SPECIES NON-EXCHANGEABILITY FOR ECOTOXICOLOGICAL RISK ASSESSMENT

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Introduction

Species Sensitivity Distributions (SSDs) are probabilistic models used to characterise the community level dose-responses for a toxicant [1]. A common usage of an SSD is to use it alongside statistical techniques in order to estimate the HC_p — the Hazardous Concentration to p% of a defined community. This is defined as the concentration below which a randomly selected species from the community will have its toxicological endpoint violated with probability p%.

Current REACH guidelines [2] allow SSD derived HC_5 values to be applied as Predicted No Effect Concentrations (subject to certain criteria and a small assessment factor). However, evidence suggests that **a key assumption to the 'SSDeology' is violated**: that the collection of species toxicity values are a set of realisations from an identical SSD. If this is true, then each species should feature equally in both halves of SSDs across a *population of substances*. If this is not true, then we denote the species as **non-exchangeable** relative to the other population of species.

In the case of pesticide risk assessment for fish, a report by EFSA [3] suggested that the rainbow trout (*Oncorhynchus mykiss*) is a typical sensitive species; see Fig. 1. This was concluded by considering the rank position of the rainbow trout's toxicity value relative to other tested species across a collection of pesticides. The rainbow trout is a standard dossier species, thus a realistic risk assessment might be influenced. Therefore it is *sufficient* to study the impact of this species alone.

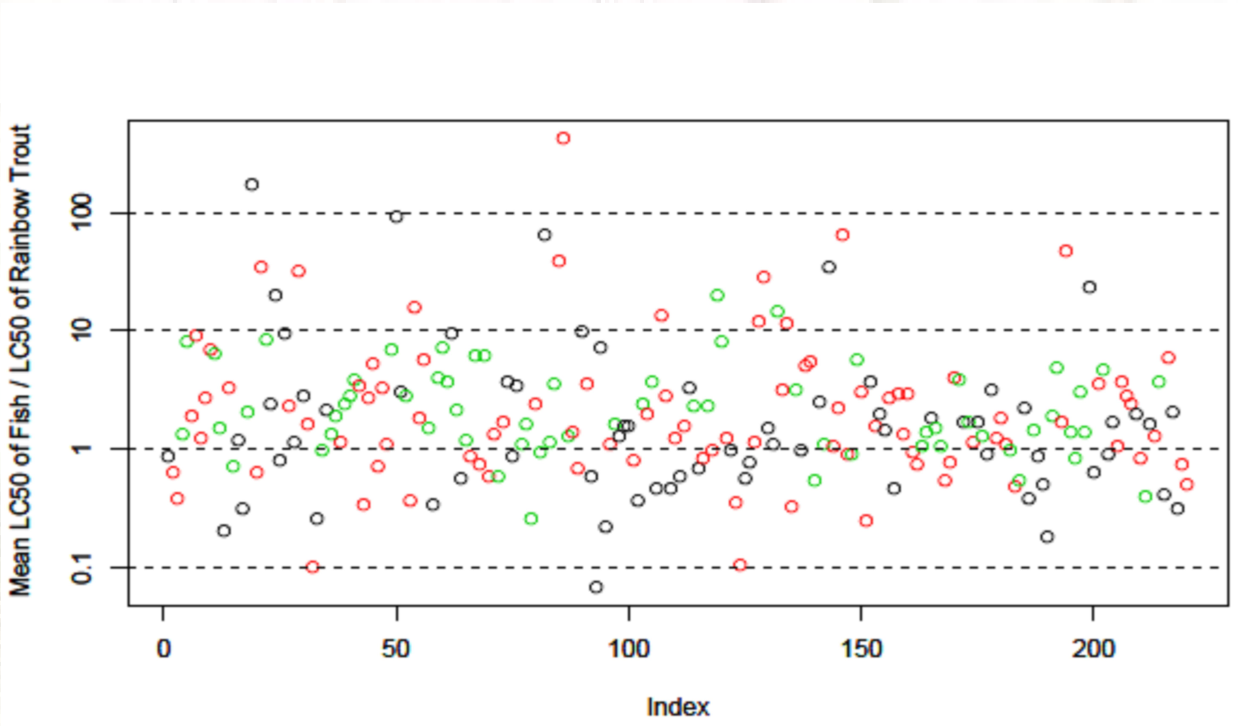

Fig. 1 (left). Each point is the per-substance (sample size n) ratio of the geometric mean of fish EC50s to the rainbow trout's EC50. Points above 1 indicate that the rainbow trout is 'more sensitive'.

Black: $n = 3$
Green: $3 < n < 8$
Red: $n \geq 8$

Data is a subset of 220 pesticides tested with fish from the database discussed in De Zwart 2002 [3].

Testing the Hypothesis

Fig. 1 is not a robust method for identifying non-exchangeable species as it contains different sample sizes and different fish species across the different pesticides. More rigour can be obtained using other available techniques; for example:

- Un-balanced two-way ANOVA,
- Non-parametric hypothesis tests:
  (i) binary rank test,
  (ii) weighted rank-order test.

Each test can be applied using different assumptions on the SSD; e.g. homogeneity [3, 5] and heterogeneity [3, 7, 8]. It was observed under all methods explored that the rainbow trout was the most significant species.

Why is This Important?

Aldenberg et al. [7] showed that for small p, say p = 5%, the HC_p was greater influenced by species' toxicity values which lay in the lower half of the SSD. This means that if a species is non-exchangeable and sensitive, then it will result in increased conservatism.

By not accounting for non-exchangeability, and subsequently violating the statistical SSD assumptions, we potentially introduce bias into the estimation procedure. Since the rainbow trout is a standard dossier species, we are particularly interested in investigating how alternative decision rules can be selected for realistic risk assessments.

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Taking Account of Non-Exchangeability

Modifying the standard SSD model to capture non-exchangeability for a single species was suggested in [3]. On the log-scale the standard SSD is typically assumed to be normal with mean μ and standard deviation σ, i.e.

$$X \mid \mu, \sigma \sim N(\mu, \sigma^2) \text{ for all species.}$$

The proposed model in [3] is:

$$X \sim N(\mu, \sigma^2) \text{ for all exchangeable species.}$$
$$X^* \sim N(\mu - k'\sigma, [\varphi\sigma]^2) \text{ for the non-exchangeable species;}$$

where k' and φ are the non-exchangeability parameters. The shift of $-k'\sigma$ to the mean μ meant that the location of the 'special species' in the SSD was maintained across the population of substances. However, this new model is at the expense of finding mathematically tractable estimates for the HC_p.

Therefore, we make a slight modification:

$$X^* \sim N(\mu - k, [\varphi\sigma]^2) \text{ for the non-exchangeable species.}$$

Using the database used to construct Fig. 1, we estimated, using Bayesian analysis, the parameters for the rainbow trout (RT) to be:

$$k_{RT} = 0.1950 \;\&\; \varphi_{RT} = 0.7016.$$

Since k is positive, it means that the rainbow trout is expected to be in the sensitive region of the SSD. This absolute-shift ($-k$) assumption has been tested statistically to be a reasonable simplification of the scaled-shift ($-k'\sigma$) model.

Adjusting the HC_p Estimator

There are a number of estimators for the HC_p based on a standard normal SSD (e.g. Aldenberg and Jaworska's estimators [7], decision-theoretic derived estimators [8], EFSA estimators [3], etc.). All these estimators are easily modified for the new SSD distribution when conditioned upon k & φ *known* [6].

Treating the non-exchangeability parameters as known implies uncertainty is not propagated. For large databases where the non-exchangeable species is a standard test species means that we can estimate k & φ with small uncertainty.

Conclusions

- To apply probabilistic techniques to ecotoxicological risk assessment one must adhere to required assumptions.
- Some species (e.g. the rainbow trout) are observed to violate the assumption of exchangeability, i.e. they are non-exchangeable.
- Estimators can be modified to account for this using a modified SSD which maintains the desirable property of tractability.
- Works suitably with per-taxon SSDs (e.g. fish only).

References

[1] Posthuma L, II Suter GW, Traas TP. 2002. *Species Sensitivity Distributions in Ecotoxicology*. Lewis Publishers, Boca Raton, Florida, USA.
[2] European Chemicals Agency. 2008. *Guidance for the implementation of REACH*, Chapter R.10.
[3] EFSA 2006. Opinion of the Scientific Panel on Plant Health, Plant Protection Products and their Residues on a Request from EFSA Related to the Assessment of the Acute and Chronic Risk to Aquatic Organisms with Regard to the Possibility of Lowering the Uncertainty Factor if Additional Species were Tested. *The EFSA Journal*. 301: 1-45.
[4] De Zwart D. 2002. Observed Regularities in SSDs for Aquatic Species. In: [1]. pp. 133-154.
[5] Luttik R, Aldenberg T. 1997. Assessment Factors for Small Samples of Pesticide Toxicity Data: Special Focus on LD50 Values for Birds and Mammals. *ET&C*. 16: 1785-1788.
[6] Craig PS, Hickey GL, Hart AD, Luttik R. 2009. On Species Non-Exchangeability in Probabilistic Ecological Risk Assessment. *In submission*.
[7] Aldenberg T, Jaworska JS, Traas TP. 2002. Normal Species Sensitivity Distributions and Probabilistic Ecological Risk Assessment. In: [1]. pp. 49-102.
[8] Hickey GL, Craig PS, Hart A. 2009. On The Application of Loss Functions in Determining Assessment Factors for Ecological Risk. *Ecotox. Environ. Saf.* 72: 293-300.