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Declaration of Apeldoorn on LCIA of Non-Ferro Metals

Tom N. Ligthart et al. (names of other authors at end)
TNO Environment, Energy and Process Innovation, Apeldoorn, Netherlands, T.N.Ligthart@mep.tno.nl

April 15, 2004, a group of specialists in the areas of LCA (Life-Cycle Assessment), LCIA (Life-Cycle Impact Assessment), and Risk Assessment came together at TNO in Apeldoorn, The Netherlands, to discuss the current practices and complications of LCIA methodologies for non-ferro metals (including essential metals such as zinc and copper). The workshop was commissioned by ICMM (International Council on Mining and Metals), ECI (European Copper Institute) and DBM (Dutch Duurzaam BouwMetaal Foundation), co-sponsored by the UNEP/SETAC (United Nations Environment Programme / Society of Environmental Toxicology and Chemistry) Life-Cycle Initiative, and was organized by TNO (Netherlands Organisation for Applied Scientific Research) and CML (Institute of Environmental Sciences, Leiden University). The purpose of the workshop was to provide input to the UNEP/SETAC Life-Cycle Initiative on issues surrounding the characterisation of metals by currently available ecotoxicity-based LCIA methods. The group, originating from industry, academia, government, research and consultancy, recognised that current ecotoxicity LCIA methods often produce a probably incorrect emphasis on the impact of metals.

Even though LCIA can use the models and the methodologies developed for Risk Assessment, LCA is designed to compare different products and systems and not to predict the maximal risks associated with single substances. However, LCIA models are still in development and do not yet take all important metal-specific properties and processes into account. They can be improved to provide a more meaningful result in ecotoxicity assessment by critically adopting and adapting advanced knowledge and models from risk assessment.

Agreement was reached that the following aspects are of major relevance for a correct understanding of the fate and toxicity of essential elements and need further elaboration:

- Speciation. This feature of metals, which determines their bioavailability and toxicity, was regarded as a highly desirable extension of LCIA, both in fate and effect modelling. The present focus on total metals concentrations in LCA and LCIA could be overly conservative.
- Persistence. Although metals may remain in a certain compartment of a model or ecosystem for a long time, they are usually not present in their bio-available form, but are rather converted to other species and/or adsorbed to particulate matter (e.g., soils, sediments, suspended matter). Infinite time horizons in steady state effect models could only be appropriate if bio-availability is properly considered.
- Essentiality. Within the essentiality window of essential metals, the possibility of adverse biological effects should be set at zero. Adverse effects may occur above or below that window. Below and within that window the LCA general principle of "less is better" does not apply.
- Bioavailability. As noted above, metals speciation determines bioavailability, which also needs to be included in LCIA. For this purpose the Biotic Ligand Model (BLM) should be used preferentially, with the Free-Ion Activity Model (FIAM) used in cases where the BLM has not been fully developed.
- Characterisation. Because LCA is used for comparative rather than predictive purposes or determinations of absolute risk, it is appropriate to use robust measures of toxicity rather than the lowest measures of toxicity, which are generally interpolated rather than directly measured. On this basis, the characterisation factor should be chosen at the HC50 (geometric mean of EC50) level rather than the HC5 or the NOEC level, based on the most representative, not the most sensitive species.
- Compartments in the multimedia model. A distinction should be made between compartments in the fate model (which should be as inclusive as possible) and in the effect model. If effects are negligible in a given effect compartment, there is no need to consider effects. This may well be the case for essential metals in the ocean.
- Spatial aspects. The consequences of regional differences in bioavailability, background concentrations, and therefore toxicity need to be further elaborated.

The UNEP/SETAC Life-Cycle Initiative was asked to provide recommendations on the integration of the above factors into LCIA methodology. On some issues further research may be necessary beyond these recommendations. The Apeldoorn workshop participants recommend the following working procedures until final recommendations from the UNEP/SETAC Life-Cycle Initiative are issued:

1. The fact that a number of critical issues regarding metals are imperfectly dealt with by present characterisation models for ecotoxicity, should be clearly communicated as part of LCIA reporting. Additionally, business or policy decisions should not, without further discussion, be made based on the results of the currently available (deficient) methods for assessing ecotoxicity in LCIA.
2. The chemical speciation of metals should be taken into account from the inventory phase onwards; emissions should be reported in terms of metal species, preferably in terms of dissolved metal instead of total metal.
3. If the contribution analysis of the LCIA shows that metals have a dominant influence on the results

(and conclusions), a sensitivity analysis should be made with the time horizon for the toxicity impact categories set to 100 years when applicable or with excluding the metals from the impact assessment.

4. The oceans are deficient in essential metals. Therefore additional inputs to the ocean will probably not lead to toxic effects. The characterisation factor for toxicity in oceans of essential metals should be set at zero. For coastal seas, this may well be different.

A full report of the workshop, the underlying scientific report and presentations can be found at www.mep.tno.nl by using the search function for 'Apeldoorn Declaration'.

From left to right: Lionel Aboussouan, Robert Jan Saft, Marianne Schönnenbeck, Michael Hauschild, Katrien Delbeke, Jaap Struijs, Andrea Russell, Helias Udo de Haes, John Atherton, Wim van Tilborg, Chris Karman, René Korenromp, Gerda Sap, Achim Baukloh, Alain Dubreuil, William Adams, Reinout Heijungs, Olivier Jolliet, Arjan de Koning, Peter Chapman, Tom Ligthart.
Not in the picture: Dik van de Meent, Jan Kuyper, René van der Loos, Rein Eikelboom, Frederick Verdonck

Challenges of Ecological Complexity in Ecotoxicology and Risk Assessment

Craig Loehle, *NCASI, cloehle@ncasi.org*
Naperville, IL, USA

Introduction

Complexity is a tremendous challenge in the field of ecology. It impacts the development of theory, the conduct of field studies, and the practical application of ecological knowledge. This is particularly true in ecotoxicology and risk assessment. Complexity is encountered at all scales, and in various guises. In this Learned Discourse I attempt to characterize the types of complexity that exist, and then discuss approaches, issues needing study, and types of analyses likely to be productive.

Sources of Complexity

Complexity in ecology is of at least six distinct types: spatial, temporal, structural, process, behavioral, and geometric. Spatial complexity has received the greatest attention because it is so visible in the forms of vegetation patterns and species distributions. In spite of this attention, our ability to describe or quantify spatial pattern is poor. Terms like "fragmentation" are subjective and not clearly related to organismal responses (e.g., Larivière 2003).

Temporal complexity arises from population dynamics, effects of fluctuating climate and weather, and from spatial complexity. Examples include metapopulation dynamics, extinctions, invasions, succession, predator-prey cycles, etc. Temporal population fluctuations make it difficult to assess the impact of a chemical on a species.

Structural complexity refers to relationships within an ecosystem. Examples include food web structure, community composition, networks of competition and facilitation, etc. Structural patterns must often be inferred from piecemeal observations, which leads to obvious difficulties.

Process complexity refers to processes which contain many steps or components. Examples include mercury bioaccumulation and pesticide degradation in soil. Such multistep distributed processes can rarely be observed directly.

Behavioral complexity is an often-overlooked aspect of overall ecosystem complexity. In contrast to the building blocks of physics, such as ideal gases and identical protons, living organisms exhibit individualistic adaptive behaviors.

Finally, geometric aspects of ecological objects add considerable complexity to systems. An obvious example is a forest canopy or individual tree crown. This type of three-dimensional complexity is both fascinating and frustrating.

Vocabulary

In order to come to grips with complexity, we need a better vocabulary for spatial and temporal patterns. For example, differences in tree crown shape and branch architecture between species and with different growing conditions no doubt exist, but good descriptors for them are lacking. A better quantitative vocabulary is clearly needed for concepts such as fragmentation, food web complexity or structure, heterogeneity, home range, etc. It is particularly important that such concepts be operationally defined so that every investigator does not mean something different when they use the terms.

Scaling

One of the successful approaches to analyzing complexity is scaling. A scaling relation shows how a regularity or pattern exists in terms of scale. Examples include fractal models, self-thinning laws, species-area relations, metabolic rates and home range sizes as a function of body mass.

Fractal models describe how a spatial pattern changes with scale. A self-similar fractal has the same statistical properties at multiple scales. This is a powerful model for scaling spatial pattern. More common in ecology are spatial patterns that are multifractals, in which complexity or pattern changes with scale; however, measurement of fractal objects or patterns is far from straightforward (Loehle and Li 1996).

It has been found that many biological processes scale with body mass (Brown et al. 2002). Such scaling relations could be utilized with advantage in ecotoxicology studies.

Sampling Frames

When considering complex ecological properties, it would be beneficial to give more weight to sampling frames. In the laboratory we need give only minimal attention to the sampling frame. In the field, even simple objects such as birds may have different detectabilities with different methods, and are subject to species-area effects. Complex properties such as food web structure are not