Determinants of the Short Term Dynamics of PCB Uptake by the Plankton.

by

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Abstract

Many equations show that various aspects of the ecological fate of a contaminant are partly determined by chemical structure, but few studies combine such "quantitative structure-activity relations" with environmental properties that may modulate those effects, so the importance of such properties remains unquantified. This study determines the effects of variations in suspended biomass, dissolved and colloidal organic carbon, and pH on the time course of 2,2',4,4',5,5'-hexachlorobiphenyl uptake by laboratory cultures of <u>Selenastrum</u> <u>capricornutum</u>. Variations in pH had no effect, but uptake was enhanced by higher levels of biomass (in ppm by volume) and depressed by higher levels of organic carbon (Abs, m^{-1}, measured as absorbance at 440 nm). The laboratory coefficients for these measured effects on hexachlorobiphenyl were combined with existing relations based on molecular connectivity (X) or capacity ratio (K') to yield semi-empirical equations to predict the instantaneous rate of uptake (rate, % min^{-1}) and bioconcentration factor (BCF) of organic contaminants as:

$$\text{Log rate} = -3.30 + 0.32\,X + 1.1\,\text{Log biomass} - 0.42\,\text{Log Abs}$$

$$\text{Lof BCF} = 4.11 + 0.86\,\text{Log}\,K' - 0.87\,\text{Log biomass} - 0.22\,\text{Log Abs}$$

The utility of these equations was assessed by comparing time courses of hexachlorobiphenyl uptake predicted from them with time courses observed in water from eleven Quebec lakes. Plots of observed vs predicted values from three replicate runs for each lake had a mean coefficient of determination (r^2) of 0.84 (range = 0.64 to 0.95); the average slope (0.84) did not differ from unity (range = 0.49 to 1.75) nor did the average intercept (2.1) differ from zero (range =

-6.2 to 11.2). Similar predictions which ignore the effects of color and biomass had similar r^2 values (mean = 0.8, range = 0.51 to 0.93) in plots of observed vs predicted uptake, but the higher slopes (mean = 2.80, range = 1.52 to 3.73) and lower intercepts (mean = -6.7, range = -19 to 6.5) indicated that the prediction based only on contaminant properties underestimated observed uptake.

Résumé

Plusieurs équations démontrent que de nombreux aspects de l'impact environnemental d'un contaminant sont partiellement déterminés par la structure chimique de ce dernier. Seules quelques études combinent les relations quantitatives entre la structure chimique d'un contaminant et ses activités biologiques, avec les propriétés environnementales qui peuvent altérer ces effets. L'importance de ces propriétés demeure donc trop souvent ignorée Cette étude évalue les effets occasionnés par une variation de la biomasse en suspension, du carbone organique dissout et colloidal, et du pH sur la course temporelle d'assimilation d'hexachlorobiphényl-2,2',4,4',5,5' par une culture de l'algue verte Selenastrum capricornutum. La variation du pH n'a eu aucun effet, cependant, le taux d'assimilation a été rehaussé par les concentrations élevées en biomasse (en ppm par volume) et réduit par les concentrations élevées en carbone organique (Abs, m^{-1}, mesurée comme étant l'absorbance à 440 nm). Les coefficients expérimentaux de ces effets ont été combinés aux relations existantes basées sur la connectivité moléculaire (X) ou le facteur de capacité (K'). Des equations semi-empiriques ont été créés pouvant prédire le taux d'assimilation (rate, % min^{-1}) et le facteur de bioconcentration (BCF) des contaminants organiques;

$$\text{Log rate} = -3.30 + 0.32\ X + 1.1\ \text{Log biomasse} - 0.42\ \text{Log Abs}$$

$$\text{Log BCF} = 4.11 + 0.86\ \text{Log}\ K' - 0.87\ \text{Log biomasse} - 0.22\ \text{Log Abs}$$

L'utilité de ces équations fut evaluée en comparant les courses temporelles d'assimilation prédites par celles-ci avec les courses temporelles observées en utilisant l'eau de onze lacs du Québec. Les graphiques représentant les valeur observées en fonction des valeurs prédites, issues de trois réplicats effectués

en laboratoire pour chaque lac, avaient un coefficient de determination moyen (r^2) de 0.84 (variation = 0.64 à 0.95), une pente moyenne (0.84) non differente de l'unité (variation = 0.49 à 1.75) et un abcisse à l'origine moyen (2.1) non différent de zéro (variation = -6.2 à 11.2).

Les graphiques représentant les valeurs observees en fonction des valeurs prédites utilisant les équations qui ignorent les effets de la couleur et de la biomasse avaient des valeurs de r^2 similaires (moyenne = 0.8, variation = 0.51 à 0.93) cependant leur pente était plus elevée (moyenne = 2.80, variation = 1.52 à 3.73) et leur valeur d'abcisse à l'origine inférieure (moyenne = -6.[illegible] variation = -19 à 6.5). Ces résultats indiquent que les predictions basees uniquement sur les propriétés du contaminant à l'étude sous-estime la course temporelle d'assimilation observee.

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Preface

The regulations of the Faculty of Graduate Studies and Research of McGill University require the following statements

This thesis is presented in the form of one paper, to be co-authored by my supervisor, Dr. R. H. Peters, for submission to scientific journals as permitted by Faculty regulations.

This thesis constitutes a contribution to original knowledge as follows

(1) The environmental variables, biomass and colour affect the instantaneous rate of uptake and bioconcentration factor (BCF) of 2,2',4,4',5,5'-hexachlorobiphenyl by the green alga Selenastrum capricornutum while the pH does not affects either.

(2) Predictive equations developed from relationships between physico-chemical properties of PCB and the instantaneous rate of uptake and bioconcentration factor were improved by including the laboratory coefficients of the effects of biomass and colour Strong correlations exist between the observed instantaneous rate of uptake and BCF from 11 lakes of Québec and values predicted from the equations Equations using physico-chemical properties alone were less effective

Acknowledgments

I am infinitely grateful to my supervisor, Dr. R.H. Peters, without whom this thesis would never have reached its completion. I consider myself extremely fortunate to have worked under the supervision of a scientific thinker of great vision yet also a joyful man with an open mind, always available for help and encouragement

En second lieu, j'aimerais remercier Helène Mailhot pour son support technique et moral durant les deux annees qu'à durée cette thèse. Je désire également remercier Donald St-Laurent d'Environnement Canada de même que, Jérome Dion, Richard Leboeuf, Denise Cormier, Anne-Marie Cousineau, Sylvie Donato, Martin Perusse, Sylvain Menard et Ghislaine Durot pour leur contribution active a cette recherche et leur précieuse amitie.

A tous mes frères et soeurs, Michel, Jacqueline, Johanne, Jean-Maurice et François, je dis un gros MERCI Finalement, je ne remercierai jamais assez ma mere, Rolande, pour la confiance qu'elle me porte, ses encouragements, sa determination et son dynamisme qui me servent si souvent de modeles, sans compter son inepuisable source de tendresse.

General introduction:

In 1976, the U.S. EPA proposed regulatory controls under the "toxic substances controls act" to discontinue the use of PCBs in heat transfer systems and to initiate the replacement of these systems with non-PCB units to prevent food contamination in industry (Cairns & al., 1986). Since then, PCB production and release into the environment have declined. However, significant quantities are still in use in older electrical equipment (Tanabe, 1988) and there is good reason to worry about the present and future concentrations of PCB in the environment. PCBs are now globally distributed in the environment, as evidenced by their detection in the atmosphere, hydrosphere, and biosphere from the Arctic to the Antarctic (Tanabe & Tatsukawa, 1986). Recent studies have also demonstrated the presence of highly toxic PCB congeners such as 3,3',4,4'-tetrachlorobiphenyl, 3,3',4,4',5-pentachlorobiphenyl and 3,3',4,4',5,5'-hexachlorobiphenyl in commercial PCB mixtures and biological samples, including humans tissues (Tanabe & al., 1987).

Laboratory tests show PCBs to be carcinogenic and to affect normal fertility, pregnancy, birth and development (Fuller and Hobson, 1986). Accidental poisoning of human beings from PCB contaminated bran-oil shows that PCB can cause acne-form eruptions and pigmentation of the skin, deformit. of the nails, increased eye discharge and, in severe cases, enlargement of the follicular pores all over the body surface, to name just a few symptoms (Higuchi, 1976; Kuratsune, 1980; Chen & al, 1981).

PCBs are a class of synthetic chlorinated organic compounds. Biphenyl is the basic structural unit, and chlorine atoms may be added at positions 2 to 6 and 2' to 6' resulting in the potential production of 209 species of chlorobiphenyls (Sawhney, 1986). PCB's do not easily break down chemically or naturally, and burn only at very high temperatures. Even then, they may form co-contaminants such as poly-chlorinated dibenzofurans (Tanabe & al., 1987). The aqueous solubility of all PCB's is very low, but solubility decreases with increases in the degree of chlorination (Sawhney, 1986). Thus weakly chlorinated compounds have the wider distribution but highly chlorinated compounds accumulate more in biota. Mono, di-, and trichlorobiphenyls are significantly biodegraded and volatilized whereas PCBs with five or more Cl atoms tend to sorb to suspended particles and sediments (Tabak & al., 1981)

To create models to predict toxicity, sorption, distribution or any other biological activity of PCB and other organic contaminants, researchers have developed a series of quantitative structure-activity relationships (QSARs). Different QSARs predict the bioconcentration factor at equilibrium (Neely & al., 1974; Metcalf & al.. 1975) and the acute toxicity (Veith & al., 1983; Zitko, 1975) of organic contaminants. Recent QSARs studies have been used to treat the time course of uptake of organic compounds by fish (Spacie & Hamelink, 1982), invertebrates (Lohner & Collins, 1987) and algae (Mailhot, 1987)

The purpose of this study is to improve the predictive power of the equations developed by Mailhot (1986, 1987) to predict the short term dynamics of sestonic uptake of contaminant. To this end, I first quantified the impacts the environmental variables, biomass, organic matter and pH, on PCB uptake by algal in laboratory experiments and thus verified the application of those results to the time course of uptake of PCB by natural seston.

Determinants of the Short Term Dynamics of PCB Uptake by the Plankton

Introduction

Planktonic contamination by xenobiotic chemicals has been a growing concern since Woodwell et al. (1967) first described bioaccumulation in a Long Island marsh. Since the plankton is a point of entry of water borne contaminants into the local food web and the biosphere (Sodergren and Gelin, 1983; Hardy & al., 1985; Mahanty, 1986), there is a need for tools that predict the sorption of pollutants by living particles in aquatic environments (Hansen, 1979). The long term fate of any xenobiotic partly depends on whether it is in solution or bound to particles, and on the extent and speed of its binding. These properties, which also represent the short term fate of the contaminant, vary greatly among contaminants, absorbants (Kanazawa, 1988) and presumably environments.

Most studies of sorption dynamics consider the interaction of the contaminants with individual species of algae, invertebrates, or fish in laboratory experiments. Comparatively few studies have looked at the dynamics of sorption in natural systems (Paris et al., 1977; Paris & Lewis, 1976; Biggs, 1980; Brown et al., 1982; Lal et al., 1987; Harding & Phillips, 1978). Of the different studies of contaminant dynamics, only the work of Mailhot (1987) was directed explicitly to the development of quantitative models to predict the time course of contaminant sorption by planktonic organisms. She examined the time course of biological uptake of nine organic contaminants by the green alga Selenastrum capricornutum and described the parameters of those time courses, the bioaccumulation factors (BCF) and the instantaneous rates of uptake, as functions of quantitative indices of chemical structure (Mailhot, 1986, 1987) The instantaneous rates of uptake were best described as a function of the first order connectivity index, a numerical measure of branching in the molecular skeleton; BCF was best described as a function of the capacity ratio a measure of retention time in a reversed-phase HPLC column system.

Mailhot's models were tested in the field using chlorinated benzenes (Mailhot & Peters, 1990) and showed similar instantaneous rates for penta- and tetra-chlorabenzenes. Unfortunately, their techniques depended on small sample volumes and an awkward concentration step, and did not measure the uptake by natural plankton reliably. As a result, neither the equilibrium concentration nor the BCF could be defined for oligo-chlorinated compounds. Rates of uptake for these oligo-chlorinated compounds were lower than expected from extrapolation of the laboratory curves, but since the same compounds were not used in the laboratory experiments, this comparison cannot be direct In addition, their field study did not include representatives of the most lipophilic and biologically active chlorinated organics, like DDT or PCB, nor did the laboratory model include the effects of environmental factors, like biomass or dissolved organic carbon, that might influence sorption Clearly, more work is needed

This study reevaluates the applicability of Mailhot's relationships for one form of PCB under a broader range of laboratory and field conditions The 2, 2', 4, 4', 5, 5'-hexachlorobiphenyl configuration was selected because of its high biological activity and because Mailhot used it in her laboratory studies. The effects of algal biomass, dissolved and colloidal organic matter, and pH on the uptake of PCB by laboratory cultures of algae were assessed first, to determine if these factors greatly influence the instantaneous rate of uptake or BCF. Biomass could dilute sestonic uptake of PCB so that the amount of contaminant per sestonic particle decreases as biomass increases. (Neudorf & Kahn, 1975; Biggs, 1980; O'Connor and Connely, 1980). Lake colour, which reflects dissolved and colloidal organic matter including humic materials, may bind to organic contaminants (Rasmussen et al., 1989; Servos et al., 1989; Leversee et al., 1983; Wershaw et al., 1969) or it could seem to enhance their solubility in water (Chiou et al., 1987; Leversee et al., 1983) in either case reducing its biological availability. Finally, pH may affect the biological activity of organics by changing the physico-chemical properties of the contaminant or the sorbing surface, as Kaiser and Valdmanis (1981) suggest pH may affect the uptake of ionizing organics, like pentachlorophenol. To test the relevance of these laboratory results to the field, I further examined the uptake of PCB in 11 lakes to compare uptake in nature with predictions based on laboratory results.

Materials and Methods

To test and extend Mailhot's model, her technique had to be modified for the field. The amount of radioactivity cannot be increased because PCB is insoluble at higher concentrations, so sample volumes were increased and the results from otherwise similar experiments compared to hers to ensure that both techniques measure the same phenomena. I then assessed the influence of biomass, pH and organic matter on laboratory uptake and finally, compared these results to uptake by natural lake plankton.

Radiochemical:

Radioactively labelled 2,2',4,4',5,5'-hexachlorobiphenyl was purchased in a ^{14}C-radiolabelled form from Sigma Chemical Company, Missouri, U S.A. The specific activity was 7.4×10^{11} Bq Mol^{-1}. This was diluted in dimethyl sulfoxide (DMSO) and stored in 2-ml ampoules at a concentration of 37 KBq ml^{-1}

Algal cultures:

A stock culture of the test organism Selenastrum capricornutum was obtained from Donald St-Laurent of Environment Canada (Longueuil, Quebec), and maintained in the synthetic media recommended in the S. capricornutum Printz algal assay: bottle test (Miller et al., 1978). Flasks were shaken at 100 rpm at 25±1°C and pH=7, illuminated from above at 400 foot-candles by cool white fluorescent light on a 15hL:9hD light cycle. Stock cultures were transferred to fresh medium every 7 days. Cell density was determined by haemocytometer counts at day 7 and at the start of each experiment. Biomass of these cultures was calculated from these counts assuming an average algal volume of 40 μm^3 $cell^{-1}$ Bacterial and fungal contamination was monitored by plating 1 ml aliquots of stock on nutrient agar and incubating these plates with the cultures Contaminated cultures were discarded.

Uptake experiments:

To begin each uptake experiment, 10 μl of radioactive PCB were added to each of three 400-ml aliquots of algal suspension or lake water in Pyrex beakers, closed with rubber stoppers to minimize evaporation of the PCB. Thereafter, at intervals from 20 min to 5h, two 5-ml aliquots were withdrawn from each of the triplicates and placed in scintillation vials to determine the total concentration of PCB in the flask. Simultaneously, 10-ml subsamples were also withdrawn and used to determine the portion of the radioactivity associated with particles To this end, the 10-ml sample was centrifuged at 2,000 rpm for 10 min, then 5 ml of supernatant were withdrawn and placed in a scintillation vial Because the pellet was too small to be handled, the remainder was vortexed to resuspend the pellet and also placed in a scintilliation vial. All samples then received 10 ml of scintillation cocktail (Ready Safe, Beckman) and their radioactivities were determined by a LKB Wallac 1215 Rack Beta II liquid scintillation counter. If A_t is the average total activity as determined in the two 5 ml replicates, A_s is the activity in the supernatant as determined in top 5 ml of the centrifugate and A_l the activity in the lower 5 ml of centrifgate, then the percentage of activity associated with particles (Y,%) can be determined as:
$Y = 100\% (A_t - A_s)/A_t$. This adjusts the total activity for any loss to the containers during handling. In these experiments the use of relatively

large volumes, short exposures and glass containers reduced such losses to 5% (SD = 15%, n = 89). These samplings were performed in duplicate at each sample time and for each flask, and the results averaged for analysis

Laboratory manipulations:

The effect of biomass on uptake was tested in the laboratory using concentrations of Selenastrum ranging from 1 to 200 ppm by volume Algal suspensions for each uptake experiment were made by diluting the cultures with sterile stock solution to yield triplicate 400-ml volumes at the appropriate cell concentration The effects of variations in organic matter and pH were examined at a standard concentration of 25 ppm (6×10^5 cells ml^{-1}). To obtain dissolved and colloidal organic material, commercial peat moss was boiled in distilled water for several hours, then the mixture was filtered four times through a 35 μm mesh and finally through a GF/C glass fibre filter Several serial dilutions produced a wide range of organic concentrations Levels of organic matter (DOC, mg l^{-1}) were measured as absorbance at 440 nm (Abs, m^{-1}) which can be converted to Hazen units from the regression in Bowling et al. (1986) and then to dissolved organic carbon following Rasmussen et al (1989) $DOC = 1.86 + 1.84\ Abs - 0.038\ Abs^2$ Salts were added to produce a nutrient solution which was identical to the algal assay medium, except for the presence of the organic material and the pH was adjusted to 7

To determine the effects of acidity, six different pH levels were obtained by adding 0.1 N NaOH or HCl to the diluted cell suspensions in the standard synthetic medium to yield pH values ranging from 4 to 9, as measured with a Corning pH meter.

Field Samples

Lake water was collected from the euphotic zone (defined as twice the Secchi disc depth) of 11 lakes in southern Quebec in July and August 1990 using a 5-m long, 2 5-cm diameter Tygon tube. The samples were then filtered through a 250 μm mesh to remove zooplankton or large phytoplankton that could increase variability in the amount of particulate matter in the experiment without significantly affecting the mean (Prepas and Rigler, 1982; Prepas and Vickery, 1984) Samples were then transported in plastic carboys to the Montreal laboratory where they were analyzed and used in uptake experiments within 24 h of collection. Concentrations of seston (mg dry weight l^{-1}), colour, total phosphorus and chlorophyll a (mg m^{-3}), and pH were routinely determined to characterize the sample. Seston dry weight was measured gravimetrically as the change in the dry mass of a preweighed, Whatman GF/C glass fibre filter, produced by filtering 1 l of lake water. Live biomass was estimated as seston dry mass/0.32 (Peters & Downing, 1984). Colour was measured as absorbance at 440 nm. Total phosphorus was estimated with the molybdenum blue procedure (Riley and Murphy, 1962), after digestion under pressure with potassium persulphate (Menzel and Corwin, 1965). Chlorophyll a, uncorrected for phaeophytin, was measured following Ostrofsky (in Peters and Bergmann, 1982).

Results and Discussion

Each uptake experiment yielded a series of estimates of the percentage of total radioactivity associated with particles at each sampling time averaged over the three replicate flasks. The results of three such experiments are shown in Figure 1.

A number of models could be fit to such data so the dynamics of uptake in different experiments and under different conditions could be compared. Mailhot (1986, 1987) assessed linear ($Y=a+bX$), exponential ($Y=a[1-e^{-bX}]$), and hyperbolic ($Y=X/[aX-b]$) models of the change in percentage uptake of ^{14}C-PCB (Y, in %) with time (X, in minutes). On the basis of coefficient of determination, the best two-parameter model was the square hyperbola:

$$Y=aX/(b+X) \qquad (1)$$

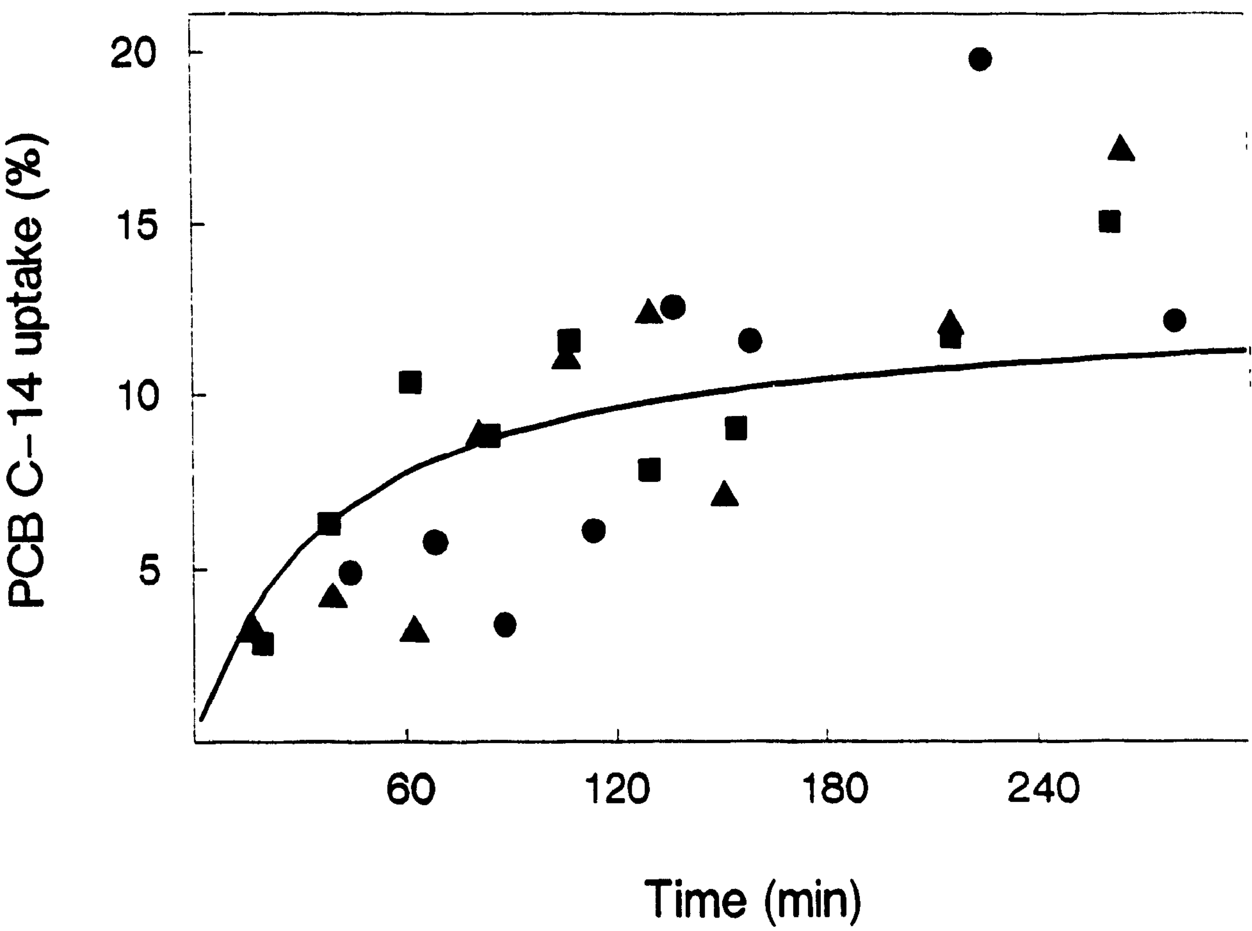
where the parameters a and b are fitted constants. Initial estimates of a and b were fit to the data by a basic program developed by Raynald Pomerleau (Formic Videotex System, personal communication). These estimates were then used to find the best fit of the data to the model with the Statgraphics commercial statistical package.

The parameters of the square hyperbola could then be used to calculate two basic descriptors of the short term flux and fate of the initially dissolved contaminants: the instantaneous rate of uptake (%/min) and the equilibrium level as reflected by the bioconcentration factor (BCF, Bq ml^{-1} algae ÷ Bq ml^{-1} solution). The instantaneous rate of uptake of PCB is the first derivative of equation 1 at time = 0:

$$\text{Instantaneous rate of uptake} = a/b \qquad (2)$$

Figure 1

The uptake of PCB C-14 by Selenastrum capricornutum. The curve represents the time course predicted using equations from Mailhot (1987) and the symbols are the mean values of duplicate measurements from each of these replicate experiments in this study. Biomass = 5ppm; pH = 7.



PCB C-14 uptake (%)
20
15
10
5
60
120
180
240
Time (min)

The bioaccumulation factor is related to a, the asymptotic value of Y achieved as time (X) approaches infinity and X/(b+X) approaches unity:

$$BCF = a/[(100-a) * \text{individual cell volume} * \text{cell concentration}] \quad (3).$$

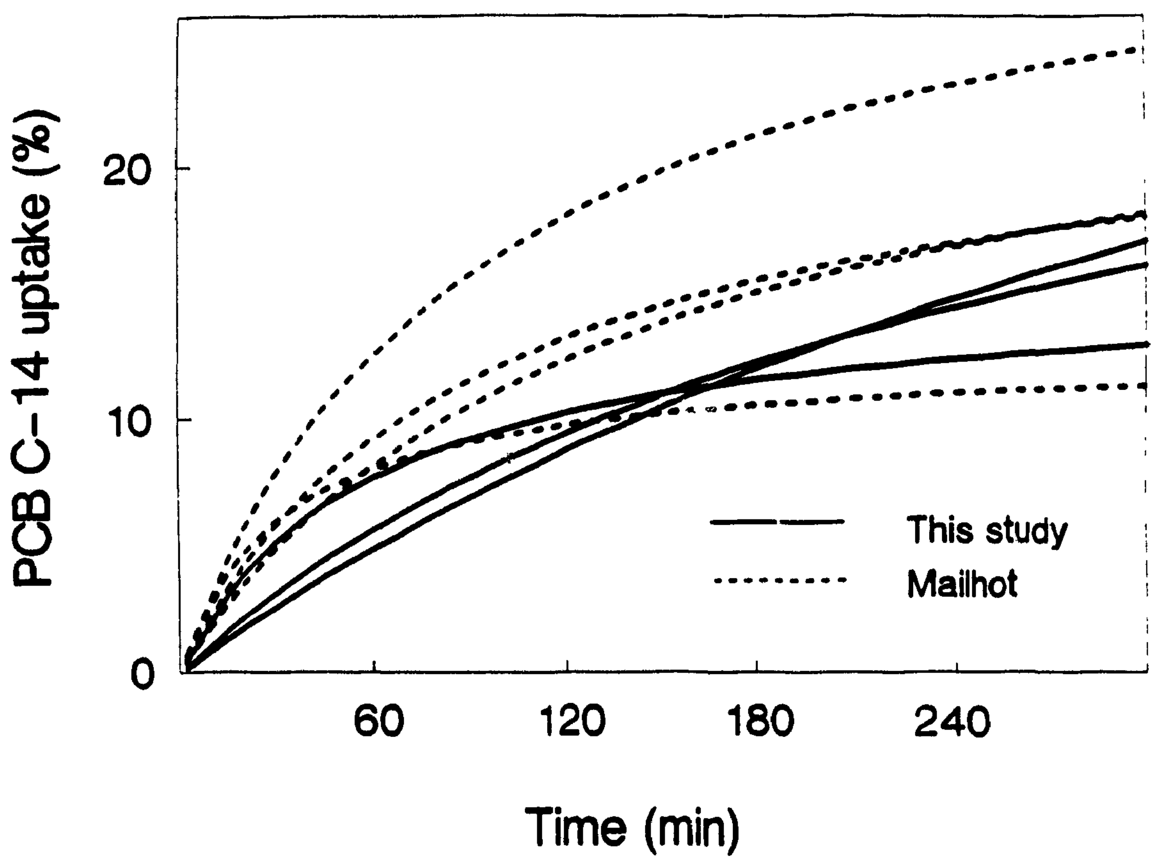
It is these variables that Mailhot (1987) used to describe and predict the short term dynamics of different organic contaminants as functions of the physical and chemical characteristics of the chemicals. The present study uses the same variables to compare its results to Mailhot's and to assess the effect of biomass, dissolved organic material and pH on PCB uptake in both laboratory cultures and natural waters.

Comparisons of Techniques

If these experiments are to be relevant to extending the predictive equations developed by Mailhot (1987), then they should yield results comparable to hers when measured under otherwise identical experimental conditions. Figure 1 compares the time course of PCB uptake by Selenastrum predicted from Mailhot's equations with the data generated by the present study under the same experimental conditions. In general, the shape and the magnitude of predictions and observations were similar, but the predicted curve tends to overestimate the observed initial uptake and to underestimate the observed equilibrium level. A similar bias occurs when Mailhot's own data are compared to the predictions of her relationships. Apparantly, Mailhot's general relations yield similar, slightly biased, descriptions of PCB dynamics and the results from the modified technique are consistent with her data.

Figure 2

Curves of best fit describing the uptake of C-14 PCB by S. *capricornutum* at a concentration of 5ppm (10^5 cells ml^{-1}) and pH = 7 as determined in four separate experiments by Mailhot (1987) and in three separate experiments in this study.



PCB C-14 uptake (%)
20
10
0
60
120
180
240
Time (min)
This study
Mailhot

Thus, it appears that the results of the two techniques are consistent in the shape of the curve, in the absolute value of the instantaneous rates of uptake and BCF, and in their relation to quantitative structure activity relationships describing general patterns in organic contaminant uptake.

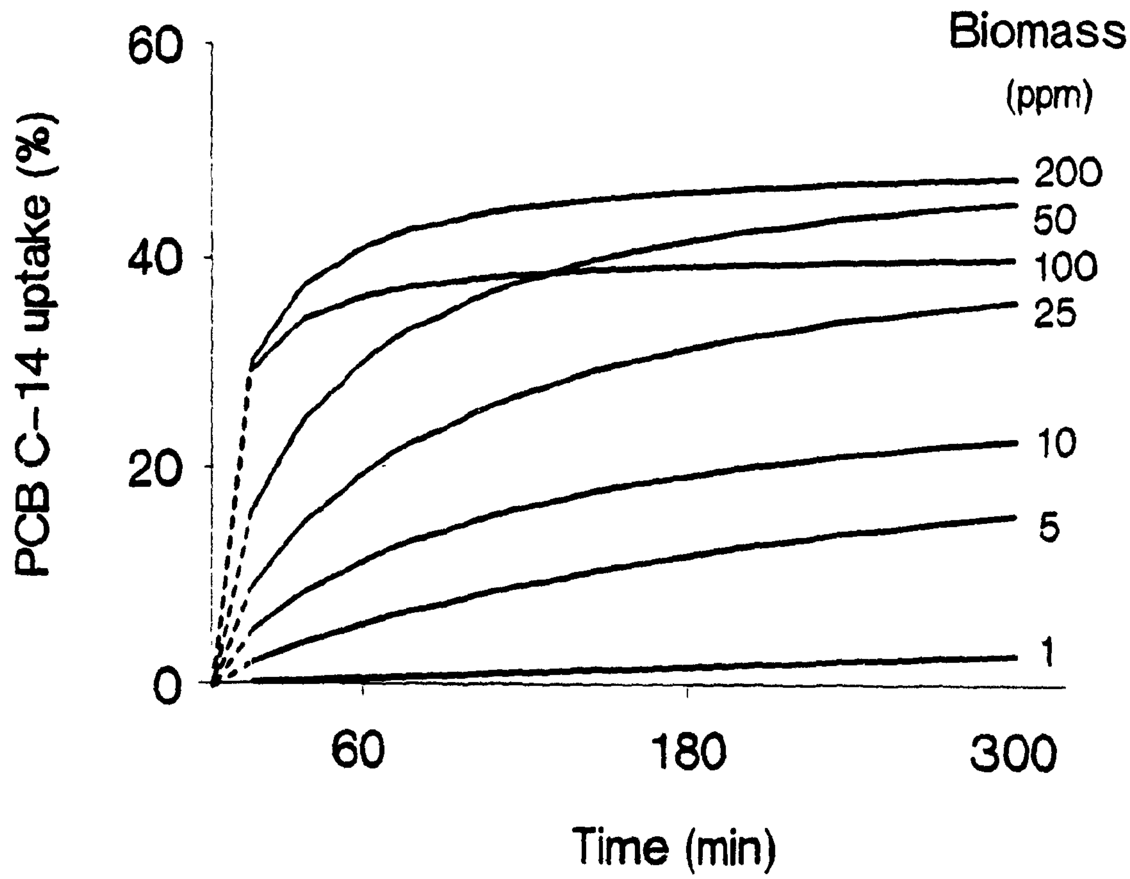
Effects of Biomass on PCB uptake by laboratory cultures:

Each uptake experiment yielded three estimates of each parameter of the square hyperbola (a and b in equation 1), each pair being based on the time course of uptake in a single flask. Because these triplicate estimates could not be considered fully independent, they were used to calculate average time courses of uptake (Fig 3) from average instantaneous rates of update and average BCF's (Fig 4) for each combination of experimental conditions. The individual estimates from separate flask were used only to guage the amount of variation among replicates.

Figure 3 shows the time courses of uptake calculated from the averaged parameters for each level of algal biomass. With the exception of experiments at the lowest Selenastrum calculations (1 ppm), the fits to the individual replicates underlying these curves were quite good. Coefficients of determination increase from 0.92 to 0.97 (mean=0.95) at 5 ppm to 0.97 to 1 0 (mean=0.99) at 200 ppm. Estimates of instantaneous rates of uptake and BCF are similarly better defined at higher algal concentrations, as is apparent in the lower standard deviation associated with these estimates at higher biomasses (Fig 4). This increased precision reflects the strength of the response at higher algal levels. As Fig. 3 shows, both the asymptote and the speed at which this asymptote is achieved increase with biomass. At the

Figure 3

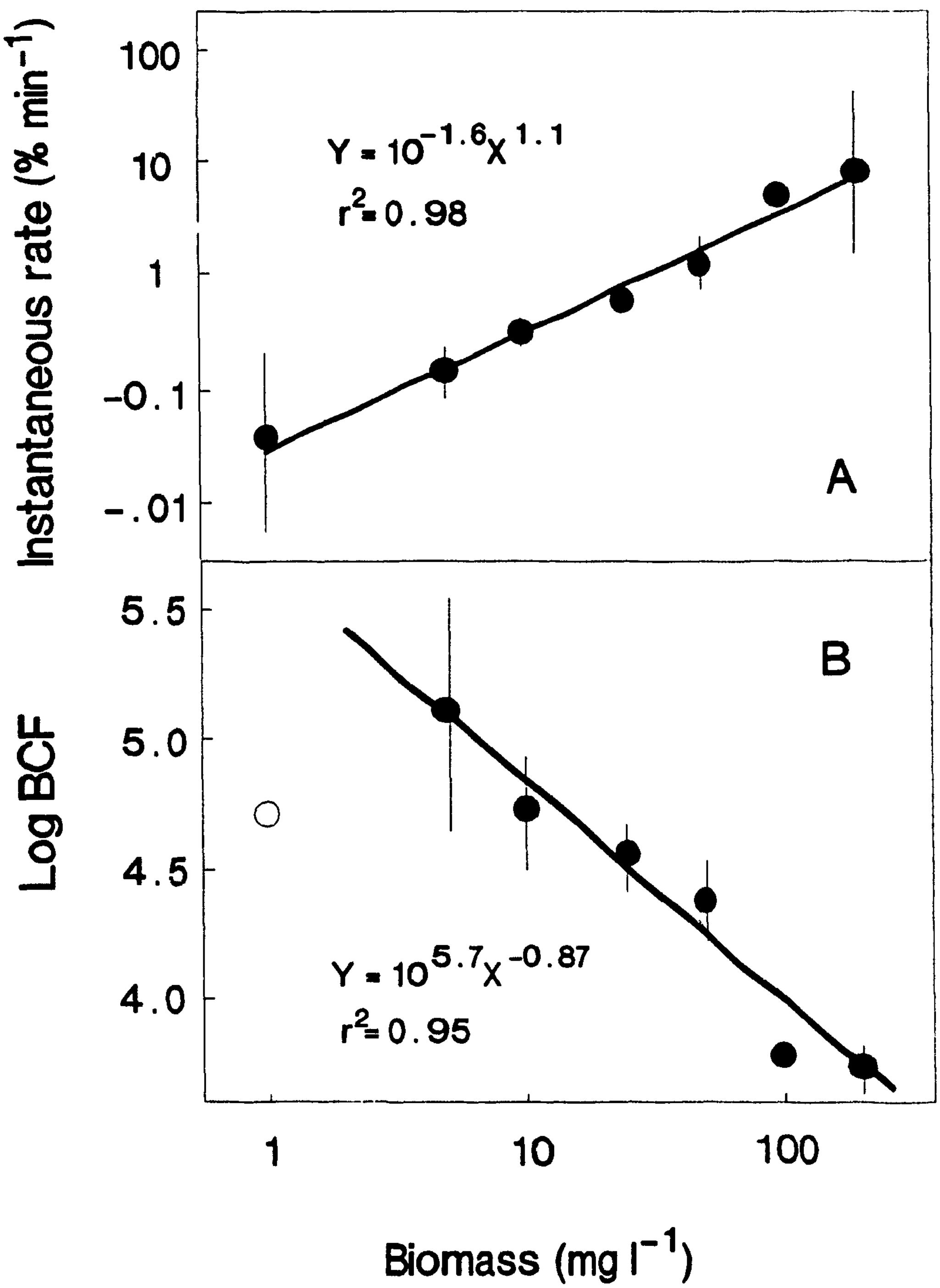
The average time course of PCB C-14 uptake by _S_. _capricornutum_ at different biomasses expressed in ppm by volume. Dotted lines join the proportion of uptake at the time of the earliest measurement to the intercept.



Biomass
(ppm)
200
50
100
25
10
5
1
60
40
20
0
PCB C-14 uptake (%)
60
180
300
Time (min)

Figure 4

The relationships between Log biomass and (A) the logarithm of the instantaneous rate of uptake and (B) the logarithm of BCF. Because the BCF at 1 ppm was poorly defined (see text), that regression is based only on the six BCF values from experiments at or above 5 ppm. The statistics associated with the regression in panel A needed to determine the confidence limits of the coefficients and predictions are $SE_{slope} = 0.09$; $SE_{intercept} = 0.14$; $S_{xy} = 0.12$; mean Log biomass = 1.52 and $\Sigma x^2 = 1.82$. Statistics for the regression in panel B are $SE_{slope} = 0.10$; $SE_{intercept} = 0.17$; $S_{xy} = 0.14$; mean Log biomass = 1.52 and $\Sigma x^2 = 1.82$.



Instantaneous rate (% min^{-1})
100
10
1
-0.1
-.01
$Y = 10^{-1.6}X^{1.1}$
$r^2 = 0.98$
A
Log BCF
5.5
5.0
4.5
4.0
B
$Y = 10^{5.7}X^{-0.87}$
$r^2 = 0.95$
1
10
100
Biomass (mg l^{-1})

highest biomass, the rate of approach to the asymptote is so fast that the instantaneous rate of uptake is again less certainly defined by these experiments.

At the lowest level of biomass (1 ppm), uptake curves were much more poorly defined (r^2=0.52 to 0.56) and the rate of uptake is so slow that the asymptotic levels could not be accurately described. Of the three asymptotes obtained, only one was of an order of magnitude consistant with those generated at higher concentrations; the other two exceeded 100% and were not used. Instantaneous rates of uptake were more consistant, but still had greater uncertainty than those measured at higher biomasses. One negative value for the instantaneous rate at 1 ppm was excluded from further analyses.

Despite the short-comings of the estimates at the lowest algal concentrates, the effects of biomass on PCB uptake are very clear. As biomass increases, PCB is taken up more rapidly and more completely, although the proportionate increase in the asymptote is much less than the proportionate increase of biomass (Fig 3). Regression showed a significant, positive, but shallow, relation between asymptote (a) and biomass, such that loga = 1.4 + 0.14 log biomass. Thus the asymptote increased less than twice with the 40-fold increase in biomass from 5 to 200 ppm and the total uptake over the 5 h of these experiments increased only 4-fold (Fig 3). As a result, the contaminant concentration in the cells, the amount per cell, and the BCF decline rapidly as biomass increases. In fact, the coefficient relating BCF to biomass (Fig 4a), is not significantly different from -1 suggesting that, over this range of algal concentrations, bioconcentration factor may be a simple inverse function of biomass. Instantaneous rates of uptake instead increase almost directly with biomass (Fig 4b). In short, these laboratory experiments show that increased biomass results in proportionately more rapid uptake, moderate increases in the total amount of uptake, but dramatic decreases in bioconcentration factor.

Several authors have made similar observations on the effect of biomass on BCF and contaminant accumulation using different compounds, species and methods (Neudorf & Kahn, 1975; Biggs et al., 1980; Hardy et al., 1985). Quantitatively, a literature survey by Thomann et al. (1986) suggest that BCF will decline as biomass$^{-1.2}$ to biomass$^{-0.44}$ over this range of concentration of suspended solids. The observations in the present study are consistent with values reported earlier by O'Connor and Connolly (1980) and show that these values apply to living organisms. The effect of biomass on rate of uptake seems not to have been assessed previously.

Effects of organic colour and pH

Dilution of the peat moss infusions provided a series of <u>Selenastrum</u> suspensions in nutrient medium that ranged from clear to deeply stained. Because absorption at short wavelengths is closely correlated with dissolved organic carbon (Moore, 1987), DOC could be estimated as lying between 3 and 20 mg l^{-1} from the equation developed earlier by combining regressions from Rasmussen et al. (1989) and from Bowling et al. (1986). Although this estimation cannot indicate if natural dissolved and colloidal material is qualitatively similar to that in peat infusions, it does show that the infusions contained amounts of DOC that were quantitatively similar to those found in nature (Bowling et al, 1986; Rasmussen et al., 1989).

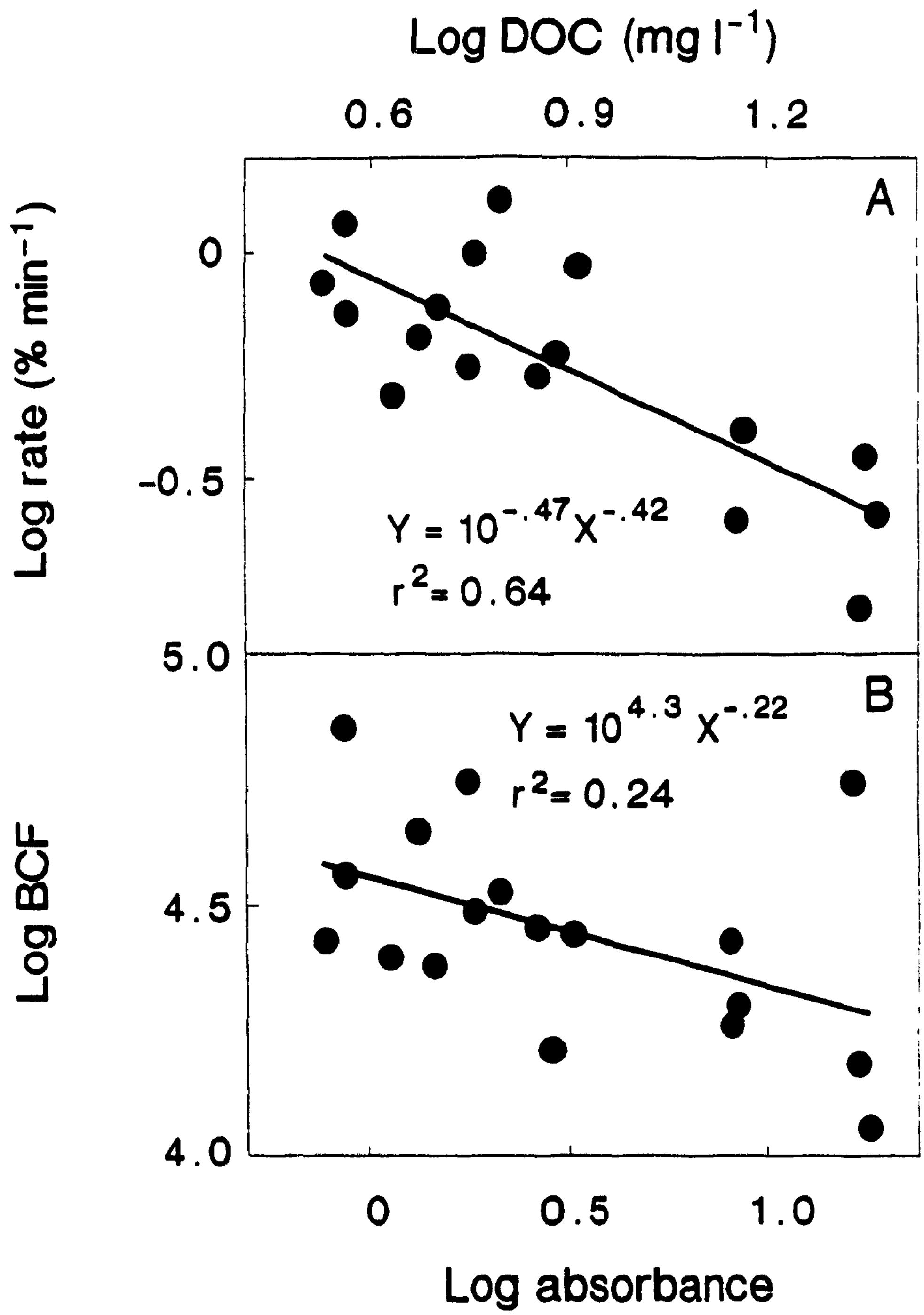
Because the intended replicates in these experiments varied substantially in absorbance, they could not be combined or averaged, so each flask was treated as an independent sample Both instantaneous rates of PCB uptake and BCF declined as absorbance increased, but these relations did not appear to be linear. Comparison of several simple transformations (linear, log-linear, quadratic, log-log) showed that double logarithmic transforms were most effective in normalizing variance and linearizing the relations. These regressions showed that instantaneous rate of uptake was reduced by 30% over the range of absorbances in our experiments. BCF also declined, but the effect was less strong and the decline less marked (Fig. 5).

These results indicate that dissolved organic carbon can reduce both the rate and extent of contaminated uptake by planktonic organisms. Since the rate of uptake is more affected than the equilibrium concentration, the main effect of DOC in this experiment was to slow uptake. The equilibrium level was less affected, but the modest reduction in BCF suggests that at least some PCB remains bound to the DOC even at the end of the experiment. A number of previous authors have suspected that DOC may influence contaminant dynamics (Mailhot and Peters, 1990; Evans, 1989; Chiou et al , 1987; Leversee et al., 1983).

Although acute changes in pH might be expected to influence the dynamics of contaminant uptake (Sawhney, 1986) Table 1 indicates no effect of pH on BCF's or instantaneous rates of uptake by Selenastrum. Since the coefficients of variation of BCF and instantaneous rate across these experiments were only 28% and 31% respectively, the lack of pattern in the response to changes in pH does not reflect large unexplained variation, but consistency in both parameters despite changes in pH under the conditions in these cultures. This does not eliminate the possibility that pH may be important under other conditions, for example where the absorptive capacity of natural dissolved organic carbon may be affected by changes in acidity.

Figure 5

The effect of colour measured as absorbance at 440 nm on (A) the instantaneous rate of uptake of PCB by Selenastrum and (B) the bioconcentration factor of PCB uptake. Absorbance has been approximately converted to equivalent concentrations of DOC to yield the upper axis. The statistics for regression in panel A are $SE_{slope} = 0.08$; $SE_{intercept} = 0.05$; $S_{xy} = 0.15$; mean Log Abs = 0.50 and $\Sigma x^2 = 3.80$. Statistics for the regression in panel B are $SE_{slope} = 0.10$; $SE_{intercept} = 0.07$; $S_{xy} = 0.19$; mean Log Abs = 0.50 and $\Sigma x^2 =$ 3.80.



Log DOC (mg l^{-1})
0.6
0.9
1.2
A
Log rate (% min^{-1})
0
-0.5
$Y = 10^{-.47}X^{-.42}$
$r^2 = 0.64$
5.0
B
$Y = 10^{4.3}X^{-.22}$
$r^2 = 0.24$
Log BCF
4.5
4.0
0
0.5
1.0
Log absorbance

Table 1. Instantaneous rates of uptake (rate) and bioconcentration factors (BCF) of hexachlorobiphenyl in suspensions of Selenastrum observed over a range of acidities. Standard deviations at each pH reflect variation among three replicates, those of the averages reflect variation among the means of those triplicates.

pH	Log rate	SD	Log BCF	SD
4	-0.12	0 13	4 66	0 12
5	0.02	0.18	4.28	0.46
6	-0.20	0.12	4.61	0.25
7	-0.24	0.10	4.45	0.33
8	0.06	0.46	4.46	0.34
9	-0.15	0.21	4.45	0.18
Average	-0.10	0 12	4.48	0.13

Uptake by natural plankton

The 11 lakes used as sources of natural water were selected to represent the range of natural conditions. Table 2 shows that this sampling was successful in terms of biomass, for the waters varied by almost an order of magnitude, and in terms of lake trophic states, for transparency and concentrations of both phosphorus and chlorophyll indicate that these waters range from oligotrophic to moderately eutrophic. Colour indicates a range from clear to moderately tea-coloured. Values of DOC calculated from absorbance suggest concentrations between 8 and 24 mg l^{-1}, which would include almost half of the lakes covered in the data collection of Rasmussen et al. (1989). The study lakes were more alkaline and less varied in pH than hoped, perhaps because they were sampled in mid-Summer. Simple correlations showed no significant collinearities among these potential predictor variables.

The time courses of PCB uptake in these samples followed the same patterns as those observed in laboratory experiments and also fit the square hyperbola. Again, as biomass increased the asymptote and the speed at which this asymptote was approached increased, and the time courses were well defined at both low and high biomasses Indeed, the coefficient of determination (r^2) for all lakes lay from 0 94 to 1.00, but one estimate of uptake rate for Lac des Piles was negative and was therefore not used in these analyses. The parameters of the square hyperbolas fit to these data were of the same magnitude as those observed in laboratory experiment and were used to generate estimates of instantaneous rates of uptake and BCF of PCB by the plankton in these lakes. These latter variables were used to compare uptake in the field with those predicted on the basis of laboratory observations.

Table 2. Selected physical and chemical characteristics of the lakes sampled for this study. Biomass (ppm by volume) is calculated as the dry weight of suspended material divided by 0.32, Abs is absorbance (m^{-1}) at 440 nm as a measure of dissolved organic carbon, TP is total phosphorus concentration (in mg m^{-3}), Chl is the concentration of chlorophyll a (chl, mg m^{-3}) and SD is the Secchi disc transparency in m.

Lake	Biomass	Absorbance	pH	TP	Chl	Secchi
des Piles	1.4	0.58	6.5	2.3	0.2	12.5
Magog	2.4	0.90	8.0	19.9	1.9	4.2
Memphremagog	2.9	0.41	7.8	7.5	2.7	3 8
Croche	4.0	1.1	6.1	4.0	1.0	4.2
Brome	4.2	0.42	7.5	4.4	5.8	4.0
Aylmer	4.4	2 3	7.3	10.9	2.1	2 5
Hertel	5.0	0.8	9.2	14.8	1 5	4 5
Lusignan	5.4	0.4	7.2	9.0	0.2	4 4
Coulombe	7.1	3.4	7.0	13.9	3.0	1.9
Waterloo	9.0	1.1	7.4	28.7	4.5	2.2
Argile	9.5	0.6	7.1	10 2	1.4	4.5

Stepwise multiple regression showed that plankton biomass had a strong effect on both instantaneous uptake and BCF (table 3). Qualitatively, biomass had similar effects in both laboratory and field studies, for instantaneous rate rose and BCF declined as biomass increased. Variations in biomass explained almost all the variation in BCF ($r^2 = 0.97$), but was a less powerful determinant of the instantaneous rate of uptake ($r^2 = 0.48$). Since the coefficients of these predictor variables were not significantly different from 1 and -1 respectively, the behaviour of PCB uptake by plankton also appears quantitatively similar to that by laboratory cultures. Neither absorbance nor pH had a significant effect in these analyses, but this might be expected, given the small number of data points available. Given that limitation, it is interesting that DOC, as measured by absorbance at 440 nm, had a negative effect on BCF that was almost significant ($P<0.1$). The consistency of this effect with the similar effect of absorbance in laboratory suggests that this negative relation may be real. By the same token, the very weak, positive effect of absorbance on instantaneous rate was not supported by the laboratory results and should probably be ignored. Acidity had no noticable effect in either field or laboratory experiments.

The laboratory regressions developed by Mailhot (1987) and in this study were combined to produce two semi-empirical relations that could be used to predict the uptake of organic contaminants in nature. Coefficients of the predictor variables were assumed to be those obtained in laboratory regressions and the elevation of each relation was calculated from the laboratory means of this study, under the assumption that the semi-empirical regressions must pass through those means and the observation that they were not significantly different from those of Mailhot's study. Connectivity index (X) and capacity

Table 3. The results of stepwise regressions of the instantaneous rate of uptake and bioconcentration factor of PCB against plankton biomass (biomass, ppm) and absorbance at 440 nm (Abs, m^{-1}). Although pH was included in the analysis it never approached significance in either model.

Equation	SD	P	S_{xy}	r^2
1. log Rate = -0.80	0.15		0.17	0.48
+0.63 log biomass				
2 log Rate = -0.55	0.28	0.09	0.17	0.54
+0.56 log biomass	0.23	0.04		
+0.19 log Abs	0.18	0.33		
3. log BCF = 5.83	0.048	0.0001	0.054	0 97
-1.12 log biomass	0.069	0.0001		
4. log BCF = 5.70	0.079	0.0001	0.047	0.98
-1.08 log biomass	0.064	0.0001		
-0.051 log Abs	0.051	0.093		

ratio (K') were used in these relations because they are the predictors Mailhot (1987) identified as the best variables to predict instantaneous rates and BCF's from indices of chemical structure.

$$\log \text{Rate} = -3.30 + 0.32\,X + 1.1 \log \text{Biomass} - 0.42 \log \text{Abs} \qquad (4)$$

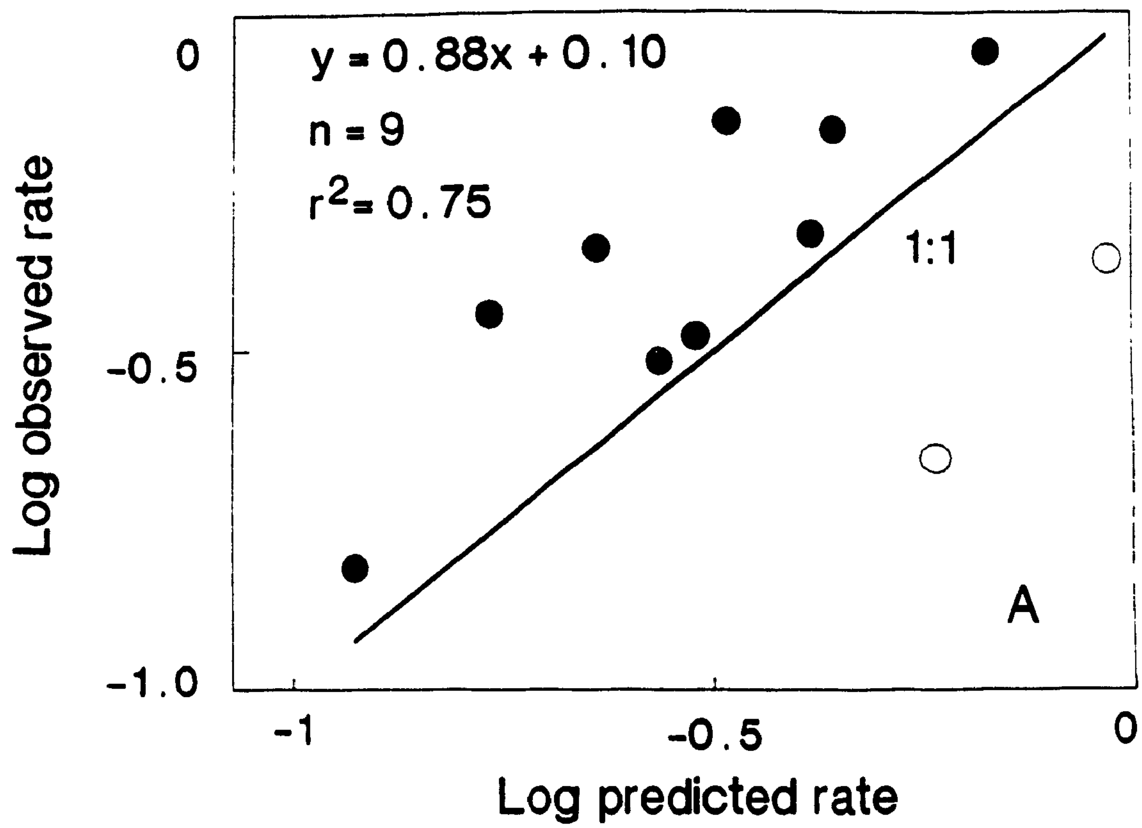
$$\log \text{BCF} = 4.11 + 0.86 \log K' - 0.87 \log \text{Biomass} - 0.22 \log \text{Abs} \qquad (5)$$

where biomass is expressed as ppm (volume/volume) and Abs is absorbance (m^{-1}) at 440 nm.

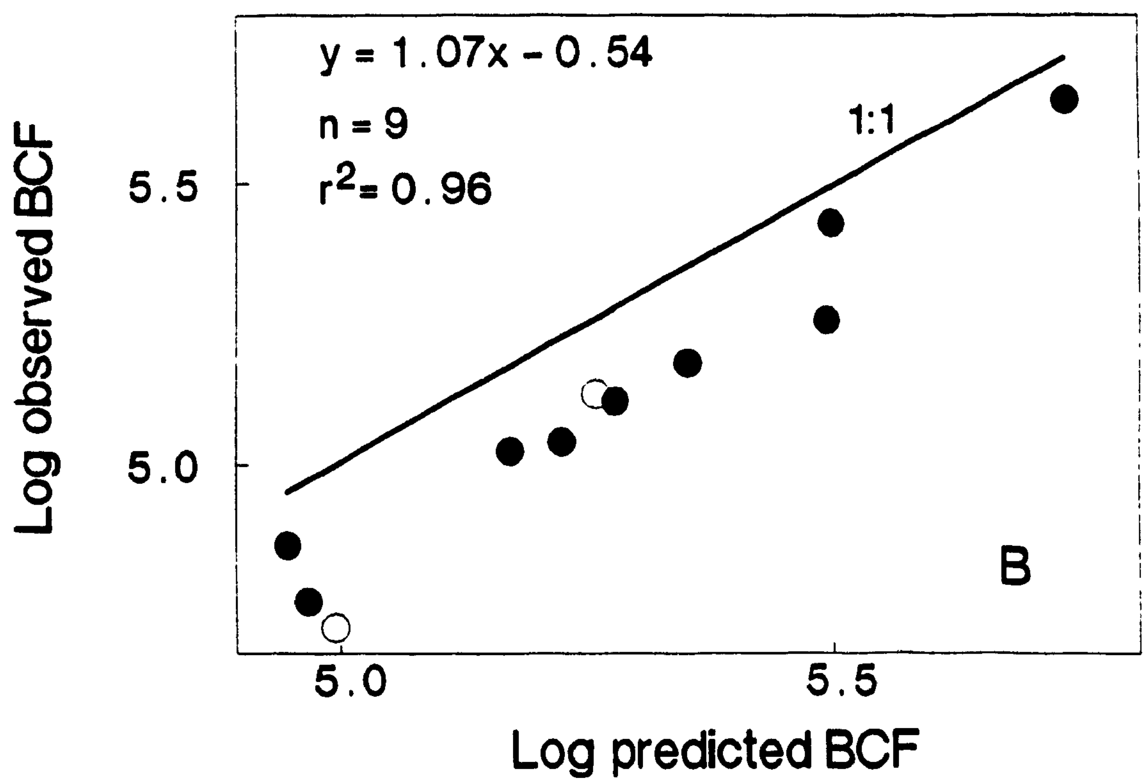
The predictive power of these relations was tested by plotting and regressing observed vs predicted values for the logarithms of both instantaneous rate and BCF. Figure 6 compares these results with the ideal 1:1 relation obtained by perfect predictions. The predictions explain a substantial part of the observed variations in both comparisons, the slopes approach the ideal value of 1 and the intercepts are not significantly different from 0. However, the instantaneous rates observed in Lac Lusignan and Lac d'Argile were so low that no significant relation existed between observed and predicted BCF when all lakes were included in the regression. These two lakes were subsequently excluded from both regressions in figure 6, even though the BCF values for both lakes appear to follow the relation for other lakes. A similar analysis in which absorbance was not used to develop the predictions was almost as effective (r^2=0.83, slope=0.79 intercept=0.39 for Log rate; r^2=0.98, slope=1.31, intercept=-1.63 for Log BCF), so DOC need not to be considered to produce these approximate predictions. However, since the range of natural lake color exceeds that studied, absorbance can be included in making the predictions until data from a larger range of DOC is used to assess its utility

Figure 6

Comparison of (A) instantaneous rates of uptake and (B) bioconcentration factors observed in experiments with the natural plankton of lakes and that predicted from laboratory relations derived from experiments with Selenastrum cultures. The solid curve is the 1:1 line. The points represented by open circles, from Lac D'Argile and Lac Lusignan, were not included in the regressions.



y = 0.88x + 0.10
n = 9
r2= 0.75
1:1
A
0
-0.5
-1.0
-1
-0.5
0
Log observed rate
Log predicted rate



y = 1.07x - 0.54
n = 9
r2= 0.96
1:1
B
5.5
5.0
5.0
5.5
Log observed BCF
Log predicted BCF

To determine the effectiveness of these predicted parameters in reconstructing the time course of PCB uptake, the predicted BCF's and rates were used to develop a predicted time course which could be compared with the time courses observed in the plankton experiments and the predicted time course from Mailhot (1987). Plots of predicted vs observed values at all sampling times in each replicate for each of the 11 lakes suggest that this approach is reasonably effective, for the explained variation was high (mean r^2 = 0.84; range = 0.64 to 0.95) and the slope (mean = 0.82; range = 049 to 1.75) and intercept (mean = 2.10, range = -6.2 to 11.2) were not far from ideal. Equations 4 and 5 are more effective in predicting observed time courses than are equations that ignore the effects of biomass and colour. Mailhot's (1987) equations yielded predicted values that were also well correlated with observed uptake (mean r^2 = 0.80; range = 0.51 to 0.93), but the slopes (mean = 2.8; range = 1.52 to 0.93) and the intercepts (mean = -6.7; range = -19.2 to 6.5) of the observed vs predicted regressions indicate that equations based solely on indices of chemical structure tended to underestimate the observed uptake (fig. 6 & 7).

The effectiveness of the predictions is most apparent when the predicted time courses are compared to the observed uptake values for lakes of high and low biomasses (Figure 7). However, the time course of uptake of Lac Lusignan and Lac D'Argile (fig.8) are not well represented by either curves predicted from equations 4 or 5 or from Mailhot (1986, 1987). I have no explanation for this discrepancy: the individual values of the physico-chemical properties measured for these two lakes are not exceptional compared to the other lakes in this study, but there are so many unmeasured properties that many explanations are still possible. For example, the high values of suspended solids and low

Figure 7

Comparison of the time courses of PCB uptake calculated from parameters predicted from equations 4 and 5 and from Mailhot (1987) with the uptake observed in waters from two lakes of very different biomasses, eutrophic Lake Waterloo and oligotrophic Lac des Piles. These two lakes represent extremes in terms of the biomass in the lake samples included in this study. The mean r^2 for all eleven fits of this study was 0.84, that for Lake Waterloo was 0.81 and that for Lac des Piles was 0.84.

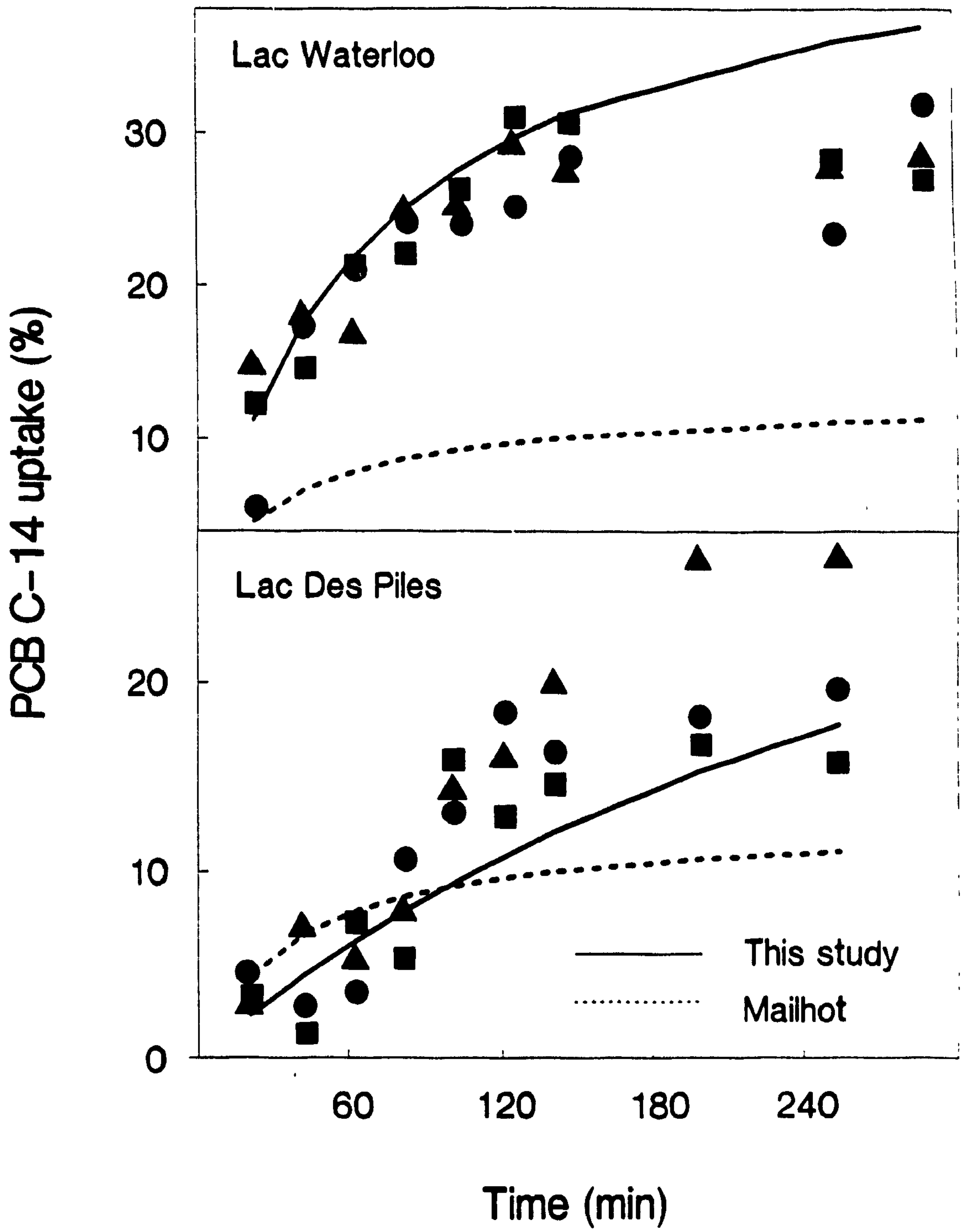
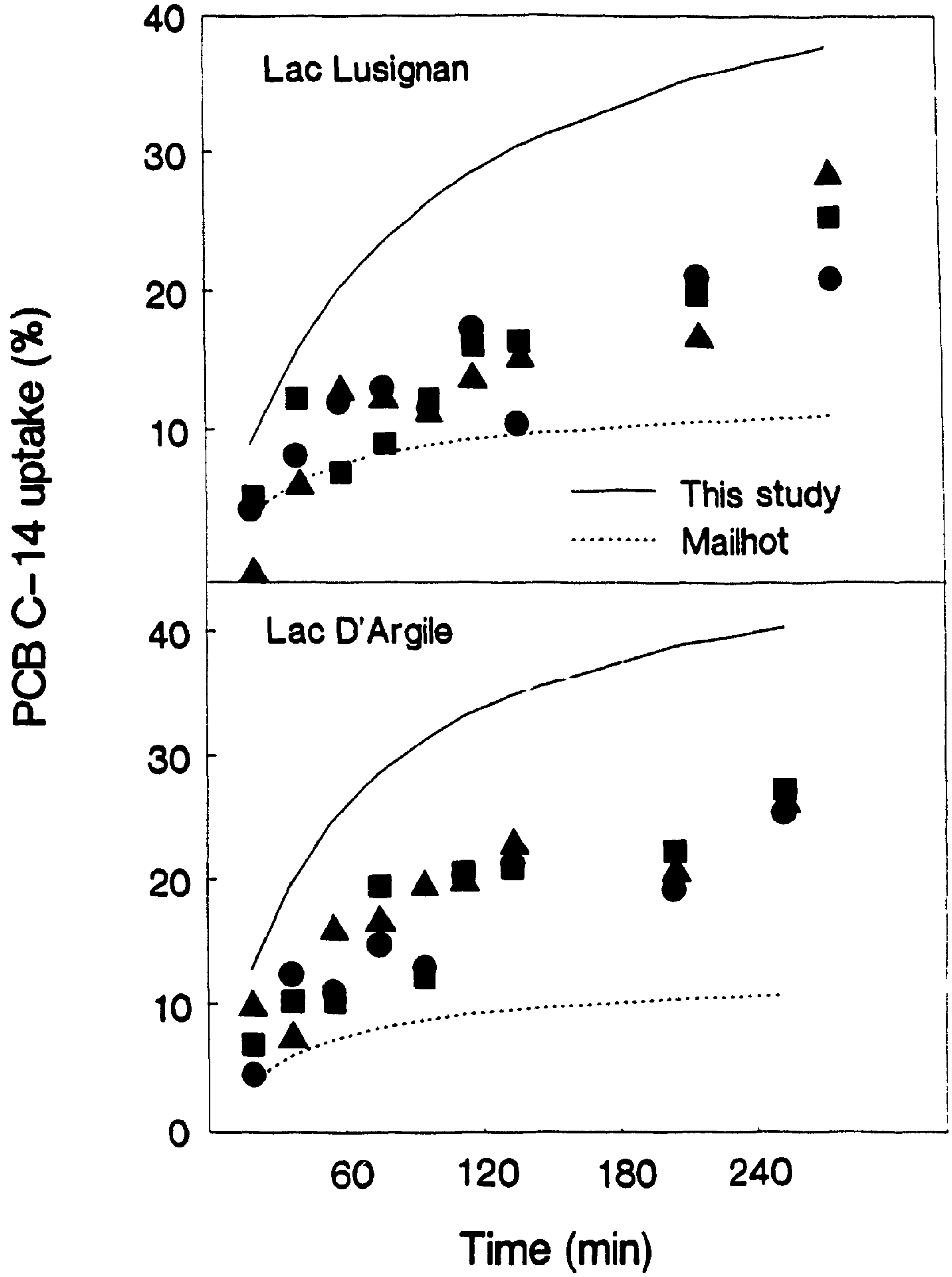

Lac Waterloo
Lac Des Piles
PCB C-14 uptake (%)
30
20
10
20
10
0
60
120
180
240
Time (min)
This study
Mailhot

Figure 8

Comparison of time course of PCB uptake calculated from parameters predicted on the basis of equations (4) and (5) of this study and of equation by Mailhot (1987) with the uptake observed in waters from Lac Lusignan and Lac D'Argile. Uptake in these lakes was not well predicted by either set of equations.



Lac Lusignan
Lac D'Argile
This study
Mailhot
PCB C-14 uptake (%)
Time (min)
0
10
20
30
40
60
120
180
240

values of chlorophyll in both lakes may indicate the presence of suspended clays that may sorb less PCB than expected. Clays have lower carbon contents than living tissue and sorption rises with carbon level (Sawhney, 1986). Unfortunately, such speculations are empty without more information that must be a goal for further research.

Conclusion:

It is gratifying that predictions from the improved predictive equations for instantaneous rate of uptake and BCF's are highly correlated with the values observed in nature for 2,2',4,4',5,5'-hexachlorobiphenyl and that these regressions allow quite good predictions of the time course of PCB uptake in 9 of 11 trials. Nevertheless, it is perfectly conceivable that these equations may not prove as powerful for another congener of PCB, or another family of compounds. For example, Leversee & al. (1983) found that the effects of a specific concentration of humic acid may depend on the chemical studied and Neudorf & Khan (1975) indicate that the size or composition of the cells may affect uptake The anomalous behavious of Lac D'Argile and Lac Lusignan in this study suggest that other environmental factors can significantly affect the uptake of even this PCB. For all these reasons, the present relations must be considered tentative and ephemeral. Nevertheless, the present level of success shows that the short term uptake of organic contaminants is a predictable phenomenon if both contaminant and sorbent and their mutual environment are considered.

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TABLE OF APPENDIX

Date	Lakes	Nearest Town	Latitude	Longitude
01.06.90	Hertel	St-Hilaire	45 33' N	73 10' W
13.06.90	Croche	St-Hippolyte	45 55' N	74 W
15.06.90	des Piles	Grand'Mère	46 40' N	72 55' W
17.06.90	Lusignan	St-Michel-des Saints	46 40' N	74 W
18.06.90	Waterloo	Waterloo	45 20' N	72 31' W
19.06.90	Memphrémagog	Magog	45 08' N	72 13' W
24.06.90	Magog	Deauville	45 20' N	72 03' W
28.06.90	Brome	Knowlton	45 15' N	72 30' W
05.08.90	Coulombe	St-Gérard	45 50' N	71 20' W
05.08.90	Aylmer	St-Gérard	45 50' N	71 22' W
05.08.90	D'Argile	Notre-Dame-de-la-Salette	45 50' N	75 32' W

PHYSICO-CHEMICAL PROPERTIES OF LAKES SAMPLED IN THIS STUDY MEASURED IN LABORATORY

Lakes	chl a (mg/l)	abs (m)	TP (ug/l)	SP (ug/l)	PP (ug/l)	dry wt (mg/l)	secchi (m)	pH
Hertel	1.462	0.078	14.85	2.35	12.5	1.61	4.5	9.2
Croche	0.965	0.113	3.97	3.24	0.73	1.27	4.25	6.1
des Piles	0.2	0.058	2.266	1.208	1.058	0.46	12.5	6.5
Lusignan	0.16	0.04	8.98	0	8.98	1.72	4.4	7.18
Waterloo	4.46	0.112	28.7	18.3	10.4	2.87	2.2	7.4
Memphre.	2.659	0.041	7.507	1.877	5.63	0.94	3.75	7.84
Magog	1.918	0.09	19.9	5.4	14.5	0.76	4.25	8.02
Aylmer	2.12	0.228	10.89	5.18	5.71	1.41	2.5	7.33
Coulombe	3.039	0.338	13.93	5.54	8.39	2.28	1.9	6.98
Argile	1.41	0.061	10.179	2.5	7.68	3.05	4.5	7.08
Brome	5.794	0.042	4.44	NA	NA	1.35	4	7.5

VALUES USED IN FIGURE 1

	mean values of duplicate experiments at 5ppm of this study			predicted % uptake using equations from Mailhot (1987)
Time (min)	exp 1	exp 2	exp 3	uptake (%)
2	NA	NA	NA	0.633341
15	NA	NA	NA	3.585172
19	NA	NA	3	4.222592
20	2.8	NA	NA	4.368212
21	NA	0	NA	4.508896
30	NA	NA	NA	5.588883
40	6.3	NA	4.1	6.496602
44	NA	4.9	NA	6.797707
45	NA	NA	NA	6.868449
60	NA	NA	NA	7.756351
62	10.3	NA	3.2	7.854614
68	NA	5.8	NA	8.127157
75	NA	NA	NA	8.408547
82	NA	NA	8.9	8.657111
84	8.9	NA	NA	8.722891
88	NA	3.4	NA	8.848186
90	NA	NA	NA	8.907897
105	NA	NA	NA	9.302496
106	NA	NA	11	9.325880
107	11.5	NA	NA	9.348941
113	NA	6.1	NA	9.480895
120	NA	NA	NA	9.622175
130	NA	NA	12.3	9.803583
131	7.8	NA	NA	9.820543
136	NA	12.5	NA	9.902419
150	NA	NA	NA	10.10850
151	NA	NA	7	10.12205
154	9	NA	NA	10.16186
158	NA	11.5	NA	10.21305
180	NA	NA	NA	10.46098
210	NA	NA	NA	10.72819
216	11.7	NA	11.9	10.77406
227	NA	19.8	NA	10.85276
240	NA	NA	NA	10.93773
261	15	NA	NA	11.05939
265	NA	NA	17.1	11.08065
279	NA	12.1	NA	11.15084
300	NA	NA	NA	11.24522

VALUES USED IN FIGURE 2

Time (min)	best fit at 5ppm in this study exp 1	exp 2	exp 3	best fit at 5ppm in Mailhot (1987) exp 1	exp 2	exp 3	exp 4
2	0.496045	0.183246	0.232103	0.386201	0.492793	0.656548	0.693972
15	3.082370	1.338866	1.656955	2.643161	3.254055	4.356861	3.834710
19	3.708653	1.682530	2.068169	3.260260	3.975549	5.329773	4.493359
20	3.855536	1.767602	2.169103	3.409514	4.147993	5.562682	4.642883
21	3.998828	1.852339	2.269305	3.556837	4.317430	5.791671	4.787007
30	5.146443	2.600266	3.139485	4.801711	5.719119	7.691376	5.882666
40	6.181242	3.401419	4.044075	6.033541	7.055276	9.511225	6.789109
44	6.539872	3.713455	4.388968	6.487437	7.535411	10.16732	7.086929
45	6.625293	3.790733	4.473754	6.597734	7.651119	10.32560	7.156694
60	7.736908	4.916087	5.680944	8.115484	9.206093	12.45918	8.025779
62	7.864606	5.061500	5.833270	8.300265	9.390790	12.71340	8.121219
68	8.223908	5.491469	6.278930	8.832613	9.917473	13.43928	8.385167
75	8.602969	5.981527	6.778384	9.414984	10.48459	14.22245	8.656509
82	8.944869	6.459559	7.257088	9.959544	11.00653	14.94465	8.895212
84	9.036484	6.593992	7.390229	10.10869	11.14810	15.14078	8.958228
88	9.212325	6.860060	7.651853	10.39893	11.42190	15.52038	9.078081
90	9.296748	6.991715	7.780390	10.54015	11.55433	15.70412	9.135116
105	9.865001	7.950839	8.698892	11.52386	12.46259	16.96666	9.510713
106	9.899251	8.013060	8.757412	11.58506	12.51829	17.04422	9.532899
107	9.933093	8.075071	8.815608	11.64576	12.57343	17.12103	9.554771
113	10.12796	8.442812	9.158142	11.99958	12.89310	17.56656	9.679771
120	10.33897	8.862676	9.543911	12.39121	13.24336	18.05534	9.813324
130	10.61354	9.445996	10.07067	12.91462	13.70571	18.70149	9.984384
131	10.63943	9.503293	10.12185	12.96478	13.74968	18.76299	10.00035
136	10.76490	9.787021	10.37379	13.21002	13.96380	19.06265	10.07738
150	11.08455	10.55782	11.04616	13.85069	14.51659	19.83736	10.27084
151	11.10577	10.61158	11.09241	13.89404	14.55365	19.88936	10.28354
154	11.16823	10.77187	11.22980	14.02229	14.66305	20.04289	10.32083
158	11.24885	10.98328	11.40990	14.18917	14.80486	20.24199	10.36874
180	11.64437	12.10081	12.34119	15.03096	15.51073	21.23457	10.60031
210	12.08015	13.51127	13.46912	16.00514	16.30849	22.35946	10.84889
216	12.15598	13.77895	13.67746	16.17991	16.44950	22.55864	10.89146
227	12.28677	14.25802	14.04595	16.48523	16.69431	22.90468	10.96442
240	12.42902	14.80556	14.46032	16.82288	16.96282	23.28458	11.04311
261	12.63452	15.64991	15.08559	17.32132	17.35501	23.84013	11.15559
265	12.67066	15.80540	15.19896	17.41030	17.42450	23.93866	11.17523
279	12.79045	16.33686	15.58239	17.70817	17.65599	24.26703	11.24001
300	12.95270	17.09867	16.12125	18.11891	17.97235	24.71626	11.32701

VALUES USED IN FIGURE 3

average time course of PCB uptake at all different biomasses

Time (min)	UPTAKE OF PCB C-14 (%) 1ppm	5ppm	10ppm	25ppm	50ppm	100ppm	200ppm
20	0.189849	2.090566	5.000797	9.009249	16.18747	29.34495	30.11994
40	0.379699	3.909714	8.601497	15.05995	24.69816	34.30239	37.51818
60	0.569549	5.507080	11.31788	19.40392	29.94635	36.34930	40.86393
80	0.759398	6.920890	13.44010	22.67401	33.50627	37.46718	42.77102
100	0.949248	8.181065	15.14388	25.22464	36.07968	38.17153	44.00318
120	1.139098	9.311356	16.54187	27.26971	38.02676	38.65600	44.86483
140	1.328947	10.33086	17.70962	28.94598	39.55135	39.00964	45.50125
160	1.518797	11.25510	18.69967	30.34496	40.77750	39.27915	45.99054
180	1.708647	12.09684	19.54972	31.53020	41.78504	39.49136	46.37843
200	1.898496	12.86665	20.28751	32.54720	42.62764	39.66278	46.69349
220	2.088346	13.57338	20.93389	33.42941	43.34274	39.80415	46.95447
240	2.278195	14.22447	21.50487	34.20197	43.95724	39.92273	47.17419
260	2.468045	14.82624	22.01290	34.88412	44.49098	40.02362	47.36172
280	2.657895	15.38409	22.46786	35.49085	44.95890	40.11050	47.52365
300	2.847744	15.90267	22.87765	36.03401	45.37246	40.18610	47.66489

VALUES USED IN FIGURE 4

panel A: mean data from all biomass experiments of this study

Log rate (%/min)	Log biom (mg/l)	predicted from regression
-1.4652	0	-1.5549
-0.8532	0.699	-0.82095
-0.4983	1	-0.5049
-0.2427	1.3979	-0.08710
0.1098	1.699	0.22905
0.7068	2	0.5451
0.9099	2.301	0.86115

Regression Output:

Constant	-1.55493
Std Err of Y Est	0.123356
R Squared	0.982172
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	1.049991
Std Err of Coef.	0.063263

Regression Output:

Constant	-1.68251
Std Err of Y Est	0.118934
R Squared	0.976143
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	1.124271
Std Err of Coef.	0.087879

panel B: mean data from all biomass experiments of this study although the regression exclude 1ppm experiment results

Log BCF	Log biom (mg/1)	predicted from regression
4.7122	0	5.084828
5.1018	0.699	4.8235
4.7194	1	4.478043
4.5469	1.3979	4.216628
4.3835	1.699	3.9553
3.7747	2	3.693971
3.726	2.301	

Regression Output:

Constant	5.691715
Std Err of Y Est	0.139063
R Squared	0.946945
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.86820
Std Err of Coef.	0.102751

Regression Output:

Constant	5.116682
Std Err of Y Est	0.307750
R Squared	0.695518
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	-0.53339
Std Err of Coef.	0.157831

VALUES USED IN FIGURE 5

panel A: data from all colour effects experiments of this study

Log abs	Log rate	regression
-1.10790	-0.06073	-0.00467
-1.05551	0.064764	-0.02668
-1.05060	-0.13351	-0.02874
-0.93554	-0.31621	-0.07707
-0.86646	-0.18644	-0.10608
-0.82390	-0.11650	-0.12395
-0.73992	-0.25014	-0.15922
-0.72353	0.002913	-0.16611
-0.65955	0.116215	-0.19298
-0.56543	-0.27803	-0.23251
-0.52143	-0.22584	-0.25099
-0.47366	-0.03143	-0.27106
-0.07727	-0.59641	-0.43754
-0.07007	-0.39737	-0.44057
-0.05354	-0.39795	-0.44750
0.232742	-0.79142	-0.56775
0.245759	-0.45466	-0.57321
0.274157	-0.58455	-0.58514

Regression Output:

Constant	-0.46513
Std Err of Y Est	0.152516
R Squared	0.639170
No. of Observations	18
Degrees of Freedom	16
X Coefficient(s)	-0.41631
Std Err of Coef.	0.078199

panel B: data from all colour effects experiments of this study

Log abs	Log BCF	regression
-1.10790	4.427242	4.583739
-1.05551	4.863132	4.572213
-1.05060	4.566343	4.571134
-0.93554	4.396704	4.545819
-0.86646	4.651810	4.530621
-0.82390	4.377979	4.521259
-0.73992	4.759796	4.502784
-0.72353	4.484769	4.499178
-0.65955	4.525899	4.485102
-0.56543	4.451617	4.464394
-0.52143	4.207311	4.454715
-0.47366	4.444716	4.444205
-0.07727	4.425191	4.357000
-0.07007	4.258589	4.355415
-0.05354	4.298154	4.351780
0.232742	4.752217	4.288796
0.245759	4.177911	4.285932
0.274157	4.043126	4.279685

Regression Output:

Constant	4.338866
Std Err of Y Est	0.192856
R Squared	0.243434
No. of Observations	18
Degrees of Freedom	16
X Coefficient(s)	-0.22436
Std Err of Coef.	0.098882

VALUES USED IN FIGURE 6

panel A: measured instantaneous rate of uptake of nine lakes sampled in this study and the predicted values using the semi-empirical equation

	Observed Log rate (%/min)	Predicted Log rate (%/min)
Lac des Piles	-0.8162	-0.92638
Croche	-0.5108	-0.56362
Memphremagog	-0.4778	-0.52224
Magog	-0.4447	-0.76650
Aylmer	-0.3481	-0.64147
Hertel	-0.3269	-0.38292
Brome	-0.1726	-0.35391
Coulombe	-0.1577	-0.48372
Waterloo	-0.0562	-0.17258

Regression Output:

Constant		0.101772
Std Err of Y Est		0.122778
R Squared		0.749311
No. of Observations		9
Degrees of Freedom		7
X Coefficient(s)	0.878165	
Std Err of Coef.	0.191983	

panel B: measured BCF from nine lakes sampled in this study and the predicted values using the semi-empirical equation

	Observed Log BCF	Predicted Log BCF
Waterloo	4.7618	4.97024
Coulombe	4.861	4.951445
Aylmer	5.0285	5.170634
Hertel	5.0476	5.223346
Croche	5.1193	5.277362
Brome	5.1851	5.348885
Memphremagog	5.2642	5.487763
Magog	5.4355	5.492434
Lac des Piles	5.6553	5.724244

Regression Output:

Constant	-0.53760
Std Err of Y Est	0.060165
R Squared	0.958563
No. of Observations	9
Degrees of Freedom	7

X Coefficient(s)	1.074515
Std Err of Coef.	0.084439

DATA USED IN FIGURE 7

Time (min)	uptake (%) of PCB C-14 in Lake Waterloo water: exp 1	exp 2	exp 3	predicted uptake (%) of PCB C-14 from Mailhot (1987) and this study: Mailhot	this study
22	5.6	12.3	14.9	4.644892	11.16410
42	17.4	14.8	18	6.650918	17.43179
62	21.1	21.4	17	7.854614	21.76829
82	24.3	22.2	25	8.657111	24.94700
103	24.1	26.4	25.3	9.254733	27.48354
125	25.4	31.1	29.4	9.715661	29.54828
147	28.6	30.7	27.5	10.06696	31.19011
251	23.5	28.4	27.8	11.00366	35.88413
287	31.9	27.2	28.5	11.18824	36.86787
			R Squared:	0.84	0.81

	uptake (%) of PCB C-14 in Lac des Piles water			predicted uptake (%) of PCB C-14 from Mailhot (1987) and this study	
Time (min)	exp 1	exp 2	exp 3	Mailhot	this study
21	4.5	3.2	3	4.508896	2.353209
43	2.7	1.2	7.1	6.725219	4.558802
63	3.5	7.1	5.4	7.902286	6.367232
82	10.5	5.3	8	8.657111	7.935424
101	13	15.7	14.3	9.205596	9.375801
121	18.3	12.7	16	9.641343	10.77037
141	16.2	14.4	20	9.979721	12.05475
199	18.1	16.5	26.6	10.63807	15.26455
253	19.6	15.6	26.7	11.01511	17.71159
			R Squared:	0.76	0.84

DATA USED IN FIGURE 8

Time (min)	uptake (%) of PCB C-14 in Lac Lusignan water: exp 1	exp 2	exp 3	predicted uptake (%) of PCB C-14 from Mailhot (1987) and this study: Mailhot	this study
19	4.7	5.3	0	4.222592	9.144592
39	8.4	12.3	6.4	6.416439	15.71613
58	12.1	7	13	7.653994	20.24339
77	13	9.1	12.6	8.482653	23.70151
97	11.7	12.2	11.5	9.102955	26.55690
116	17.4	16.1	14	9.543016	28.74033
136	10.7	16.4	15.4	9.902419	30.63107
215	21.3	19.8	16.9	10.76657	35.62594
273	21.2	25.5	28.6	11.12153	37.88543
			R Squared:	0.76	0.81

	uptake (%) of PCBC-14 in Lac D´Argile water			predicted uptake (%) of PCB C-14 from Mailhot (1987) and this study	
Time (min)	exp 1	exp 2	exp 3	Mailhot	this study
19	4.8	7	10.2	4.222592	13.02018
36	12.7	10.6	7.5	6.162950	19.94912
54	11.2	10.5	16.2	7.435930	24.88225
74	15	19.6	17.1	8.370502	28.72138
94	13.1	12.5	19.9	9.021892	31.51470
112	20.5	20.7	20.1	9.459636	33.44916
132	21.5	21.2	23.2	9.837303	35.15667
204	19.6	22.6	20.9	10.68005	39.10185
252	25.7	27.3	26.8	11.00941	40.69662
			R Squared:	0.83	0.84

DATA USED IN FIGURE 9 IN APPENDIX

uptake (%) of PCB C-14 in Lake Aylmer water

predicted uptake (%) from Mailhot (1987) and this study

Time (min)	exp 1	exp 2	exp 3	Mailhot	this study
20	11.4	11.8	9.2	4.368212	4.046938
40	10.6	11.9	11.2	6.496602	7.344444
57	16.5	9.9	12	7.601199	9.702231
77	18.5	11.6	18	8.482653	12.07043
97	15.7	21.3	20.7	9.102955	14.09164
117	13.7	11.4	13.3	9.563189	15.83692
140	23.4	22.2	21.5	9.964608	17.57088
200	25	23.8	22.8	10.64661	21.09574
250	31.4	23.8	20.4	10.99788	23.27464
			R Squared:	0.62	0.7

uptake (%) of PCB C-14
in Lake Brome

predicted uptake (%) from
Mailhot (1987) and this study

Time (min)	exp 1	exp 2	exp 3	Mailhot	this study
17	8.9	6.7	7.2	3.915469	6.6232
37	15.8	12.3	15.6	6.249700	12.42689
55	20.1	22.7	20.3	7.492205	16.43251
74	20.4	16.8	19	8.370502	19.80109
95	21.8	23	21.4	9.049319	22.79064
115	28.5	27.4	24.2	9.522580	25.11434
137	23	27.3	20.6	9.918233	27.23224
197	30	33.2	25.8	10.62078	31.45540
			R Squared:	0.9	0.88

	uptake (%) of PCB C-14 in Lake Hertel water			predicted uptake (%) from Mailhot (1987) and this study	
Time (min)	exp 1	exp 2	exp 3	Mailhot	this study
20	4.5	6.2	5.2	4.368212	7.015267
42	14.3	17.1	13.4	6.650918	12.61372
62	15.4	14.7	18.7	7.854614	16.46763
81	17.3	14.3	17.9	8.623392	19.38515
102	20.2	20	20.4	9.230340	22.00422
121	21.2	19.5	28	9.641343	23.96530
141	25.5	21.3	24.8	9.979721	25.71011
206	30.1	27.3	27.5	10.69636	29.86025
263	24.3	27	25.5	11.07009	32.31243
			R Squared:	0.89	0.88

Time (min)	exp 1	exp 2	exp 3	Mailhot	this study
	uptake (%) of PCB C-14 in Lake Magog water			predicted uptake (%) from Mailhot (1987) and this study	
20	8.4	5.7	4.6	4.368212	3.954205
40	14.8	11.1	9.5	6.496602	7.232478
62	11.7	10.9	14.1	7.854614	10.24695
83	16.7	17.7	13.4	8.690273	12.67772
102	13.8	20	20.8	9.230340	14.57979
123	22.3	19.7	23.2	9.678964	16.41681
141	24.2	20.3	23.5	9.979721	17.80808
208	26.3	24.6	23.5	10.71241	21.89174
253	25.3	26.3	29.8	11.01511	23.94727
			R Squared:	0.87	0.91

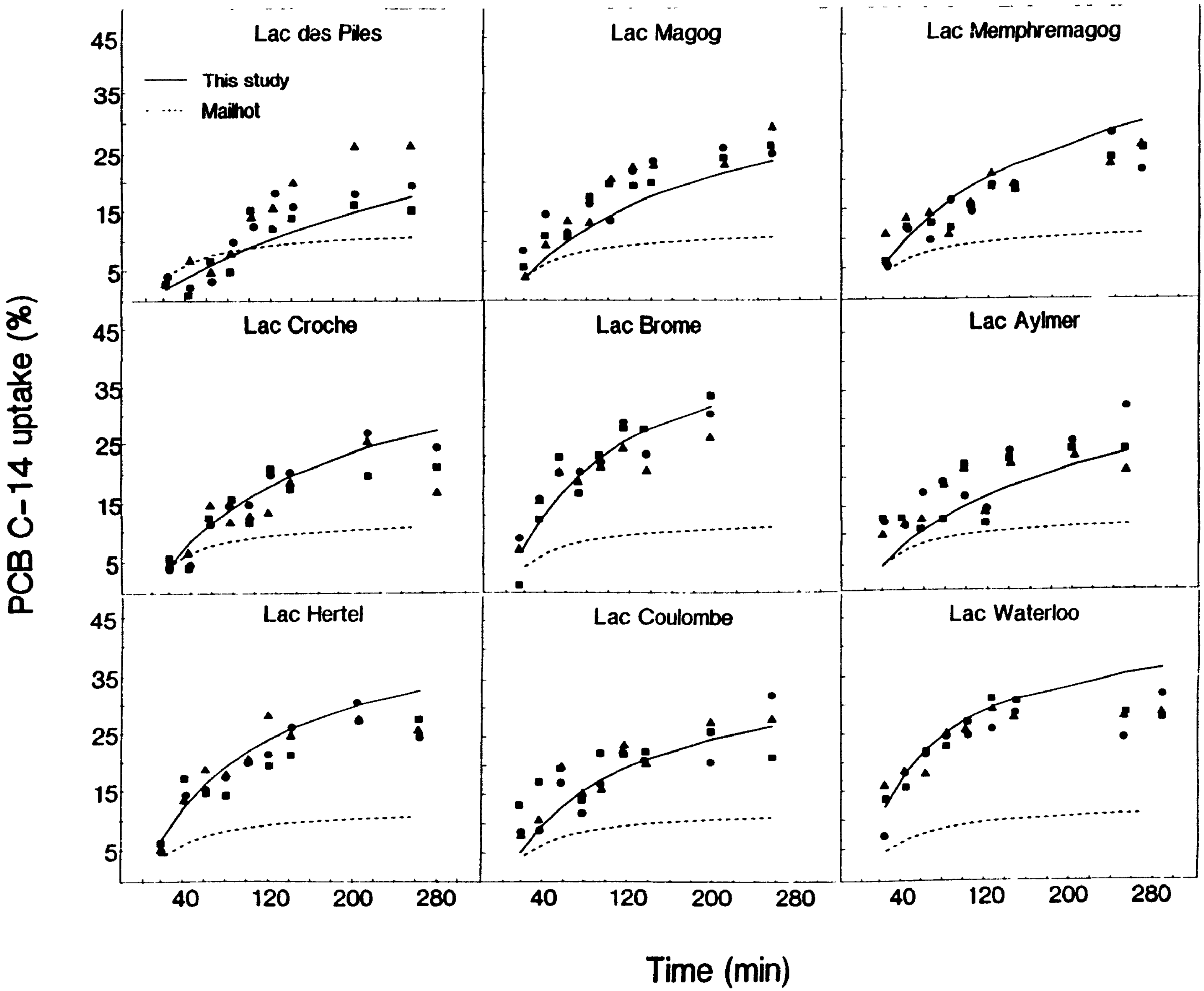
Time (min)	uptake (%) of PCB C-14 in Lake Coulombe water			predicted uptake (%) from Mailhot (1987) and this study	
	exp 1	exp 2	exp 3	Mailhot	this study
17	8.6	12.7	7.5	3.915469	4.851824
35	8.7	16.4	10	6.073825	8.829032
55	16.8	18.8	19.1	7.492205	12.28857
75	11.5	13.8	14.4	8.408547	15.03846
93	16.6	21.9	15.2	8.994046	17.07183
115	22.2	21.8	22.9	9.522580	19.13404
135	20.8	21.9	19.6	9.886422	20.7
196	20.5	25.6	26.9	10.61202	24.25189
253	32	21.2	27.3	11.01511	26.52091
			R Squared:	0.73	0.77

	uptake (%) of PCB C-14 in Lake Croche water			predicted uptake (%) from Mailhot (1987) and this study	
Time (min)	exp 1	exp 2	exp 3	Mailhot	this study
20	4.5	5.9	5.1	4.368212	4.884090
39	4.8	4.5	7	6.416439	8.596
59	11.6	13.1	15.2	7.705700	11.79451
79	15.2	16	12.1	8.554226	14.44859
98	15.4	11.9	13.4	9.129181	16.58283
117	20.4	21.2	14.1	9.563189	18.42
137	20.7	17.9	18.8	9.918233	20.09645
213	27.1	20.1	25.8	10.75140	24.80959
280	24.6	21.4	17.3	11.15562	27.60183
			R Squared:	0.82	0.82

Time (min)	uptake (%) of PCB C-14 in Lake Memphremagog water: exp 1	exp 2	exp 3	predicted uptake (%) from Mailhot (1987) and this study: Mailhot	this study
24	5.5	6.1	10.9	4.903725	6.295690
44	12.1	12.4	13.5	6.797707	10.39363
66	10	13	14.6	8.039803	14.05237
85	16.8	11.8	10.9	8.754979	16.67685
105	15.1	16.4	15.9	9.302496	19.02824
125	19.6	19.1	21.2	9.715661	21.04609
145	19.6	18.3	19.3	10.03852	22.79668
237	28.4	24.1	22.9	10.91883	28.56030
266	22.2	25.8	26.3	11.08588	29.85739
			R Squared:	0.8	0.88

Figure 9

Comparison of the time course of PCB uptake calculated from equations developed in this study and from Mailhot (1987) when applied to all sampled lakes except Lac D'Argile and Lac Lusignan.



Lac des Piles
Lac Magog
Lac Memphremagog
This study
Mailhot
Lac Croche
Lac Brome
Lac Aylmer
Lac Hertel
Lac Coulombe
Lac Waterloo
PCB C-14 uptake (%)
Time (min)
45
35
25
15
5
40
120
200
280

DATA FROM ALL BIOMASS EXPERIMENTS

uptake (%) of PCB C-14 by
Selenastrum capricornutum at 1ppm

Time (min)	1ppm exp 1	1ppm exp 2	1ppm exp 3	5ppm exp 1	5ppm exp 2	5ppm exp 3	10ppm exp 1	10ppm exp 2	10ppm exp 3
19	NA	NA	-2.9	NA	NA	3	NA	NA	-1.1
20	-3.2	NA	NA	2.8	NA	NA	5.3	NA	NA
21	NA	-4.1	NA	NA	-3.6	NA	NA	-0.7	NA
40	3	NA	-2.5	6.3	NA	4.1	10.6	NA	9.4
44	NA	-9.9	NA	NA	4.9	NA	NA	8.2	NA
62	2.4	NA	-3.1	10.3	NA	3.2	15.7	NA	10.5
68	NA	-1.3	NA	NA	5.8	NA	NA	13.6	NA
82	NA	NA	-1.5	NA	NA	8.9	NA	NA	12
84	1.2	NA	NA	8.9	NA	NA	13.5	NA	NA
88	NA	1.8	NA	NA	3.4	NA	NA	9.4	NA
106	NA	NA	0.7	NA	NA	11	NA	NA	18.4
107	9.7	NA	NA	11.5	NA	NA	12.8	NA	NA
113	NA	-1.3	NA	NA	6.1	NA	NA	13.8	NA
130	NA	NA	0.9	NA	NA	12.3	NA	NA	19.2
131	-1.8	NA	NA	7.8	NA	NA	23.4	NA	NA
136	NA	1.2	NA	NA	12.5	NA	NA	22.5	NA
151	NA	NA	-0.9	NA	NA	7	NA	NA	18.4
154	6.5	NA	NA	9	NA	NA	19	NA	NA
158	NA	1	NA	NA	11.5	NA	NA	23.9	NA
216	3.8	NA	2	11.7	NA	11.9	17.6	NA	16.2
227	NA	6.2	NA	NA	19.8	NA	NA	21.6	NA
261	1.3	NA	NA	15	NA	NA	21.9	NA	NA
265	NA	NA	5.5	NA	NA	17.1	NA	NA	21.4
279	NA	1.9	NA	NA	12.1	NA	NA	21.2	NA

Time (min)	25ppm exp 1	25ppm exp 2	25ppm exp 3	50ppm exp 1	50ppm exp 2	50ppm exp 3
21	NA	NA	1.9	NA	17.8	11.7
27	-16.5	5.9	NA	5.9	NA	NA
45	NA	NA	11.6	NA	36.9	32.1
51	18.7	15.9	NA	29.4	NA	NA
67	NA	NA	25	NA	41.8	38.9
77	25	21	NA	23.7	NA	NA
90	NA	NA	24.1	NA	43.4	35.4
102	29.1	22.6	NA	35.3	NA	NA
114	NA	NA	26.6	NA	39.4	35.9
124	29.4	42.6	NA	32.3	NA	NA
138	NA	NA	29.9	NA	44	41.7
149	36.3	30.7	NA	31	NA	NA
161	NA	NA	35.2	NA	46.1	42
173	35.9	27.1	NA	41.4	NA	NA
230	NA	NA	30.9	NA	45	44.9
242	35.9	30.7	NA	34.9	NA	NA
285	NA	NA	34	NA	37.9	58.8
302	33.3	24.3	NA	35.4	NA	NA

Time (min)	100ppm exp 1	100ppm exp 2	100ppm exp 3	200ppm exp 1	200ppm exp 2	200ppm exp 3
22	31.4	28.2	26.9	44.9	39.4	32.9
42	NA	33.6	35.5	NA	NA	12.8
48	31.2	NA	NA	44.6	48.1	NA
65	NA	40.4	28.9	NA	NA	38.8
69	44.5	NA	NA	43.2	46.1	NA
86	NA	37.7	38	NA	NA	38.3
89	36.6	NA	NA	44.3	44	NA
108	NA	37.1	33.8	NA	NA	40.7
112	36.8	NA	NA	45.6	50.3	NA
128	NA	39.9	37.3	NA	NA	40.1
135	39.3	NA	NA	43.3	49.4	NA
150	NA	41.1	42.2	NA	NA	46.2
158	41.4	NA	NA	48.5	53	NA
222	40.8	NA	NA	44	48.8	NA
226	NA	35.3	35.4	NA	NA	41.2
285	42.5	NA	NA	46.3	52.6	NA
289	NA	43.7	41.1	NA	NA	49.6

DATA FROM ALL COLOUR EXPERIMENTS

uptake (%) of PCB C-14 by S.capricornutum

absorbance /m at 440nm.

Time (min)	0.78	0.88	0.89	1.16	1.36	1.50
19	4.9	NA	NA	NA	NA	6.8
20	NA	NA	5.3	NA	3.7	NA
21	NA	0.8	NA	NA	NA	NA
27	NA	NA	NA	-5.4	NA	NA
40	20.8	NA	NA	NA	NA	20.2
41	NA	NA	19.1	NA	18.7	NA
42	NA	35.8	NA	NA	NA	NA
52	NA	NA	NA	27.5	NA	NA
61	25.7	NA	NA	NA	NA	18.9
63	NA	34.7	NA	NA	NA	NA
64	NA	NA	26.2	NA	26.4	NA
79	22.2	NA	NA	NA	NA	18.7
83	NA	41.5	NA	20.9	NA	NA
86	NA	NA	28.5	NA	27.8	NA
98	26.4	NA	NA	NA	NA	24.3
106	NA	39.9	30.2	18.1	34.1	NA
121	30.4	NA	NA	NA	NA	27.6
127	NA	NA	33.8	NA	34	NA
128	NA	42.5	NA	NA	NA	NA
131	NA	NA	NA	22.4	NA	NA
139	24.6	NA	NA	NA	NA	19.4
148	NA	44.7	28.9	18.1	31.5	NA
166	NA	NA	NA	19	NA	NA
203	NA	NA	36.2	NA	36.2	NA
204	31.3	NA	NA	NA	NA	30.7
227	NA	NA	NA	25.6	NA	NA
228	NA	47.4	NA	NA	NA	NA
257	29.4	NA	NA	NA	NA	26.3
269	NA	NA	36.6	NA	42	NA
280	NA	46.8	NA	33.1	NA	NA

absorbance /m at 440nm.

Time (min)	1.82	1.89	2.19	2.72	3.01	3.36
19	NA	NA	9.5	NA	NA	6.9
21	10.4	11.4	NA	6.5	NA	NA
27	NA	NA	NA	NA	11.9	NA
38	NA	NA	30	NA	NA	17.8
42	13.5	21.5	NA	14.1	NA	NA
52	NA	NA	NA	NA	16.6	NA
59	NA	NA	30.1	NA	NA	30.2
63	19.1	31.1	NA	19.4	NA	NA
78	NA	NA	37	NA	NA	28.3
83	25.2	NA	NA	NA	15.4	NA
84	NA	28.7	NA	24.2	NA	NA
97	NA	NA	29.3	NA	NA	27.7
104	NA	27.8	NA	25	NA	NA
106	26.8	NA	NA	NA	12.3	NA
119	NA	NA	37.4	NA	NA	29.2
123	NA	31.9	NA	26	NA	NA
128	26.9	NA	NA	NA	NA	NA
131	NA	NA	NA	NA	17.9	NA
141	NA	NA	39.6	NA	NA	32.1
143	NA	26.8	NA	18.2	NA	NA
148	31.6	NA	NA	NA	19.4	NA
166	NA	NA	NA	NA	16.2	NA
204	NA	NA	42.3	NA	NA	38.4
218	NA	38.8	NA	27	NA	NA
227	NA	NA	NA	NA	19.2	NA
228	35.1	NA	NA	NA	NA	NA
255	NA	NA	38.9	NA	NA	30.4
279	NA	36.8	NA	35.1	NA	NA
280	34.4	NA	NA	NA	28.2	NA

absorbance /m at 440nm.

Time (min)	8.37	8.51	8.84	17.09	17.61	18.80
19	NA	NA	4.7	NA	NA	0.5
20	NA	2.5	NA	NA	NA	NA
21	-22	NA	NA	NA	4.3	NA
27	NA	NA	NA	-23.2	NA	NA
38	NA	NA	NA	NA	NA	3
40	NA	NA	12.1	NA	NA	NA
41	NA	3.7	NA	NA	NA	NA
42	7	NA	NA	NA	6.1	NA
52	NA	NA	NA	11.7	NA	NA
59	NA	NA	NA	NA	NA	13.8
61	NA	NA	15	NA	NA	NA
63	10.1	NA	NA	NA	13.5	NA
64	NA	11.5	NA	NA	NA	NA
78	NA	NA	NA	NA	NA	14
79	NA	NA	11.4	NA	NA	NA
83	12.9	NA	NA	14.1	NA	NA
84	NA	NA	NA	NA	14.3	NA
86	NA	16	NA	NA	NA	NA
97	NA	NA	NA	NA	NA	9.3
98	NA	NA	16.2	NA	NA	NA
104	NA	NA	NA	NA	16.2	NA
106	14.1	16.7	NA	13.3	NA	NA
119	NA	NA	NA	NA	NA	9.2
121	NA	NA	18.9	NA	NA	NA
123	NA	NA	NA	NA	14.8	NA
127	NA	18.2	NA	NA	NA	NA
128	17.2	NA	NA	NA	NA	NA
131	NA	NA	NA	15.1	NA	NA
139	NA	NA	20.7	NA	NA	NA
141	NA	NA	NA	NA	NA	12.8
143	NA	NA	NA	NA	11.7	NA
148	18.3	20.6	NA	13.2	NA	NA
166	NA	NA	NA	15.2	NA	NA
203	NA	23	NA	NA	NA	NA
204	NA	NA	25.2	NA	NA	21.3
218	NA	NA	NA	NA	17.3	NA
227	NA	NA	NA	24.2	NA	NA
228	19.5	NA	NA	NA	NA	NA
255	NA	NA	NA	NA	NA	10
257	NA	NA	19.9	NA	NA	NA
269	NA	26.5	NA	NA	NA	NA
279	NA	NA	NA	NA	17.9	NA
280	17.5	NA	NA	25.7	NA	NA

DATA FROM ALL THE pH EXPERIMENTS

uptake (%) of PCB C-14 by S.capricornutum in medium at different pH

pH4

Time (min)	exp 1	Time (min)	exp 2	Time (min)	exp 3
19	8.1	20	11.3	18	9.8
40	15.1	43	19.1	37	29
61	17.8	64	23.7	58	29.2
82	23.7	91	26.2	79	31.9
104	25	110	24.7	100	38.8
126	32	130	27.7	121	40.8
148	32.1	152	31.3	143	38.1
213	32.9	214	36.2	197	45.2
276	32.8	265	36.2	265	48.4

pH5

Time (min)	exp 1	Time (min)	exp 2	Time (min)	exp 3
21	12	21	8.9	19	7.4
41	18	41	21.5	39	9.9
62	32	62	23.3	58	12.8
84	31.9	84	20.1	79	11.8
106	31.3	106	28.1	97	8.7
128	39.3	128	30.6	117	11.1
143	30.9	143	27.2	141	12.6
222	37.8	222	33.2	207	7.5
277	37	277	38	276	12.9

pH6

Time (min)	exp 1	Time (min)	exp 2	Time (min)	exp 3
19	4.2	20	7.7	18	7.1
40	13.6	43	21.1	37	14
61	16.3	64	24.1	58	21.3
82	19.6	91	35.8	79	24.3
104	27	110	27.2	100	19.7
126	27.5	130	31.5	121	22.1
148	24.8	152	37.8	143	28.3
213	29.3	214	37.7	197	30.1
276	32.4	265	39	265	25.7

pH7

Time (min)	exp 1	Time (min)	exp 2	Time (min)	exp 3
21	4.2	19	10.5	20	1.8
41	18.8	39	13.1	40	11.5
62	31.3	58	10.1	64	16.6
84	23.8	79	21	87	13.9
106	40	97	21.1	106	22.2
128	39.7	117	22.7	127	21.3
143	36.2	141	21.8	148	17.3
222	41.3	207	27.1	212	20.5
277	42.6	276	25.1	265	19.9

pH8

Time (min)	exp 1	Time (min)	exp 2	Time (min)	exp 3
21	4.5	19	3.5	20	3.1
41	10.3	39	51.2	40	8.9
62	30.7	58	13	64	16.9
84	37.1	79	17.8	87	19.7
106	40.2	97	18.4	106	14.8
128	41.1	117	20.4	127	17
143	39	141	23.2	148	19.1
222	40.6	207	23.2	212	17.6
277	43.9	276	15	265	16.8

pH9

Time (min)	exp 1	Time (min)	exp 2	Time (min)	exp 3
19	5.9	20	10	18	3.4
40	11	43	28.2	37	10.7
61	16.2	64	23.7	58	18.6
82	25.4	91	29.9	79	26.1
104	25.9	110	26.4	100	18.5
126	30.5	130	36.9	121	22.7
148	24.4	152	29	143	24.7
213	30.3	214	27.2	197	31.1
276	27.3	265	37.1	265	27.6