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Project Summary

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An Age-Dependent Model of PCB in a Lake Michigan Food Chain

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An age-dependent food chain model that considers species bioenergetics and toxicant exposure through water and food was developed. It was successfully applied to PCB contamination of the Lake Michigan lake trout food chain represented by phytoplankton, *Mysis*, alewife, and lake trout. The model indicated that for the top predator lake trout, PCB exposure through the food chain can account for greater than 99 percent of the observed body burden. A simple steady-state computation indicated that ratios of chemical concentration in predators to that in prey in feeding experiments may be as low as 0.2 and still result in significant food chain transfer.

It was estimated that a criterion specifying that PCB concentrations of all ages of lake trout be at or below 5 μg/g (wet weight) in the edible portion would require that dissolved PCB concentrations be reduced to between 0.5 and 2.5 ng/L. The range reflects uncertainty in the PCB assimilation efficiency of the species and the dissolved PCB concentration.

This Project Summary was developed by EPA's Environmental Research Laboratory, Duluth, MN, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The PCB concentration in the fishes of Lake Michigan has been a matter of study and concern for a number of years. Concentrations of PCB in adult lake trout *(Salvelinus namaycush)* in 1971, for example, averaged about 5-20 μg/g(w), substantially above the U S. Food and Drug Administration (FDA) guidelines of 5 μg/g(w) in the edible portion of fish.

In order to understand the mechanisms that give rise to these levels, it is necessary to analyze the data through use of a model of the principal phenomena of chemical uptake and transfer. These mechanisms include two principal routes:

1) uptake of PCB directly from water, and
2) accumulation of PCB through consumption of contaminated food

The significance of the food chain route, i.e., the degree to which a chemical such as PCB's may be accumulated in an organism by predation, needs to be placed in a mechanistic predictive framework to be able to calculate expected levels under field conditions

It has been suggested that the maximum environmental concentration in fish can be estimated without recourse to a food chain route. Such an approach assumes that a first approximation to expected levels of a chemical can be obtained either from simple partitioning concepts or from a simple model of direct uptake from the water.

The issue of whether a simple calculation of uptake of a chemical directly from the water is sufficient relates to the degree to which such a calculation would actually reproduce observed field data for important species such as the lake trout. If such a calculation does account for the observed data in the field, then there is no need for a model that includes a food chain component If a simple partitioning calculation fails to reproduce the observed data, then the principal feature of the food chain must be included

The principal objectives of this effort therefore were to.

1 develop an age-dependent food chain model of uptake and transfer of potentially toxic chemicals,

2 determine the relative importance of water uptake and food chain routes of PCB in a Lake Michigan food chain with specific emphasis on lake trout,

3. test the utility of simple partitioning approaches for PCB that do not include the food chain route, and

4 provide a preliminary projection of response in PCB concentration in the lake trout following a reduction in PCB water concentration.

Approach

The accumulation of PCBs in the Lake Michigan food chain was modeled assuming a four species food chain consisting of phytoplankton, *Mysis relicta,* alewife (*Alosa pseudoharengus*), and lake trout *(Salvelinus namaycush)* This species linkage constitutes the major energy transport route to the lake trout Both *Mysis* and alewife were viewed as representative species of the middle levels of the food chain acknowledging that other invertebrates and small fish also contribute to the observed PCB levels in lake trout The phytoplankton component of the model was assumed to represent nonliving particulate organic material as well as living plankton

Phytoplankton were represented by a single compartment that was assumed to be in dynamic equilibrium with water column dissolved PCB. PCB concentrations in the other species were calculated in time using a framework that considers uptake directly from water, uptake from food, excretion and growth The uptake and excretion rates were calculated from the species bioenergetics Uptake from water and excretion were related to respiration rate Uptake from food was related to consumption rate which was calculated from the respiration and growth rates

The species above phytoplankton were separated into discrete age classes. Predator-prey relationships were specified for each age class based on observed feeding habits.

Results

Data for 1971 were used in the calibration of the model A constant dissolved PCB concentration of 5 ng/L was assumed The model successfully reproduced the observed data for alewife and lake trout with the exception of the early age classes of lake trout No combination of parameters was successful at reproducing the high PCB values in age class 2 and 3 lake trout while maintaining consistency with reported parameter values and reproducing the observed concentrations in the upper age classes. A possible explanation of these high values is that young trout may be exposed to higher dissolved PCB concentrations because of their tendency to stay in near shore areas.

The data and the model both indicate that PCB concentrations in lake trout are 3 to 4 times those in alewife. The computed increase results from the higher PCB concentration in lake trout prey (alewife) relative to alewife prey *(Mysis)*. The model calculated that greater than 99% of the PCB in adult trout is taken up in food.

Empirical evidence indicates that the extent of accumulation of organic chemicals by aquatic species in laboratory studies is related to the lipophilic nature of the chemicals.This lipophilic nature is normally expressed as the equilibrium concentration ratio of the chemical partitioned between *n*-octanol and water, i.e., the octanol-water partition coefficient. Some evidence indicates that field observed contaminant concentrations may be directly estimated from water concentrations using lipid content and the octanol-water partition coefficient of the contaminant. To test this possibility, the highest reported octanol-water partition coefficient available in the literature ($10^{6.72}$ for HCB) was used with the lake trout lipid content to predict lake trout PCB concentration. The resulting PCB concentrations were 4 to 5 times lower than the data and food chain model calculation for adult trout and clearly an unsatisfactory estimation of lake trout contamination. The poor fit results from the failure to consider exposure through food which, as shown earlier, is the dominant contributor of PCB to the top predator lake trout.

The model was used to assess the effect of reduced dissolved PCB concentrations on PCB levels in the lake trout. The results indicate that a period of abou 5 years would be required to "clear out' the initial higher concentrations for th upper age class fish. The overal relationship between age class and th required dissolved water concentration t maintain 5-10 μg/g(w) on a whole fis basis (estimated to result in approximatel 5 μg/g/w for the edible portion) wa determined. The older age classe require the lowest dissolved PCB wate concentration to meet the 5-10 μg/g(w level. If a level of 2 ng/L were obtained then whole fish 6 years and older woul have concentrations between 5 and 1(μg/g(w). Conversely, whole fish less tha 6 years old would have PCB concentra tions less than 5 μg/g(w). In order to hav the PCB concentrations of all age classe of lake trout at or below 5 μg/g(w) in th edible portion, it is estimated that th dissolved water concentrations woul have to be between 0.5-2.5 ng/L usin growth rates representative of stocke fish.

Conclusions

The contamination of Lake Michiga alewife and lake trout by PCB can b adequately modeled using an age dependent computation that consider species bioenergetics and uptake of PC from water and food. The mode successfully reproduces the age dependent trends and magnitude of PC contamination observed in 1971.

Both the model and the PCB dat compiled for this study indicate that foo chain transfer is a significant route c contamination. Data from 13 species c fish suggest an increase in PC concentration as one proceeds up th food chain to the top predators. Transfe of PCB through the food chain is th major contributor to calculated PCB cor centrations, accounting for greater tha 99% of the body burden in adult lak trout. A simple steady-state computatio indicates that ratios of chemical concer tration in predators to that in prey i feeding experiments may be as low as 0. and still result in appreciable food cha transfer.

An empirical relationship between lak trout excretion rate and lipid conter significantly improved the lake trout cal bration, suggesting that lipid tissue is a important factor in PCB dynamics.

A simple empirical correlation betwee octanol/water partitioning of PCB an partitioning between water and fish lip tissue failed to reproduce the observe concentrations in alewife and lake trou It is concluded that although this simp partitioning approach may be useful in assessing trends, it cannot estimate actual concentrations, especially in higher trophic level species, because it does not consider food chain transfer

Projections of the response of the lake trout food chain to reduced water concentrations indicate that a period of about 5 years is needed to reduce whole body PCB concentrations in upper age class lake trout. In order to have the PCB concentrations of all age classes of lake trout at or below 5 μg/g(w) in the edible portion, it is estimated that the dissolved water concentrations would have to be between 0.5-2.5 ng/L. The range results from the uncertainty of the parameter values in the model. These water concentrations represent a 75-95% reduction of apparent 1961-1971 water concentrations. Young age classes can generally be exposed to higher water PCB concentrations than older age classes without exceeding the objective of 5 μg/g(w) As a result, if water quality projections indicate a lower bound in the achievable PCB water concentrations, a size-dependent fish consumption guideline can be developed

Recommendations

This analysis of the PCB contamination of a Lake Michigan food chain has illustrated gaps of knowledge that add uncertainty to the estimation of the effect of concentration reductions. These gaps are most significant in regard to the compound-related parameters needed by the model, i.e., assimilation efficiency and excretion rate It is therefore *recommended that experimental investigations be conducted to more accurately determine these parameters.* Of significant value would be relationships, both within and across species, between these parameters and characteristics of the compound and species, e.g., octanol/water partition coefficient and % lipid.

Additional significant gaps of knowledge are the PCB concentrations of the invertebrate and plankton components of the food chain and accurate estimates of the water concentration.

Differences were found between growth rates of pre-stocked and stocked lake trout. The model was shown to be sensitive to these differences. It is recommended that lake trout growth rate be investigated to provide an accurate estimate that will decrease uncertainty in the model projections

An empirical relationship between lake trout excretion rate and % lipid significantly improved the model calibration suggesting that lipid content is an important factor in accumulation. It is recommended that the model structure be modified to include a more fundamental description of lipid, possibly separating the species into lipid and non-lipid components.

The sediment of Lake Michigan contains a substantial quantity of PCB Because the sediment responds more slowly to reductions in PCB loading than does the water column, it will have significant PCB concentrations even when water column concentrations decline to some "acceptable" level A significant question, then, is the extent to which benthic fauna may transfer this sediment PCB to the pelagic food chain, thus mitigating the concentration reduction in that food chain This question should be addressed by including a benthic component in the food chain

The food chain model was calibrated to data collected in 1971. Data are also available through 1979. These data indicate a decline of lake trout PCB concentrations after 1975. A further calibration of the model, using these data, would increase confidence in its prediction capability It is also recommended that the model be applied to other chemicals for which a sufficient data base exists. This would test the applicability of the model as a general framework for assessing the response of the food chain to toxic substances exposure

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The complete report, entitled "An Age-Dependent Model of PCB in a Lake Michigan Food Chain," (Order No. PB 84-155 993; Cost: $13.00, subject to change) will be available only from:
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