November 19, 2003

Lecture 21 Biotic Phase Transfer (Bioconcentration, Bioaccumulation, Bioavailability)

I. **Bioconcentration:** A term coined sometime in the 1970s to refer to "the amount of a chemical residue accumulated by an organism by adsorption, and by absorption via oral or other route of entry, which results in an increased concentration of the pesticide by the organism or specific tissues" (Kenaga 1973)
   A. Residues of compounds accumulate on the external surfaces of organisms as well as internally.
      1. By the original definition of bioconcentration, the accumulation (or uptake) was via surface (i.e., organism's "skin" or integument) and food exposure.
      2. Although bioconcentration and other terms associated with uptake, i.e., **bioaccumulation** and **biomagnification**, have very negative connotations, all organisms "naturally" bioconcentrate nutrients and other chemicals (for ex., any secondary plant metabolites, many of which are biologically active in other organisms)
   B. Today's usage of bioconcentration refers to **non-food** routes of uptake of a chemical into tissue from soil, water, or air.
      1. In the 1980's, the term bioconcentration was distinguished from biomagnification (Ernst 1985), where
         a. **Bioconcentration was the direct uptake** of a substance by an organism from water **without consideration of the ingestion** of contaminated materials. Similarly, for terrestrial organisms, bioconcentration is the direct uptake through the "skin", which is most relevant for invertebrates in soil. However, bioconcentration should also be considered for plants—either through direct exposure of leaf surfaces or roots in soil.
   C. Bioconcentration factor (**BCF**) is defined as the ratio of the measured residue in an organism compared to the residue of the pesticide in the ambient air, water, or soil environment of an organism.
      1. The result of such a process (i.e., the uptake of the chemical from an environmental phase) is reported as the bioconcentration factor, **BCF**, or the ratio of the concentration in the organism and the ambient medium.
         a. $\mathbf{BCF = C_{org}/C_{phase}}$; where phase is generally considered soil or water
      2. BCF may be expressed on a whole body weight basis (fresh or dry) or on fat content basis.
      3. BCFs are experimentally determined but only valid when measured after the body and environmental media burdens of residues have reached a steady state.
      4. Note that equilibrium will not really be reached because the concentrations in the body (as well as the environment) are constantly changing, shifting the process away from true equilibrium.
   D. **Bioaccumulation** refers to the uptake of pollutants via food and water
      1. As for the BCF, a bioaccumulation factor (BAF) can be determined.
         a. Indeed, the BAF is most appropriate when uptake through the integument cannot be distinguished from uptake via ingestion of contaminated food.
   E. Biomagnification
      1. Bioconcentration/Bioaccumulation and Biomagnification may often be confused.

2. **Biomagnification** is considered to result from the direct uptake of a substance by an organism via food and the accumulation of a contaminant at increasingly higher levels in higher trophic levels, i.e., the so-called food chain effect.

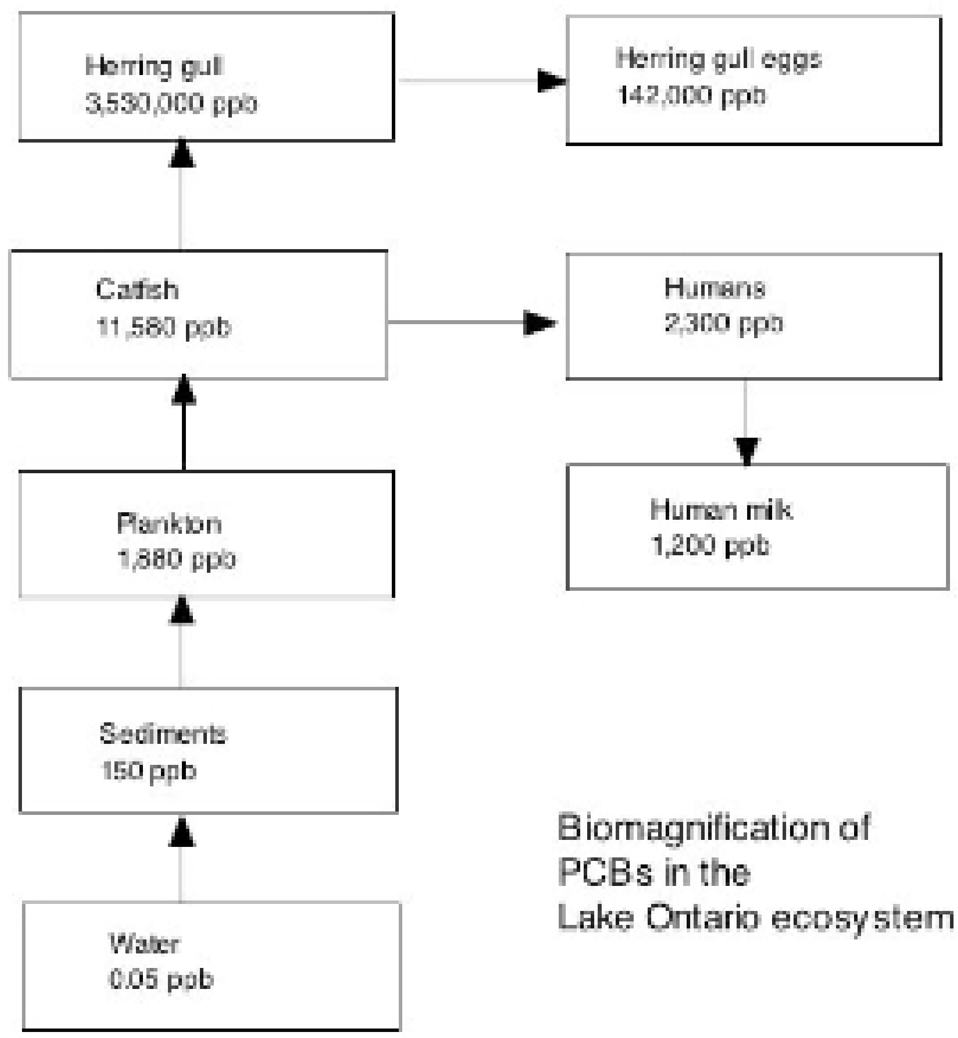

Figure 1. Increase in PCB concentrations among successive trophic levels in Great Lakes basin (Safe, S. 1980, *in* Halogenated Biphenyls, Terphenyls, Naphthalenes, Dibenzodioxins and Related Products, R. K. Kimbrough, ed., Elsevier, citing the Int'l. Joint Commission Report)

3. Biomagnification is the result of bioconcentration and bioaccumulation, but it is distinguishable from these chemodynamic processes.
   a. Biomagnification is characterized by body burdens of a contaminant in higher trophic level organisms (as indicated by tissue concentration) that are higher than in lower trophic organisms that the higher trophic levels are consuming.
4. Food Chain Effects (biomagnification along trophic levels)
   a. One of the early issues in ecotoxicology (before the term was coined) was whether contaminants could be transferred from one trophic level to another, and whether the chemical could accumulate at the highest trophic levels to lethally toxic effects.
      1. This notion of biomagnification was popularized in Rachel Carson's *Silent Spring*.
   b. One early study involved an examination of the transfer of DDT to robins after spraying elm trees; some time after the first year's application in 1950, dying robins were observed, especially after rainfall.

1. Concentrations of DDT in soil after spraying in the top two inches ranged from 6 to 18 ppm.
2. Concentrations of DDT on leaves ranged from 15 - 263 ppm (includes 1 day before the second spray and 1 day after)
3. Earthworms contained from 33-164 ppb DDT
4. Barker (1958) suggested that earthworms tended to come to the soil surface, especially after heavy rains; the earthworms had concentrated DDT by selective feeding on sprayed leaf mulch (concentrations of DDT were ~25 ppb in autumn); robins fed on the earthworms

c. The Barker (1958) study led to the hypothesis that successive predators will inevitably acquire higher residues than their prey contain, but this principle is not well founded because it ignores
   1. The variable degree of assimilation; i.e., the amount of pollutant within the predator decreases as the percentage assimilation decreases.
   2. Growth dilution; growth of the predator increases both food consumption and the mass of tissue within which the pollutant is distributed.
   3. Depuration rate may alter with exposure route
   4. Different tissues and organs within an organism may have different concentration of pollutant, and approach steady states at different rates.
   5. Pollutant concentration will be higher than in the prey only when the rate of food consumption as a proportion of the predator's body weight exceeds the rate constant for excretion plus metabolism.

5. **Food Web Concept**; organisms do not necessarily feed at one trophic level only; therefore, food source or relationships between prey and predator should be considered more of a food web rather than a food chain.
   a. Furthermore, the type of food eaten will vary by season and year
6. The steady-state concentration of a pollutant will vary among trophic levels depending on the half-life of the pollutant and the daily food intake of the next higher trophic level as a proportion of body weight
   a. The table below (Table 1) shows the steady-state concentration for pollutants with different half-lives in five successive trophic levels, assuming a concentration of 1 μg/g in individuals of the first level. Animals are treated as single compartments, with first-order kinetics for intake and loss of pollutant, and 10% assimilation of the ingested pollutant

Table 1. Effect of trophic level and contaminant half-life on concentration in successive trophic levels

Trophic Level	Daily Food Intake As Proportion of Body Weight	Steady-state Concentration for $T_{1/2}$ (days) of			Concentration Factors for $T_{1/2}$ (days) of		
		10	50	150	10	50	150
1	1.00	1	1	1	-	-	-
2	0.04	0.58	2.9	8.7	0.58	2.9	8.7
3	0.20	0.17	4.2	37.5	0.29	1.4	4.3
4	0.10	0.024	3.0	81.1	0.14	0.72	2.2
5	0.05	0.0017	1.1	87.8	0.07	0.36	1.1