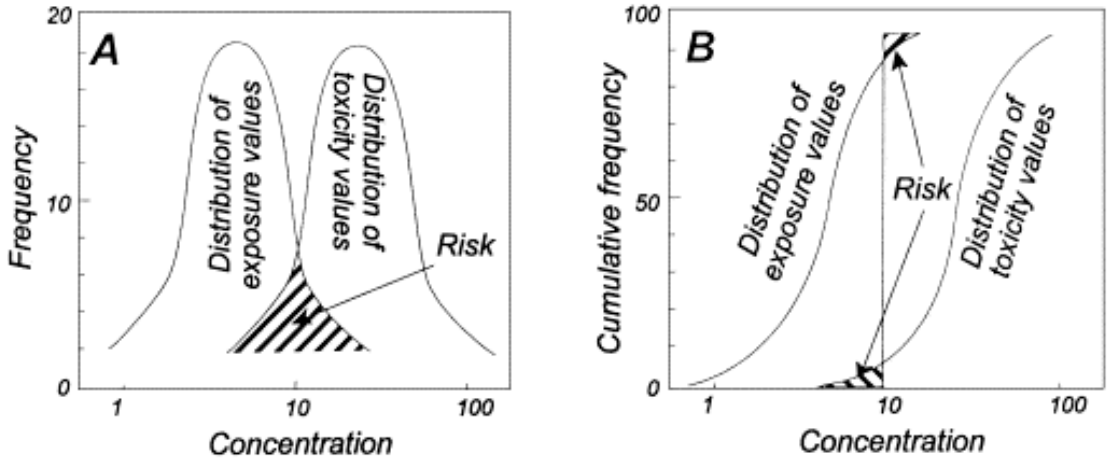

Figure 5. Derivation of cumulative frequency distribution (right hand side) from frequency distribution (left hand side) of overlapping exposure and toxicity distribution functions (from Solomon, K., J. Giesy, and P. Jones. 2000.

Probabilistic risk assessment of agrochemicals in the environment. Crop Protection 19:649-655.)

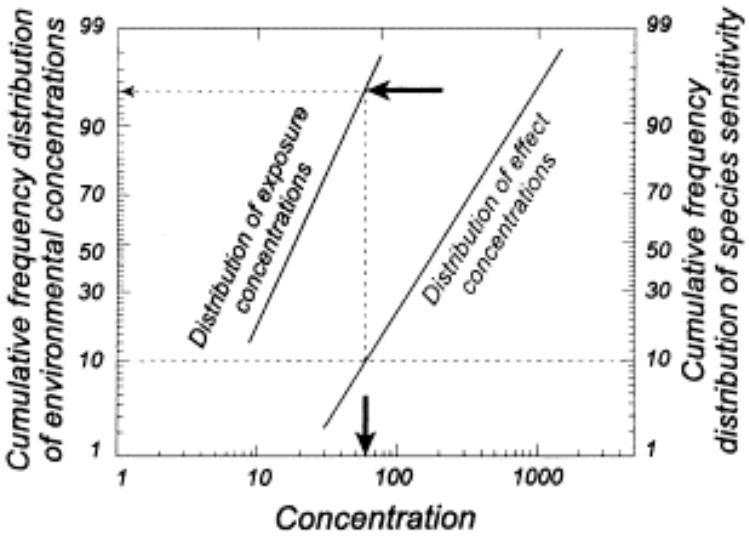

Figure 6. Linearization of cumulative frequency curves for exposure and toxicity distributions (from Solomon et al. 2000, Crop Protection)

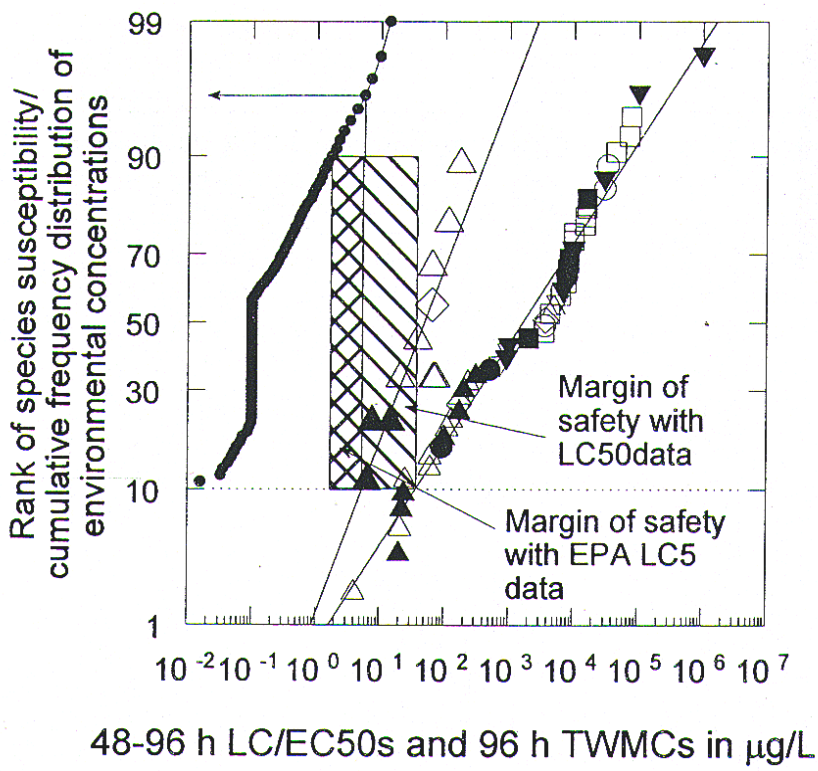

Figure 7. Probabilistic risk characterization of atrazine in N. American waters illustrating the overlap of cumulative frequency distributions on a

logarithmic scale for exposure (μg/L atrazine concentration) and toxicity endpoint (LC50 and LC5, μg/L). (Solomon et al. 1996, ETAC)

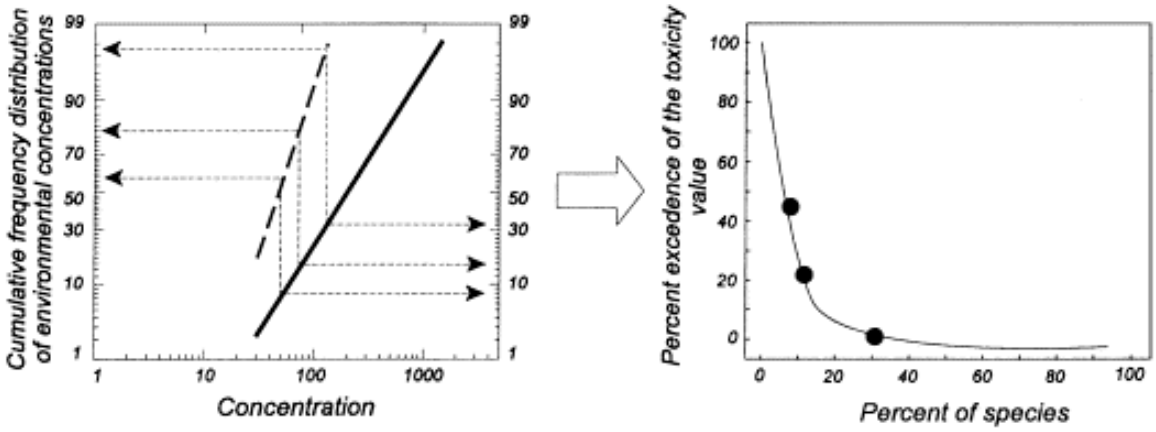

Figure 8. Transformation of cumulative frequency distribution curves to joint probability curve (aka exceedance frequency profile) (from Solomon et al. 1996)

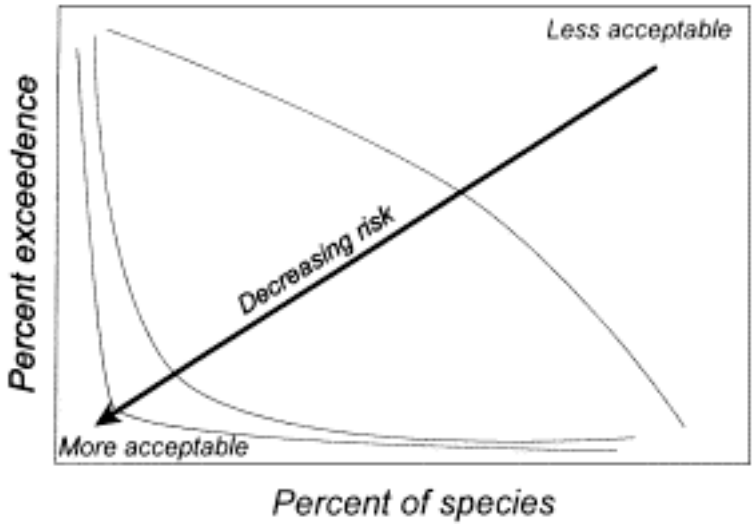

Figure 9. Example of how the joint probability curve/exceedance frequency profile curve can aid decision making. The region between the upper curve and lower most curve could influence the decision to take action (i.e., implement mitigation prior to the "risk" moving into the unacceptable region.

II. Applications of Probabilistic Risk Assessment

A. Probabilistic risk assessment essentially can help answer two questions according to van Straalen 2002 (Theory of ecological risk assessment based on species

sensitivity distributions. In *Species Sensitivity Distributions in Ecotoxicology*, Posthuma et al. (ed.), CRC Press, pp. 37-48).

1. The forward problem (or application)
    a. The exposure concentration is considered as given and the risk associated with that exposure concentration is estimated.
        1. This use applies to chemicals that are already present in the environment.
2. The inverse problem
    a. Risk is considered as a given (i.e., set at a certain level, for ex., the maximum acceptable value; EPA risk presumption guidelines) and the concentration associated with that risk has to be estimated.
        1. Applicable for deriving environmental quality standards.

B. In the revised atrazine ecological risk assessment, EPA has used a semi-probabilistic approach to analyzing atrazine by using a distribution of residues.
    1. Different toxicological endpoints can than be overlain on these distributions (Figure 10).

Figure 5. USGS 1993 Mid-Western Lake/Reservoir Sampling Results
Maximum Atrazine Concentrations

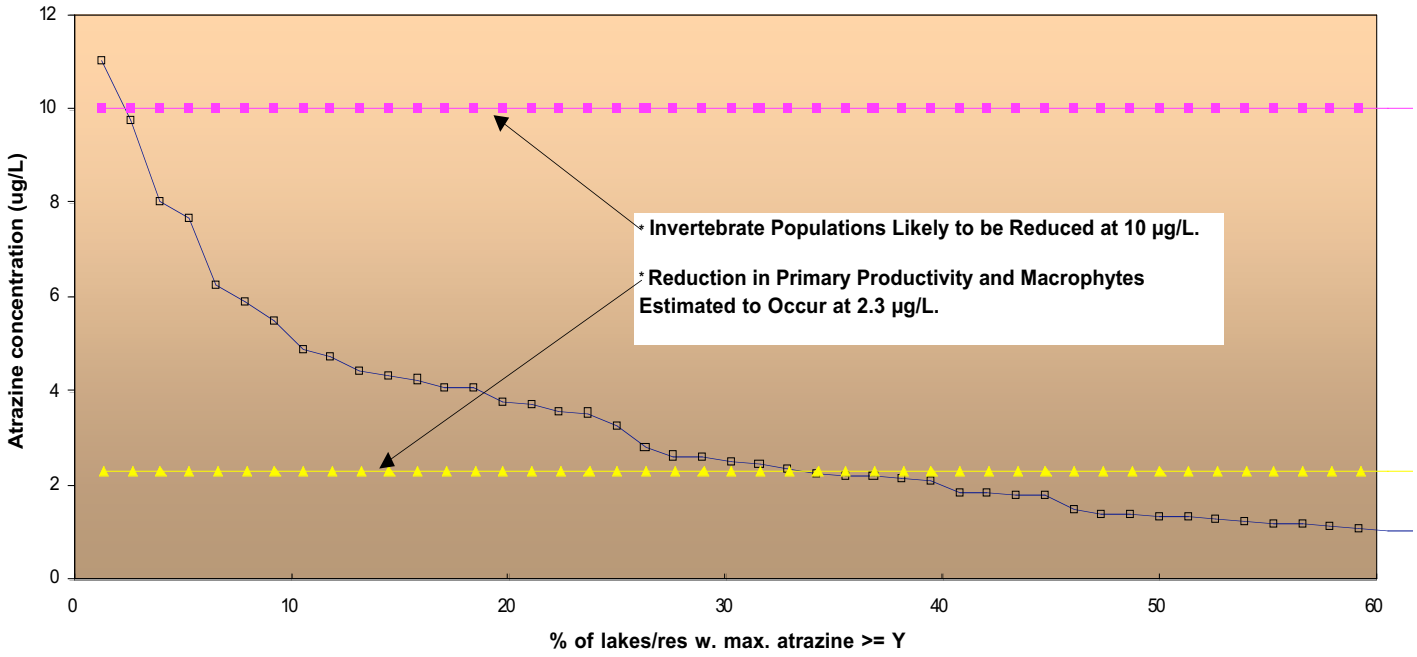

Figure 10. Semi-probabilistic ecological risk assessment of atrazine by the EPA using residue data from the NAWQA program and deterministic endpoints for invertebrate populations and reductions in primary productivity and macrophytes. The overlap of the toxicity lines (yellow and purple) with the

residue distribution indicates the percentage of lakes having an atrazine concentration likely to be at or greater than the toxicity benchmark.

C. Mapping the fraction of the potentially affected species in a geographic region (Figure 11) (Klepper, O., J. Bakker, T. P. Traas, and D. van de Meent. 1998. Mapping the potentially affected fraction (PAF) of species as a basis for comparison of ecotoxicological risks between substances and regions . Journal of Hazardous 61 (1-3): 337-344)

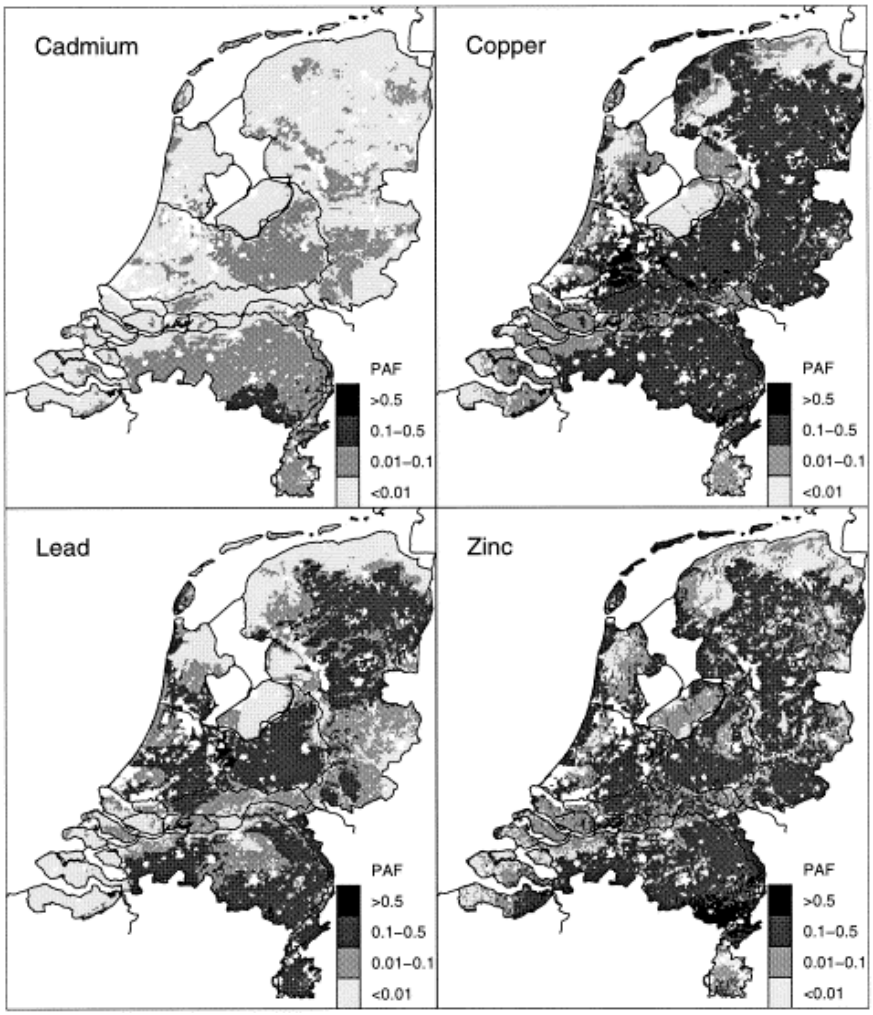

Figure 11. Mapping the PAF (potentially affected fraction of species, which is the fraction of species exposed to a concentration above the NOAEC) in a region (the Netherlands) for risk characterization of heavy metal hazards (from Klepper et al. 1998).