Studying the bioaccumulation of chemicals in aquatic organisms: PCBs in fish

Margherita Panzieri[1,2,3], Nadia Marchettini[1,2], Enzo Tiezzi[1,2]
[1]*Department of Chemical and Biosystems Sciences and Technology, University of Siena, Italy.*
[2]*A.R.C.A. Onlus (Associazione Ricerca e Consulenza Ambientale), Italy.*
[2]*RINA SpA, Italy.*

Abstract

PCBs are mixtures of chlorinated biphenyls with different degrees of chlorination, are hydrophobic chemicals, very persistent and bioaccumulative in aquatic organisms, especially in fishes that are at the end of the food chain and are the final receptors of toxicants. PCBs can be classified as narcotics: they produce no change in the biophase and elicit anesthetic reversible effects. Bioaccumulation in fish can occur through the food chain (biomagnification) and through partitioning between the water environment and the fish body (bioconcentration) and depends both from the physicochemical properties of the chemicals and on the morpho-physiological characteristics of the fish. All the PCBs residues in aquatic organisms arise from human activity in that they are not present in the natural environment and can be used as an index of human impact on ecosystems.
Here we study the bioaccumulation in fish of PCB 1254 and 1260 for different concentrations in the water of two polluted creeks inside the Oak Ridge Reservation (USA). The study is carried out using an uptake model, FGETS [1] that considers both bioconcentration and biomagnification. The results are validated with measures of bioaccumulation in the fish species under study, *C. commersoni*, and with its distribution in the water body, highly influenced by bioaccumulation of PCBs. The results obtained demonstrated how powerful is the modelling approach to study bioaccumulation of hydrophobic chemicals in fish and to evaluate the magnitude of human impact on natural environment.

Introduction

PCBs can be classified as xenobiotic chemicals, which derive their name from the Greek words "ξενος" meaning foreign and "βιος" meaning life: they are chemicals foreign to life, which are usually derived synthetically or from an abiotic process. Xenobiotic chemicals are pollutants in the biosphere although not all pollutants are xenobiotic chemicals [2].
PCBs, once discharged in the water body, can accumulate in aquatic biota following two routes: biomagnification from the food and bioconcentration from the water environment. The relative importance of the two mechanisms changes depending on the type of aquatic organism considered. For fishes, located at the top of the food chain, biomagnification is quite important and is determined by the specific diet of each species. The morpho-physiological characteristics of the fish are important both for biomagnification and bioconcentration.
In this paper we use a mathematical model by Barber [1], FGETS (Food and Gill Exchange of Toxic Substances) which considers, as the name says, both biomagnification, based on the specific fish diet, and bioconcentration, driven by thermodynamic potential [3]. The model is applied to find bioaccumulation in fish of two PCBs congeners, PCB 1254 and PCB 1260 in two creeks which flow inside the Oak Ridge Reservation in East Tennessee (USA) and receive chemical pollutants from the federal research facilities located in the Reservation. The model is run for *Catostomus commersoni*, a fish species well representative of the fish fauna of Tennessee, and its calibration is made with bioaccumulation measures. Comparison of the results with the fish distribution at different stations located along the streams gradient help to find a correlation between PCBs pollution and the fish abundance.

Methodology

In bioaccumulation studies the environment is considered to be made up of a number of different phases, such as water, air, soil, and biota. When a chemical is discharged it distributes among different phases according to its properties; at equilibrium the concentrations in each pair of phases are characterized by the partition coefficient K which is the ratio of the concentrations in the two phases and is constant. Dealing with water pollution, the water-to-biota partition coefficient determines bioaccumulation. Bioaccumulation of organic hydrophobic chemicals, such as PCBs, mainly happen in the lipid body fraction of the organisms. For this reason, by the end of the 60s researchers began to use the n-octanol-to-water partition coefficient (K_{ow}) as a property which could be used to quantify the bioaccumulation capacity of compounds (Hansch, 1969 [4]), being n-octanol well assimilable to animal fat.

Transactions on Ecology and the Environment vol 49, © 2001 WIT Press, www.witpress.com, ISSN 1743-3541

FGETS is an individual-based upatke model that describes passive bioaccumulation of organic chemicals from the aqueous environment and contaminated food in fish [1]. It is based on the physicochemical properties of the chemicals and on the morpho-physiological characteristics of the fish. The n-octanol/water partition coefficient determines the partitioning of the chemical between the fish's lipid and the aqueous environment, while molecular volume is used to compute the aqueous diffusivity.

It simulates the bioaccumulation of nonmetabolized organic chemicals through a set of diffusion and forced convection partial differential equations, coupled with a process-based fish growth formulation. The fish's total body burden, B_f, is given by the diffusive mass fluxes across the gills, from the water, J_g, and across the intestine from the food, J_i:

$$\frac{dB_f}{dt} = J_g + J_i$$

The dynamics of fish body weight, W, can be written as:

$$\frac{dW}{dt} = F - E - R - EX - SDA$$

where F, E, R, EX, and SDA are mass fluxes from feeding, egestion, respiration, excretion, and specific dynamic action.

The case study

FGETS was used to determine bioaccumulation in fish of PCB 1254 and PCB 1260 in two creeks that flow inside the Oak Ridge Reservation built in East Tennessee (USA) in 1940s as support facilities to Manhattan Project. The Reservation presents a high polluted environment, due to chemical release from the laboratories here located. In particular the water of the creeks East Fork Polar Creek and its tributary Bear Creek has low water quality and reduced aquatic biota especially in the upper sites located further from the mouth of the two creeks.

A typical fish of this region, *Catostomus commersoni*, was chosen as bioindicator of the local fish community health. FGETS model was calibrated for this fish giving all the specific parameters and was used to quantify the bioaccumulation of PCBs in its body. Bioaccumulation measures in *Catostomus commersoni* of the two PCBS congeners were available for the station located at 0.6 km of Bear Creek. Once calibration of the model was done using these data,

Transactions on Ecology and the Environment vol 49, © 2001 WIT Press, www.witpress.com, ISSN 1743-3541

it was run to find bioaccumulation of PCBs 1254 and 1260 in *Catostomus commeersoni* given their water concentrations. The reference year is 1993.
Allometric feeding was assumed to describe fish growth and the "food web" simulation mode of FGETS was chosen to simulate field conditions with feeding based on the diet of the particular fish. Parameterization of the model for the two PCB congeners was done using the physical chemical properties of the compounds. K_{ow}, the *n*-octanol/water partition coefficient [5,6,7] for the PCB present in the highest percentage in each mixture, was used for the two congeners.
In addition to water concentrations of the two PCBs and to their bioaccumulation values in *Catostomus commersoni,* for every station of the two creeks were also collected the total number of the present fish species and the number of *Catostomus commersoni*. These measures were used to obtain a sort of validation of the model.

Results

The distribution of *Catostomus Commersoni* and the total fish species number along the two creeks for different stations located at growing kilometers from the mouths of the two creeks are given in Table 1.

Table 1. Distribution of *Catostomus commersoni* in Bear Creek and in East Fork Poplar Creek

Station (km)	*Catostomus commersoni* number*	Total fish species number*
Bear Creek		
0.6	0	17
3.3	2	10
7.8	69	7
9.4	12	7
9.9	33	6
11.0	0	4
11.8	0	3
12.3	0	4
East Fork Poplar Creek		
6.3	0	18
13.8	1	16
23.4	60	14

* Referement year: 1993

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The total number of fish species, that is the fish biodiversity, results low, particularly in Bear Creek, where the lowest values are found in the upper sites closer to waste disposal areas. *Catostomus commersoni* is absent in these sites from kilometer 11.0 to 12.3 of Bear Creek but is also absent at the mouths of both creeks,. The highest abundance of this species is in the middle of Bear Creek (from 7.8 to 9.9 kilometers) and in the uppest station of East Fork Poplar Creek. Thus, although this fish species is well representative of the local fish fauna, its distribution along the two streams gradients has not the same trend of the fish biodiversity.
PCB 1254 and PCB 1260 water concentrations and maximum bioaccumulation in *Catostomus commersoni* are given in Table 2 for both streams. The set of data relative to bioaccumulation was extended to all the stations using FGETS, in that direct measures were available, as previously said, only for the station located at km.0.6 of Bear Creek.

Table 2. Water concentration and maximum bioaccumulation of PCB 1254 and PCB 1260 in *Catostomus commersoni* in Bear Creek and in East Fork Poplar Creek

Station	Water concentration*		*Catostomus commersoni* maximun bioaccumulation*	
(km)	PCB 1254 (ppb)	PCB 1260 (ppb)	PCB 1254 (ppm)	PCB 1260 (ppm)
Bear Creek				
0.6	0.30	0.30	0.99	1.01
3.3	1.00	1.00	2.98	3.01
7.8	0.96	0.96	2.86	2.90
9.4	0.99	0.99	2.95	2.98
9.9	0.96	0.96	2.86	2.90
11.0	1.00	1.00	2.98	3.01
11.8	1.00	1.00	2.98	3.01
12.3	1.10	1.10	3.26	3.30
East Fork Poplar Creek				
6.3	0.16	0.26	0.60	0.88
13.8	0.63	0.52	1.93	1.64
23.4	0.15	0.77	0.57	2.35

* Referement year: 1993

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The concentration and the bioaccumulation of the two congeners show the same values and the same trend along Bear Creek, while in East Fork Poplar Creek are different. Water concentration data result high in comparison with the value of 0.05 ppb given as criterion for fresh water and aquatic life protection by the U.S. EPA [8].
In East Fork Poplar Creek bioaccumulation is lower than in Bear Creek and this is consistent with the higher fish biodiversity found in this stream. In both creeks the bioaccumulation values appear too high, in consideration that a whole-body concentration in fish of about 229 ppm was found to kill guppies [9].
Figure 1 and Figure 2 show the correlation of the two PCBs concentrations in *Catostomus commersoni*, the distribution of *Catostomus commersoni* and the total fish species number, respectively along Bear Creek and along East Fork Poplar Creek .
In both streams *Catostomus commersoni* distribution has a good correlation with the PCBs bioaccumulation data, except for the stations located downstream, at km.0.6 in Bear Creek and at Km.6.3 in East Fork Poplar Creek, where the bioaccumulation values found using the model are quite low, but this species is not present. One explanation could simply be a low affinity of this fish species to live at the mouths of streams.
The fish biodiversity, given by the total number of fish species, curiously results more consistent with the PCBs bioaccumulation values than the distribution of the fish species under study for which the model was calibrated.
Anyway, as the two figures show, there is a good fitting between the bioaccumulation values found using the model and the distribution of the fish species and fish biodiversity, and this can be considered a good validation of the model .

Conclusions

The results obtained in this study show that the modelling approach is a valid methodology to study the problem of bioccaumulation of organic ecotoxicants in fish and allow the conclusion that the loads of ecotoxicants in the effluents strongly affect the biotic compartment and consequently the biodiversity of the two creeks.

Transactions on Ecology and the Environment vol 49, © 2001 WIT Press, www.witpress.com, ISSN 1743-3541

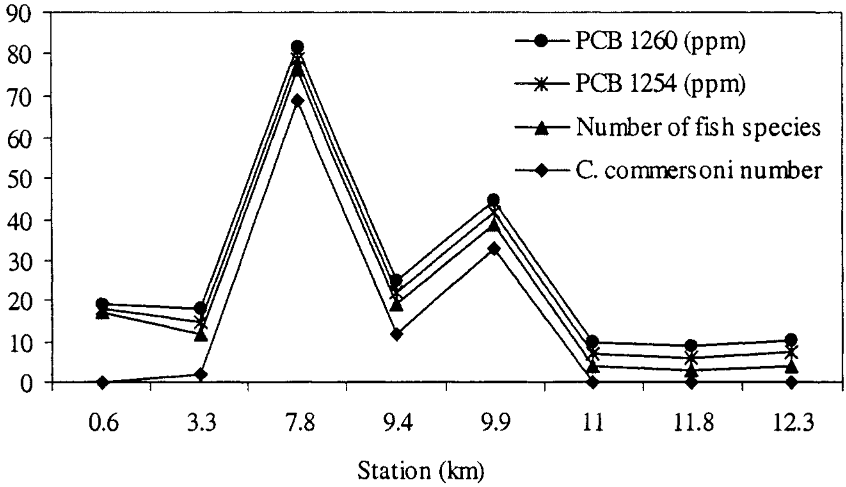

Figure 1: Number of fish species, *C. commersoni* distribution and PCBs bioaccumulation in Bear Creek in 1993.

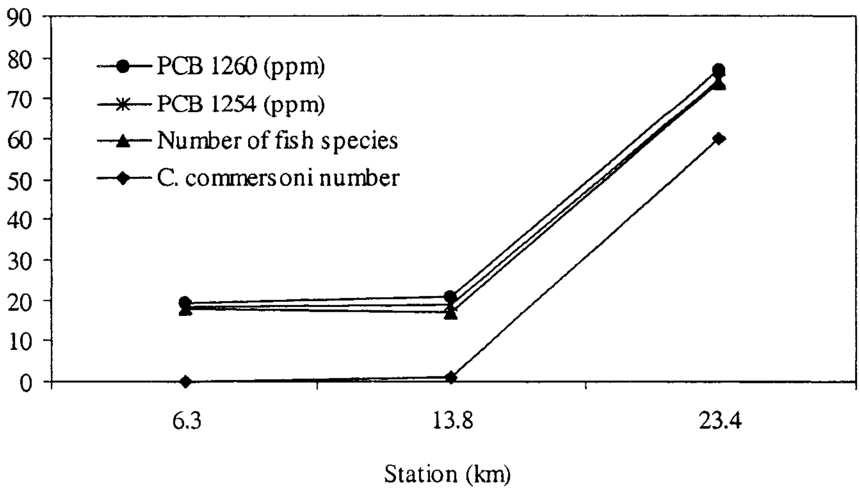

Figure 2: Number of fish species, *C. commersoni* distribution and PCBs bioaccumulation in East Fork Poplar Creek in 1993.

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