Applying multimedia models to calculate Trophic Magnification Factors (TMFs): exploring basic assumptions and the role of the physical environment

Jon A. Arnot[1], **Lawrence P. Burkhard**[2], **and Liisa Reid**[3]

[1]Department of Physical and Environmental Sciences, University of Toronto Scarborough, Toronto, ON, Canada
[2]U.S. Environmental Protection Agency, Mid-Continent Ecology Division, Duluth, MN, USA
[3]The Canadian Centre for Environmental Modelling and Chemistry, Trent University, Peterborough, ON, Canada

Introduction:

- Chemicals are subject to bioaccumulation ("B") assessment; few measured data are available [1, 2].
- The Trophic Magnification Factor (TMF) is a steady state metric for assessing "B":
  if TMF > 1, then "B"; if TMF < 1 then "not B" (in most cases) [3].
- The TMF is the average factor by which the (lipid) normalized chemical concentration in biota of a food web changes per trophic level. The TMF is derived by linear regression of log transformed (lipid) normalized chemical concentration in biota and trophic position of the sampled biota [3].
- Fugacity (*f*; Pa) is a chemical quantity and a thermodynamic equilibrium criterion.
- Lipid normalized concentration ≈ fugacity.

Objectives:

- Develop, apply and evaluate a model to calculate TMFs.
- Explore differences in selected food web components, chemical mode-of-entry (M-O-E) to the environment, and disequilibrium conditions in the environment on TMFs.
- Use sensitivity analysis to determine key parameters relating to the TMF.

Methods:

- Risk Assessment IDentification And Ranking (RAIDAR) model (**Figure 1**) [4] :
  - combines fate and food web mass balance fugacity calculations at steady state;
  - provides either Level II (equilibrium in air, water, soil and sediment) or Level III (disequilibrium in air, water, soil and sediment) environmental fate calculations;
  - includes a range of representative species residing in air, water, soil and sediment;
  - includes biomagnification and biotransformation processes for vertebrate species.
- RAIDAR revised to calculate TMFs in various food webs (e.g., aquatic, terrestrial, marine, overall):
  - Chemicals with measured TMF data used to evaluate model predictions (**Table 1**) [2].
  - Hypothetical chemicals used to explore maximum TMFs in various food webs.

Table 1: Chemical properties (half-life: *HL* is normalized to a 10 g organism) [2]

Chemical	Log K_{OW}	Log K_{OA}	Biotransformation *HL* (days)	Qualitative rate
Pyrene	5.19	8.73	2.1	moderate
Hexachlorobenzene (HCB)	5.61	7.12	272.9	very slow
Di(2-ethylhexyl) phthalate (DEHP)	7.56	13.01	2.8	moderate
PBDE-47	6.39	10.44	39.5	slow
PBDE-153	7.08	11.89	102.6	very slow
PBDE-209	8.68	15.29	14.5	slow
PCB-52	5.95	8.22	132.0	very slow
PCB-153	6.86	9.45	352.4	very slow
PCB-209	8.27	10.95	731.1	very slow

Results and Discussion:

- Modeled TMFs are in reasonable agreement with measured TMFs (**Figure 2**).
- TMFs can be calculated in various food webs for a range of organic chemicals (**Figure 3**), and thus the RAIDAR-TMF model may be useful for screening-level TMF assessment.
- Chemical disequilibrium in the physical environment (i.e., fugacities in air, water, soil and sediment, and thus "TL 1") can span several orders of magnitude influencing TMFs (**Figure 4**).
- Chemical M-O-E to the environment can influence TMF (**Figure 5**).
- The organisms and food webs selected for measurement influence the TMFs (**Figure 5**).
- Biotransformation half-lives are sensitive parameters, particularly when TMF < 1 (**Figure 6**).

Figure 4: TMFs calculated for HCB and pyrene using all representative RAIDAR species

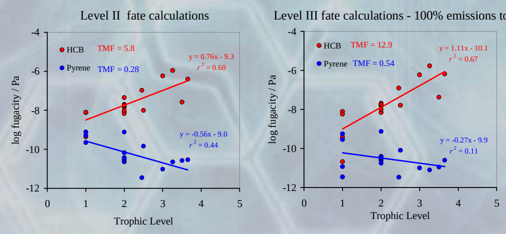


Figure 5: Influence of M-O-E (left) and differences in organisms sampled (right) on TMF

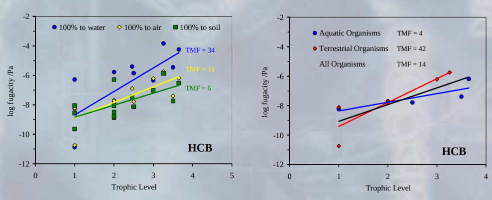


Figure 1: Development of the RAIDAR-TMF model; relative trophic level (TL) of the representative species determined based on selection of dietary preferences

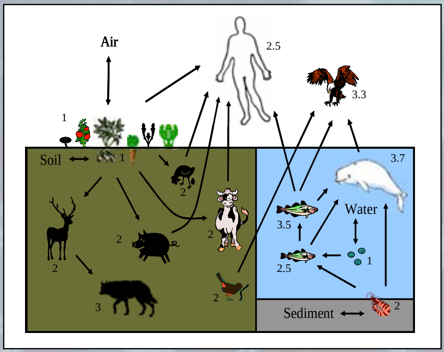


Figure 2: RAIDAR-TMF model evaluation using data from aquatic food webs

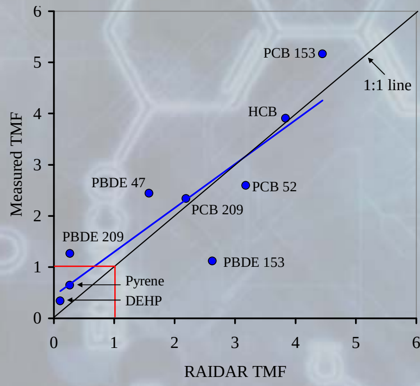


Figure 3: Maximum Level II fate calculation based fugacity ratios (*f*organism / *f*environment)
A: Piscivorous fish; B: Marine mammal; C: Wolf; D: Human – mixed diet

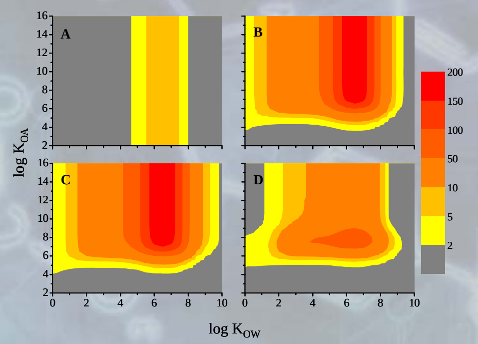
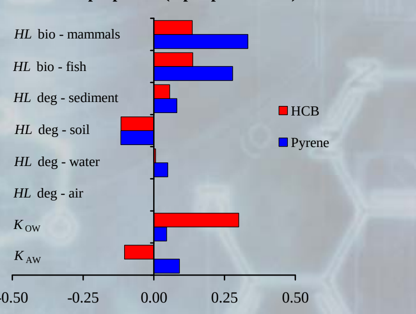


Figure 6: Sensitivity of chemical properties (input parameters) on modelled TMFs



Level III fate calculations - 100% emissions to air; all organisms in the model environment included in TMF calculation

References:

1. Arnot JA, Gobas FAPC. 2006. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in fish. *Environ Rev* 14, 257-297.
2. Burkhard LP, Arnot JA, Embry M, Farley K, Hoke R, Kitano M, Leslie HA, Lotufo GR, Parkerton TF, Sappington KG, Tomy GT. Comparing laboratory and field measured bioaccumulation endpoints. Accepted with revisions *Integr Environ Assess Manag.*
3. Gobas FAPC, de Wolf W, Burkhard L P, Verbruggen E, Plotzke K. 2009. Revisiting bioaccumulation criteria for POPs and PBT assessments. *Integr Environ Assess Manage* 5, 624 – 637.
4. Arnot JA, Mackay D. 2008. Policies for chemical hazard and risk priority setting: Can persistence, bioaccumulation, toxicity and quantity information be combined? *Environ Sci Technol* 42, 4648-4654.

Acknowledgments: Natural Sciences and Engineering Research Council of Canada (NSERC) and Cefic-LRI-ECO15 Project.