Bioaccumulation factors for PCBs revisited

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Introduction

Bioaccumulation factors (BAF) describe the net increase of organic contaminants such as PCBs dissolved in water ($[PCB]_{WD}$) to biota ($[PCB]_{BIOTA}$): ($BAF=[PCB]_{BIOTA}/[PCB]_{WD}$, L kg^{-1} lipid[1]. The bioconcentration factor (BCF) is a special case of bioaccumulation in which BCF is the equilibrium ratio between PCBs in biota and the surrounding environment due to abiotic exposure only; however, BAF and BCF are calculated the same way. Although usually calculated on a wet weight basis[1], lipid normalized BAFs and BCFs are more useful when comparing across animals as variation due to variable lipid content is eliminated.

The BCF for a chemical on a wet weight basis can be predicted from the octanol-water partitioning coefficient (K_{OW}) by models such as BCFWIN™ used by the US EPA. In absence of environmental measurements, these predicted BCFs are useful tools for exposure and risk assessments of chemicals; however for animals with dietary exposure and uptake of chemicals bioaccumulation may be under-predicted.

As field BAFs show large variability, we have summarized data from Arctic marine ecosystems and from the Great Lakes of North America to investigate uncertainties of field measurements of BAFs and factors affecting the calculated values. Specifics and more information about the present work can be found elsewhere[2].

Materials and Methods

We selected studies which report both water and zooplankton PCB concentrations as well as other work in which water and zooplankton were collected in the same region or lake but analyzed by separate groups (see [2] for references). BAFs were compared to the ones predicted from K_{OW}, they were compared among seasons and among zooplankton size fractions.

Correlations between field BAFs and measured PCB concentrations were determined to investigate if BAFs were dependent on exposure level.

Results and Discussion

The marine and freshwater BAFs for individual PCB congeners ranged widely around the 1:1 relationship with K_{OW}. The difference between maximum and minimum marine log BAFs ranged from 0.18 to 7.78 for the individual congeners, with largest difference for high K_{OW} congeners (n=43, R_P= 0.370, p=0.015. R_S=0.295, p=0.054). For the Great Lakes, differences between maximum and minimum BAF ranged from 0.002 to 4.01 for the individual congeners, and decreased slightly with increasing K_{OW} (n=86, R_P= -0.231, p= 0.032. R_S=-0.155, p=0.153). Thus, the relationship between differences in observed freshwater log BAFs and log K_{OW} was opposite to that of the marine studies, but neither the marine nor the freshwater non-parametric correlations were significant.

Marine BAFs did not correlate with zooplankton PCB concentrations (ΣPCB r_S=0.20, p=0.704, ΣPCB_{10} r_S=0.25, p=0.486), and indicates that the PCBs in zooplankton were determined in a similar and comparable way among studies. Lake zooplankton PCB concentrations, however, were positively correlated with BAFs (ΣPCB r_S=0.93, p=0.0002, ΣPCB_{10} r_S=0.96, p=0.0005). The positive correlation may be due either to compromised PCB measurements, which seems unlikely given the elevated PCB levels in biota and the high extraction efficiency of lipids and associated PCBs, or it may be due to inclusion of a wide variety of zooplankton size fractions and trophic guilds in the different studies.

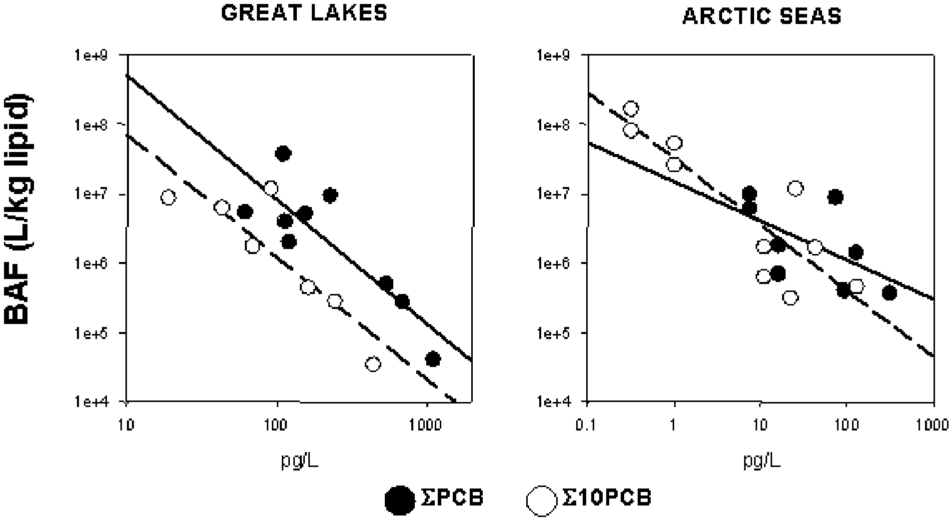

Figure 1. Relationship between BAFs and measured zooplankton and water concentrations in marine and freshwater studies[2].

BAFs decreased significantly with increasing seawater and lake PCB concentrations (**Fig. 1**). The significant correlations between BAFs and water PCB concentrations suggest either that some PCB measurements were compromised or that different sampling techniques (water collection, particle separation, volume extracted, extraction method) resulted in differences in fractionation of dissolved PCBs. Differences in water PCB measurements most likely explain the large variation in BAFs among the Arctic marine studies, as PCB concentrations in similar zooplankton species did not differ between the studies, whereas the water concentrations differed widely[3,4]. When quantifying PCBs in water, water collection and contaminant extraction is the step associated with most uncertainties[5], and early work may not have thoroughly accounted for shipboard and laboratory contamination[6]. Overestimated dissolved water PCB concentrations were also noted when reviewing BAFs from the early 1970s[7].

Both marine and freshwater BAFs vary seasonally due to variations in lipid content of zooplankton, as well as with the suspended particulate matter concentrations, which influence the bioavailability of a chemical, but the seasonal variation in log BAFs for ΣPCBs was less than 1 order of magnitude[8,9] (**Fig. 2**). Log BAFs for ΣPCBs varied with size fraction of marine zooplankton, but less than 0.5 orders of magnitude[8] (**Fig. 2**). Also, calanoid copepods species with different body size showed different BAFs, however, usually less than 0.5 orders of magnitude[4]. Thus, seasonal, zooplankton or size specific BAF variation was much lower than the BAF difference of 2-3 orders of magnitude observed between studies carried out at the same time of year including the same zooplankton species[2-4].

a) Marine - Resolute Bay b) Freshwater – Lake Michigan GTB

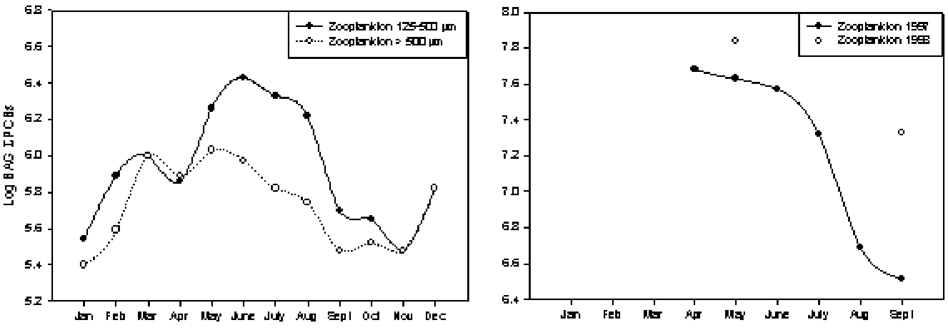

Figure 2. Seasonal variation in a) marine (*8*) and b) freshwater (*9*) zooplankton BAF.

Higher BAFs than predicted by $K_{OW,}$ and a curvilinear relationship between log BAF and log K_{OW}[e.g. 3], suggest that PCB concentrations in zooplankton are not in equilibrium with water[1,3,4]. Biomagnification may occur between the lowest trophic levels of the food web[10,11], leading to higher BAFs than predicted from K_{OW}[12]. One reason why this has often been overlooked may be erroneously high quantification of PCBs in water, as indicated by the negative relationship between BAFs and measured water PCB concentrations. Zooplankton biomagnification factors (BMF, $[PCB]_{ANIMAL}/[PCB]_{DIET}$[1]) from studies carried out in the early 1970s were ≥ 1, indicating biomagnification also at lower trophic levels[7]. Unfortunately, it was not possible to calculate BMFs in the present study because prey items of the zooplankton were not analyzed, and because different size fractions of zooplankton consist of various trophic guilds[8], between which the trophic links are not well established. However, a feeding zooplankton community showed rapid PCB uptake and increased bioaccumulation compared to non-feeding zooplankton community[10], probably related to over-saturation of PCBs since the elimination rate is slow and equilibrium between water and biota is therefore not reached[3]. In the feeding zooplankton community, most BAFs (organic carbon adjusted) were 1-2 orders of magnitude higher than K_{OW}, whereas they were in the range of K_{OW} values in non-feeding situations.

The present study has demonstrated that BAFs for PCBs are greater in recent Arctic marine and Great Lakes studies than previously reported in the same regions, and that they are at least 10 times higher than predicted from K_{OW}[2]. It seems difficult to establish exact BAFs for PCBs in marine and freshwater zooplankton, as the variability of the system and the use of different methods for water and zooplankton results in BAFs that vary more than one order of magnitude. The negative dependence of BAFs to PCB exposure from water, in combination with the wide variety of methods used in water PCB measurements, suggest that earlier BAFs were too low due to overestimated water measurements. In addition, partitioning into other organic phases and dietary uptake of contaminants may lead to BAFs for PCBs above the ones predicted by K_{OW}.

The large variability of BAFs for PCBs in zooplankton illustrated in the present study needs to be considered in future assessments of potential new bioaccumulative chemicals that rely on laboratory or field measured BAFs, such as the European Union **REACH** program, the nomination of chemicals as future POPs under the Stockholm Convention and other assessment programs.

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