Bioaccumulation: definitions and implications

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Bioaccumulation describes a chemical's tendency to be taken up and stored by living organisms from their environment and diet. It is widely used at EU and global levels to prioritise substances that may be persistent, bioaccumulative and toxic (PBT) for regulatory action. Bioconcentration is the uptake of chemicals into the body uniquely from water (e.g. through the gills), whereas bioaccumulation is uptake through water and food. Biomagnification occurs when body concentrations are found to increase up the food chain. Often the word bioaccumulation is used as a generic term for all the above processes.

Bioaccumulation: up-take and retention via any route
Although often viewed as a negative effect of man-made chemicals, bioaccumulation is in fact a necessary process for organisms' survival. Animals bioaccumulate vitamins A, D and K, trace elements, essential fats and amino acids.

Bioaccumulation is considered to be of concern when substances are present at harmful levels. It can occur via all environmental and dietary routes of exposure, including respiration (eg through the gills) or digestion of food (through the gut). For air-breathing animals, inhalation of substances is included in bioaccumulation, but dietary exposure is generally considered more important. The extent of bioaccumulation depends on the organism's rates of uptake, distribution, metabolism and excretion. The bioaccumulation factor (BAF) indicates a chemical's tendency to bioaccumulate from food. It is the ratio – in a steady state situation – of the concentration of the chemical inside an organism to the concentration in its food.

Bioconcentration: up-take uniquely from water
Bioconcentration occurs when an organism takes up and concentrates a chemical directly from the surrounding environment. For aquatic organisms that breathe through gills, bioconcentration from water is the major up-take route for many substances.

The bioconcentration factor (BCF) gives an indication of a chemical's ability to build up within an organism. It is the ratio of the chemical's concentration in an organism compared to the surrounding water. BCF values above 1 l/kg indicate bioconcentration; levels above 2,000-5,000 l/kg are considered a potential concern.

Factors affecting bioconcentration and bioaccumulation
The tendency of a chemical to bioconcentrate depends on:

- Its physical and chemical properties, including solubility in water and in fat, molecular weight, and ease of metabolism (transformation of the chemical in the body) or degradation (transformation in the environment);
- Environmental conditions, including water quality (hardness, dissolved and particulate organic carbon content, pH, etc);
- The nature of the organism, including its ability to metabolise the chemical and its fat (lipid) content. Animals with a higher fat content, such as those living in cold climates, tend as a result to have higher body burdens of fat-loving (lipophilic) chemicals.

Bioaccumulation depends on the same factors as bioconcentration, plus dietary factors (feeding rate, numbers and proportions of contaminated foods eaten) and how readily the organism absorbs the chemical from its food.

Biomagnification through the food web

Biomagnification is defined as accumulation and transfer of substances via the food web, with an increase of concentrations in organisms at successive trophic levels. The biomagnification factor (BMF) is the ratio of the concentration of a substance in the predator compared with the prey. To assess biomagnification, measured body burdens should be adjusted for lipid content. Food webs are highly complex, and feeding relationships between organisms must be verified through existing ecological techniques.

A critical review of scientific literature published between 1970 and 2000 concluded that biomagnification occurs, but is less common than generally believed due to inaccurate reporting of results and confusion about definitions. For example of all papers that claimed biomagnification occurred for methyl mercury, PCB and DDT/DDE, respectively 42%, 54% and 67% correctly demonstrated this while the other studies were flawed.

Less widely known is that certain naturally-made organohalogens (eg some halogenated bipyrroles thought to be produced by marine organisms) have been shown to biomagnify in an Arctic invertebrate-fish-seabird food web.

Estimation of BCFs and BAFs

Bioconcentration and bioaccumulation of many organic substances is linked to their relative solubility in lipids (found in fatty tissues) and water. For some substances bioaccumulation potential can be predicted based on its relative solubility in octanol (representing fatty tissue) and water. This is expressed as the logarithm of the octanol-water partition coefficient: log K_{ow}. A substance with a log K_{ow} higher than three has a greater preference for fatty tissue and therefore a high bioaccumulation potential. However, this takes account only of the chemical's physicochemical properties, and not of its behaviour in living organisms such as metabolism. Therefore the log K_{ow} is only an indicator of the bioaccumulation *potential*.

Substances with a molecular weight higher than 800 do not easily bioaccumulate. This is due to their size, which may hinder their passage through the cell membrane. BMFs cannot be estimated reliably; they must be measured experimentally.

Water: a key source of bioaccumulative chemicals

Water is a much more important source of bioaccumulative chemicals – even lipophilic ones - than food. For example, in trout, uptake of tetrachlorobenzene from contaminated food is relatively minor; most is absorbed through the gills. Even for many sediment-dwelling invertebrates that ingest large amounts of sediments, most contaminant uptake is from surrounding pore water.

Consequences for regulatory approaches

Environmental legislation often uses a chemical's log K_{ow} – viewed as an indication of its potential to bioaccumulate – to prioritise substances for regulatory action. As a pragmatic screening tool, this has a sound scientific basis. However, for a substance to be positively identified as bioaccumulative, experimental evidence is needed.

Although the EU Technical Guidance Document on Risk Assessment of Chemicals estimates BMFs based on K_{ow} values, there is little scientific basis for this. Events in real food webs are highly complex and the scientific literature is sometimes flawed. As a result, such simple estimates are of limited value. Assessment of risks caused by biomagnification should ideally be based on experimental evidence. If the risk is estimated, each substance should be assessed by experts on a case-by-case basis.