Final Report to Michigan Sea Grant Submitted by:

Kashian, D. R., [1] K. Drouillard [2], D. Haffner[2], A. Krause[3], Z. Liu[3], and L. Sano[4]

What are the Causes, Consequences and Correctives of fish contamination in the Detroit River AOC that cause health consumption advisories?

[1]Department of Biological Sciences, Wayne State University, Detroit, MI, USA

[2]Great Lakes Institute for Environmental Research (GLIER), University of Windsor, Windsor, ON, Canada

[3]Environmental Sciences, University of Toledo, Toledo, OH, USA

[4]Cooperative Institute of Limnology and Ecosystem Research, University of Michigan, Ann Arbor, MI, USA.

CHAPTER 4:

ASSESSING UNCERTAINTY IN FISH CONSUMPTION ADVISORY DATA FOR THE DETROIT RIVER: APPLICATION OF A PROBABILISTIC APPROACH

Abstract

The fish consumption advisory process is characterized by several sources of uncertainty: managers and regulators must combine the best available science on human health effects with information on contaminant concentration in recreational fish and risk factors of a general public to decide when and how to issue an advisory. Because several of the parameters associated with this process are unknown or not fully resolved, there are many ways in which uncertainty propagates through the process. To better assess the nature of uncertainty in the data used to develop consumption advisories, we reviewed relevant literature and developed a probabilistic model to assess the potential impact of uncertainty in key parameters related to these advisories. Available information for polychlorinated biphenyls (PCBs) in fish indicates high variability in some fish populations, including cases of sex-based differences in contaminant levels. PCB levels were also found to vary seasonally in some fish species, indicating a potential need for more consistent field sampling protocols. Available data on human consumption rates suggest that certain subpopulations of the general public vary in both the quantity of sport fish they consume and the way in which they prepare their meals. These variations in consumption habits, in particular, may serve to increase the chance that some individuals are exposed to concentrations exceeding human health endpoints. A simple probabilistic Monte Carlo model was developed to evaluate the effect of data uncertainty on potential human consumption rates. The results of the simulations indicate that variations in fish PCB concentrations and the ingestion rate of contaminated fish strongly affect the estimated chronic daily intake for PCBs. The main implications of these results for Detroit River fish consumption advisories are 1) to improve the rigor of sampling effort for fish used to derive consumption advisories (both in terms of temporal consistency and quantity of samples), 2) to improve information about the consumption habits of high risk groups in the Detroit River, and 3) to target outreach efforts to those populations with the greatest level of risk and exposure – namely minority subsistence fisherpersons, women of childbearing age, and children under the age of 15. These outreach efforts should be developed in the context of the well-known health benefits of eating fish, which are known to be a good source of protein and omega-3 fatty acids.

Introduction

Fish consumption advisories (FCAs), like all risk-based decision processes; rely on the best available science to develop guidelines to protect the health of a diverse population. In general, the consumption advisory process addresses uncertainty by using conservative estimates for risk factors, primarily in the estimation of human health risks. As with other risk-based management decisions, uncertainty is a key, but sometimes overlooked, part of the process. These uncertainties are inherent to many elements of FCAs, including the estimation of no-adverseobservable effect levels, the derivation of reference doses, assumptions regarding the characteristics of the exposed population, and knowledge about variability in exposure rates.

Many of the uncertainties associated with the human health effects of PCBs are addressed through the application of safety factors. These factors are used to counterbalance a lack of information about contaminant effects in humans, since most dose-response data on health risks are derived from non-primate animals. The US Environmental Protection Agency, for example, uses both uncertainty factors and modifying factors to protect human health given a range of unknowns in how the data are derived (US EPA 2000). These factors vary depending on the type of available toxicity studies: for example, a 10-fold uncertainty factor is often used when only subchronic studies (versus chronic exposure studies) are available. Modifying factors, in contrast, are used to cover a wider range of circumstances, including differences in the absorption rates between study species and humans or differences in species-specific tolerances to a given chemical.

There are additional sources of uncertainty that extend beyond human health that are important to consumption advisories. These include the limited size range of fish from which advisories are based, the limited information on variability in PCB concentrations in the actual field populations, seasonal differences in fish contaminant levels, and potential differences between concentrations in raw fish versus consumed fish (subject to freezing and cooking).

An important component of this integrated assessment was to better characterize the range of uncertainties associated with the consumption advisory process. There were two main objectives associated with this original part of the effort:

1) To evaluate current trigger-levels used in issuing fish consumption advisories;

2) To assess options for a toxicologically-defensible and more probabilistic approach for these advisories including assessing whether toxicity equivalency factors (TEFs) improve the consumption advisory process.

As part of the integrated assessment framework used in this study, we focused on the type of uncertainty associated with consumption advisories for PCB. This review assesses the use of these trigger levels and the state of science regarding probabilistic approaches that may be applied in issuing FCAs. In doing so, it draws from other sections of this final report.

Tissue Trigger Analysis

Use of tissue trigger levels in Michigan

Fish consumption advisories are usually issued when contaminant levels in fish exceed a certain threshold (i.e., the tissue trigger level). In the Great Lakes region, most states use advice contained in the Protocol for a Uniform Great Lakes Sport Consumption Advisory (i.e., Protocol; Anderson et al. 1993). This protocol applied a weight-of-evidence approach to identify a health protection value (HPV) for sensitive subpopulations of 0.05 μg total PCBs/kg/day. Using a range of assumptions regarding cooking methods, consumption rates, and exposure duration, the HPV was then used to derive consumption guidelines based on the measured wet weight of PCBs in fish tissue. These ranges are provided in Table 1.

The Michigan Department of Community Health (MDCH) establishes, modifies, and removes sport fish consumption advisories. Currently the state uses the HPV for sensitive subgroups, as prescribed in the Protocol. In contrast, the concentrations used in issuing advisories for the general public derive from the US Food and Drug Administration's action level for PCBs of 2.0 ppm (mg/kg).[12] In terms of the latter, when concentrations in more than 10% of the samples from a particular length of a given fish species exceed 2.0 ppm, MDCH advises the general public to eat no more than 1 meal per week. When concentrations in 50% of more of the samples fish of a given length range exceed this value, MDCH advises the general public against eating any of the fish from that location.

Both advisories are based on fish collected from various locations throughout the state. In most cases, fish length and associated consumption advice are based on sampling results from at least 10 individuals of a given species.

Table 1. PCB concentrations in fish that trigger consumption advisories for fish, as outlined in the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory (Anderson et al. 1993).

Group	**PCB conc. (ppm)†**
Unrestricted consumption	0 – 0.5
1 meal/week	0.06 – 0.2
1 meal/month	0.21 – 1.0
6 meals/year	1.1 – 1.9
No consumption	> 1.9

†In parts-per-million (mg/kg) wet weight and for raw skin-on fish fillets.

Based on fish collected throughout state waters in 2008, total PCB concentrations for women and children[13] exceeded a tissue trigger level in 41% of samples (n=275) and for 88% of all locations (n=17). For the general public, total PCB concentrations were greater than or equal to the trigger level in 0.4% of the samples (n=275) and for 6% (n=17) of the locations.

Sampling intensity for FCA monitoring

Each year, the Michigan Department of Natural Resources (MDNR) collects fish from water bodies throughout the state. In 2007, MDNR collected samples of 361 fish collected from 30 locations, in 2006, they collected 150 fish from 12 locations, and in 2003 they collected 4 fish from 1 location. For the state, a total of 15 species of fish were analyzed as edible portion

[12] Although Michigan still relies on US FDA action levels in issuing consumption advisories for the general public, both the US FDA and the US EPA now advise states against this practice.

[13] In the state of Michigan, women and children under the age of 15 are considered sensitive subpopulations, and consequently a lower tissue trigger level is used to better insure protection of health.

samples for issuing the 2008 report[14].

In the Detroit River, the most recent fish collections were in 2004, in which 8 individuals of carp and 10 individuals each of freshwater drum, redhorse sucker, and yellow perch were collected by the MDNR for analysis. The PCB concentrations in these fish (based on congeners) were used in developing the advisories for this site in this and subsequent years.

Given the limited ability to collect and analyze a wider range of fish, there are many important uncertainties inherent to the FCA process including a limited size range of fish from which to issue the FCAs and unknown variability in contaminant concentration in the actual fish population.

Key assumptions in FCA models

There are several assumptions that are integral to the advisory process including an assessment of contaminant concentrations associated with human health effects, an assessment of exposure potential (including fish consumption rate, frequency of exposure, duration of exposure, and consumer body weight), and an assessment of contamination level in the fish population of interest.

In terms of human health effects, the USEPA uses a risk-based approach to estimate effect-level contaminant concentrations. The USEPA does this by calculating a reference dose (RfD), which is an estimate of a daily exposure that is likely to be without appreciable risk of deleterious effects during a lifetime (USEPA 2000). The RfD is calculated by determining a no-observed-adverse-effect level (NOAEL) or a lowest-observed-adverse-effect level (LOAEL) from the published literature. Depending on the availability of the studies, safety factors are then applied to take into account a range of uncertainties, including extrapolations from non-human models to humans, from data gaps and other factors. These safety factors can range from 1 to 10,000. For PCBs, the EPA uses for example an RFD of 0.00002 mg/kg/day for Aroclor 1254, the most commonly cited reference compound in establishing PCB FCAs.

In terms of the exposure assessment, the US EPA recommends assuming an average consumption rate of 227 grams (or 8 ounces) per day, an exposure duration of 30 years, and a generic consumer body weight of 70 kilograms (about 154 pounds).

For the consumption rate, it should be noted that people are assumed to eat fish in direct proportion to their body weight. The fish consumption advisories established using these meal consumption limits assume that the portion size of fish is proportional to a person's body weight. So, for instance, a child weighing 24-32 kilograms (51-70 pounds) is advised to eat an 85 gram (3 ounce) portion of fish at a meal; however, this relationship is not always linear, and children often consume food at a higher proportional rate than adults. Thus the RfD is the same for children and adults, although children are known to consume more food on a per weight basis.

Toxic equivalency factors

---

[14] Samples for the edible portion sampling program in Michigan are targeted toward sites of known or suspected contamination, sites popular with sport anglers, and sites with public access.

Some PCBs have a planar conformation and activate the aryl hydrocarbon (Ah) receptor. These PCBs are thought to share a common mode of toxic action with 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8,-TCDD). The toxicity of coplanar PCBs is converted into TCDD equivalents by using a toxicity equivalency quotient that is based on an assumption of a common mode of action (van den Berg et al. 1998). For coplanar PCBs, the cancer risk is estimated by multiplying total PCB TEQs from fish consumption by a TCDD cancer slope factor[15]. This approach, however, does not account for the toxicity of some of the more abundant coplanar congeners.

In 2008, Michigan began measuring and calculating the concentrations of dioxin-like PCB congeners in fish samples. Total 2,3,7,8-TCDD TEQs are calculated using the 2005 World Health Organization's factors (Van den Berg et al. 2006). The concentrations of individual dioxin, dibenzofuran, and dioxin-like PCB congeners in a fish sample are then multiplied by a toxic equivalency factor and the resulting products summed to calculate a 2,3,7,8-TCDD TEQ concentration. Any individual congener concentration that is less than the detection level were assigned a value of 0 for the purpose of calculating the dioxin TEQ. To be consistent with past calculations, the dioxin-like PCBs are not included in the calculation of TEQ for the whole fish trend samples.

Methods

Standard deviation estimates of PCB variability in freshwater fish

A literature review was conducted to evaluate the potential range in PCB concentrations in freshwater fish and to assess the drivers of these variations. Keyword searches using "fish and PCB" and "fish and tissue and PCB" and "fish and tissue and PCB and analytical." Additional details about the methods and results of this literature review are detailed in an earlier portion of the report. Resulting publications were then reviewed for relevance to this effort. After appropriate publications were identified, the data related to variations in PCB concentrations in populations of fish were used to derive the distributions for the Monte Carlo analysis.

Monte Carlo model for fish PCBs

In order to assess the potential impact of variation in contaminant concentrations in fish on consumption risks associated with PCBs, an equation for chronic daily intake was employed. This is based on the chronic daily intake as specified in the USEPA's Risk Assessment Guidance for Superfund sites. It helps establish the potential full range and variability in exposure of a given population and has been used to assess the variability in human health risks associated with consumption of contaminated fish (see Harris and Jones 2006). Chronic daily intake of PCBs can be expressed as:

$$CDI = C \text{ x } IR \text{ x } FI \text{ x } ED \text{ X } EF/BW \text{ x } AT$$

where CDI is in mg/kg d, C is the concentration of PCB in tissue (mg/kg), IR is the ingestion rate (kg/d or kg/meal), FI is the fraction ingested from the contaminated source, ED is the exposure

[15] AhR activation by environmental chemicals such as dioxin are known to cause immune, reproductive, and neurotoxicity; more recent data now also implicate AhR activation in cancer progression.

duration (yr), EF is the exposure frequency (d/yr or meals/yr), BW is the body weight (kg) and AT is the averaging time (d).

A Monte Carlo simulation was developed using a range of parameter estimates. The simulations were run with point estimates (as are currently used for the FCA process) and using a Monte Carlo sampling approach. In terms of the latter, Crystal Ball was linked with an Excel™ database to allow for variations in PCB concentrations in fish tissue (and several other parameters, as deemed necessary).

For sport fish tissue concentrations, we used lognormal distributions of measured PCB concentrations in walleye and carp collected from the Detroit River. The PCB concentration data were fit to a lognormal distribution, based on a best fit of some of the existing data sets, and is consistent with observations from other studies (e.g., see Rypel et al. 2007). We separated out data on Aroclor from that on PCB congeners and ran the analysis separately for these two analytical scenarios. A continuous uniform distribution model was used for ingestion rate, exposure duration, exposure frequency, and averaging time. Finally, for body weight, a normal distribution was assumed.

PCB distributions in fish

Significant sex-based differences in fillet PCB concentrations have been found for channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides*) and spotted bass (*Micropterus punctulatus*: Rypel et al. 2007). In contrast, there were no such differences for striped bass (*Morone saxatilus*), black crappie (*Pomoxis nigromaculatus*) and freshwater drum (*Aplodinotus grunniens*). This may have implications when analyzing fillet samples for FCA advisories; however, Rypel et al. 2007 note that the sexual differences reported in their study should not be considered universal and that variations in ecosystems may be an important driver of sexual differences in PCB bioaccumulation.

Results

Monte Carlo model for fish PCBs

The statistics of PCB concentrations in fish collected from the Detroit River are given in Tables 2 and 3. The two species used in the Monte Carlo model simulation were common carp (*Cyprinus carpio*) and walleye (*Sander vitreus*), both of which are currently included in the Detroit River FCAs. Data are given for concentrations of both total PCBs (Table 2) and total Aroclors (Table 3). The former is the current analytical technique used in the monitoring program, while the latter is the older method for measuring PCB concentrations. As can be seen in Table 2, data for total PCBs is limited, and based on only 8 fillet samples for carp and 6 fillet samples for walleye. The mean total PCB concentrations in carp are substantially higher than for walleye (2.956 ppm versus 0.7710 ppm, respectively). Carp demonstrate considerable variability in this small sample set, with a minimum concentration of 1.263 ppm wet weight and a maximum concentration of 6.754 ppm wet weight. Total PCB concentrations in walleye have a minimum concentration of 0.2840 ppm and a maximum concentration of 1.381 ppm.

Table 2. Total PCB concentrations (i.e., sum of the individual congeners) in the Detroit River, for edible portion fillet sampling

Species	No. of samples	Length Min	Max	Total PCBs (wet weight; ppm) Mean	Median	Min	Max	S.D.
Carp	8	46.2	67.8	2.956	2.340	1.263	6.754	1.951
Freshwater drum	10	38.2	51.2	0.4139	0.4250	0.0590	0.8890	0.2510
Walleye	6	53	67.3	0.7710	0.7650	0.2840	1.381	0.3860

Table 3. Total aroclor concentrations in the Detroit River, for edible portion fillet sampling

Species	No. of samples	Length Min	Max	Total PCBs (wet weight; ppm) Mean	Median	Min	Max	S.D.
Carp	40	42	69	6.273	4.110	0.7000	25.60	6.411
Walleye	30	40	66	0.4250	0.3340	0.0860	2.570	0.4470

In contrast to total PCB concentrations, fish from the Detroit River were analyzed for total Aroclor concentrations over a longer time period and therefore provide a larger sample size. The mean total aroclor concentration for carp was 6.273 ppm wet weight, with a range of 0.700 ppm to 25.60 ppm. For walleye, the mean total aroclor concentration was 0.425 ppm wet weight, with a range of 0.086 ppm to 2.570 ppm (Table 3).

The parameters used for the Monte Carlo simulations are provided in Table 4. The resulting statistics related to the CDI are given in Table 5. These statistics are based on 10,000 simulations (i.e., using the chronic daily intake equation and sampling independently 10,000 times from the probability distributions for all parameters). Because of the larger datasets for aroclors, the software program (Crystal Ball) was able to fit a lognormal distribution curve to the existing dataset; however, for total PCBs, only the mean and standard deviation were used for fish concentration given the limited number of data points.

Using the CDI for walleye based on total aroclor concentrations, the mean forecast value was 0.003173 mg/kg-day compared to a point estimate of 0.001378 mg/kg-day. The range for the forecast value was 0.000103 mg/kg-day to 0.06283 mg/kg-day. The distribution curve for the forecast CDI is given in Figure 1a. In comparison, the forecast mean CDI value for walleye based on total PCB congeners was 0.0059017 mg/kg-day compared to a point estimate of 0.002500 mg/kg-day. The range for this scenario was 0.0003612 mg/kg-day to 0.04996 mg/kg-day. The distribution curve for the forecast CDI is given in Figure 1b.

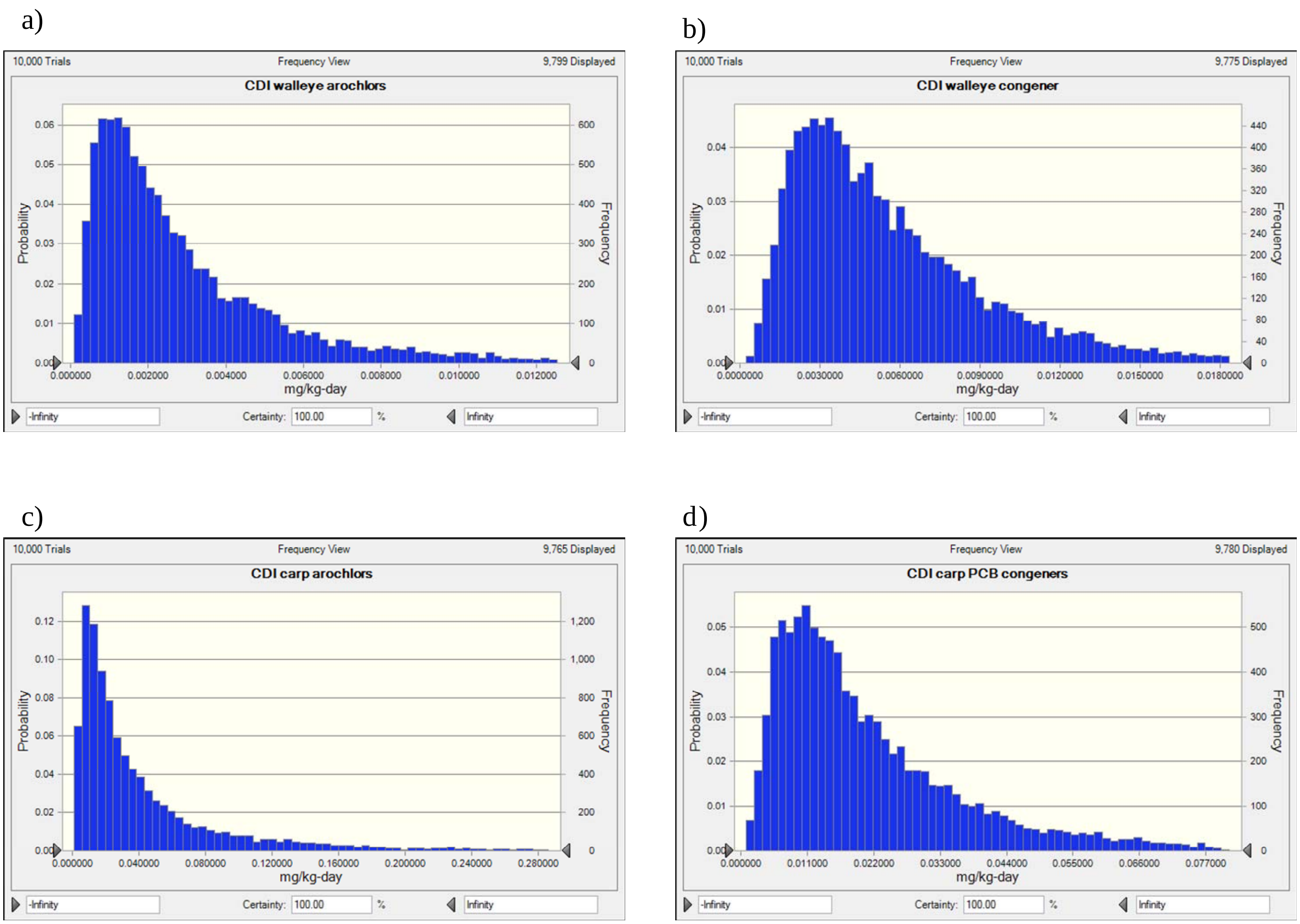

Figure 1. a) CDI walleye aroclors; b) CDI walleye congeners; c) CDI carp aroclors; and d) CDI carp congeners.

For carp, the forecast CDI value based on total aroclors was 0.05160 mg/kg-day compared to a point estimate of 0.02211 mg/kg-day. The range for the forecast value was 0.0009960 mg/kg-day to 1.495 mg/kg-day and the distribution curve for the CDI forecasts is given in Figure 1c. In comparison, for total PCB congeners in carp, the forecast CDI was 0.02278 mg/kg-day compared to a point estimate of 0.009586 mg/kg-day. The range for the former (forecast value) was 0.0009190 mg/kg-day to 0.3087 mg/kg-day. The distribution curve for this scenario is provided in Figure 1d.

Table 4. Parameters used for the chronic daily intake equation used in the Monte Carlo simulations related to fish consumption advisories in the Detroit River.

Parameter	**Value**	**Unit**	**Comments**
Mean fish concentration (C)	See Table 3	mg/kg	For Aroclors, from MNDR database
Mean fish concentration (C)	See Table 2	mg/kg	For PCB congeners, from MDNR database
Ingestion Rate (IR)	0.200-0.800	kg/day	EPA default is 0.227 kg/day; new Louisiana protocol ranges from 0.2 to 1.65 kg/day
Exposure frequency (EF)	365	days/year	Assumes daily exposure (as opposed to bolus dosing)
Exposure duration (ED)	30 to 70	years	USEPA 2000
Body weight (BW)	70	kg	Adult mean weight
Averaging time (AT)	10,950	days	30 years, but up to 70 (25,550 days)
Reference dose (RfD)	2×10^{-5}	mg/kg-day	USEPA IRIS (for Aroclor 1254)

Data from a sensitivity analysis for each model scenario were also compiled and are presented in Table 6. For all of the different model scenarios (in which all parameters were selected from a range of potential parameters), the fish tissue concentration had the largest effect on model outcome (i.e., the forecast value was most influenced by the variability in this parameter). The influence of fish tissue concentration ranged from 78.4% for the CDI estimate for carp based on aroclors to 44.6% for the CDI estimate for walleye based on total PCB congeners. The simulations were also sensitive to the ingestion rate, particularly for the total PCB congener analysis for both walleye and carp.

Table 5. Statistics associated with different simulations of the chronic daily intake (CDI) using probability distributions for 5 of the equation parameters (see Table 4).

Parameter	**Forecast value**	**Point estimate**
CDI – walleye Aroclors		
Mean	0.003173 mg/kg-day	0.001378 mg/kg-day
Median	0.002174 mg/kg-day	
Standard deviation	0.003339	
Minimum	0.0001030 mg/kg-day	
Maximum	0.06283 mg/kg-day	
CDI walleye congener		
Mean	0.005902 mg/kg-day	0.0025 mg/kg-day
Median	0.004754 mg/kg-day	
Standard deviation	0.004372	
Minimum	0.0003612 mg/kg-day	
Maximum	0.04996 mg/kg-day	
CDI – carp Aroclors		
Mean	0.05160 mg/kg-day	0.02212 mg/kg-day
Median	0.02527 mg/kg-day	
Standard deviation	0.08374	
Minimum	0.0009960 mg/kg-day	
Maximum	1.495 mg/kg-day	
CDI – carp congener		
Mean	0.02278 mg/kg-day	0.009586 mg/kg-day
Median	0.01667 mg/kg-day	
Standard deviation	0.02073	
Minimum	0.0009190 mg/kg-day	
Maximum	0.3087 mg/kg-day	

Table 6. Sensitivity analysis of parameters used in developing equations for chronic daily intake (CDI). Separate simulations were run based on Aroclor concentrations in fish and PCB congeners concentrations.

Simulation	**Fish tissue conc**	**Ingestion rate**	**Exposure duration**	**Averaging time**	**Body weight**
CDI walleye aroclors	63.7%	18.9%	8.6%	-7.4%	-1.5%
CDI walleye congeners	44.6%	30%	12.6%	-12.1%	0.7%
CDI carp aroclors	78.4%	11.3%	-4.9%	4.2%	-1.2%
CDI carp congeners	56.4%	21.7%	-10.3%	9.5%	-2.1%

Summary and Conclusions

Monte Carlo model for fish PCBs

There are several potential benefits to using a probabilistic approach when issuing FCAs. For example, because only a limited number of fish are sampled from a given population in monitoring for contaminant concentrations, a probability approach can allow managers to better integrate data variability when estimating tissue trigger levels. The utility of this approach was demonstrated in a study by Harris and Jones (2008), which found that a Monte Carlo simulation model produced a consistently lower risk estimate for consumption hazards to anglers than a default or point estimate models because it drew from an entire distribution of each assumption variable. The key to maintaining this advantage, however, is to ensure that the parameters used in the model are well defined.

The Monte Carlo model developed for this application highlights the potential importance of variability in fish tissue concentrations in its impact on the CDI. For all of the forecast simulations, the use of probability distributions for this and the other parameters both increased the mean forecast value of PCB concentrations and added a considerable amount of variation to the range in the CDI. The forecast distributions were skewed, with the greatest probability of CDI values falling towards the lower end of the spectrum; however, there is the potential to have individuals with high exposure, depending on the given scenario configuration.

Importantly, the sensitivity analysis indicates that for this simulation model, fish tissue concentration and ingestion rate strongly influence the values of the forecast. Future efforts to improve the predictive value of FCAs in the Detroit River would likely need to improve the certainty of these two parameters, by better defining the average and range in these values.

Although the initial intent of the literature meta-analysis was to identify a potential range in variability in PCBs in freshwater fish populations (see Table 7), the utility of these data are limited. Most studies indicate that variability in concentrations of PCB in fish are somewhat site specific and can be influenced by the ecology of fish in the area and by other factors such as sex and the time of year in which the fish are sampled. The large variability in the actual field data from the Detroit River suggest that additional sampling of fish from this site could greatly improve our understanding of the level of risk posed to fish consumers from this site.

One of the other key parameters to the advisory process that remains poorly defined is the actual consumption rate for subsistence fisherpeople, especially minority groups. When the original Uniform Protocol guideline was developed, the main sensitive subgroup that was targeted was women of childbearing age and children/infants. This was driven largely by the particular sensitivity of these groups to the toxicity of PCBs. Since this time, however, it has become increasingly recognized that there are other subgroups that may be at higher risk to PCB effects due to their consumption habits. For example, several more recent studies have found a relationship between race and fish consumption, with African Americans and Asians consuming significantly more fish and larger portion sizes than their Caucasian counterparts (Burger et al. 1999; Harris and Jones 2008). This has important implications both when issuing advice for those portions of both the sensitive subpopulations and the general population who may be minorities with a higher consumption rate of contaminated fish.

Finally, this study initially set out to evaluate the utility of TEQs in improving the FCA process. Since the study was initiated, the state of Michigan added dioxin-like PCBs to its advisories for dioxin. This approach is consistent with the trend in other states and is supported by the World Health Organization. Thus, the limited review of the literature on this topic indicates that the use of TEQs to Michigan's advisory is supported by the most recent science on the topic.

References

Anderson, H.A., J.F. Amrhein, P. Shubat, J. Hesse. 1993. Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory. Great Lakes Fish Advisory Task Force. Protocol Drafting Committee.

Burger, J., W.L. Stephens Jr., C.S. Boring, M. Kuklinski, J.W. Gibbons, M. Gochfeld. 1999. Factor in exposure assessment: ethnic and socioeconomic differences in fishing and consumption of fish caught along the Savannah River. Risk Analysis 19:427-438.

Carlson, D.L. and D.L. Swackhamer. 2006. Results from the US Great Lakes fish monitoring program and effects of lake processes on bioaccumulative contaminant concentrations. J. Great Lakes Res

Carlson, D. L., and D. L. Swackhamer. 2006. Results from the US Great Lakes fish monitoring program and effects of lake processes on bioaccumulative contaminant concentrations. *J Great Lakes Res* 32: 370-385.

Harris, S.A., and J.L. Jones. 2008. Fish consumption and PCB-associated health risks in recreational fishermen on the James River, Virginia. Environmental Research 107:254-263.

Madenjian, C.P., D.J. Jude, R.R. Rediske, J.P. O'Keefe, G.E. Noguchi. 2009. Gender difference in walleye PCB concentrations persists following remedial dredging. Journal of Great Lakes Research 35:347-352.

MDEQ 2009. Michigan Fish Contaminant Monitoring Program. MI/DEQ/WB-09/044. 2008 Annual Report.

Rypel, A.L., R.H. Findlay, J.B. Mitchell, and D.R. Bayne. 2007. Variations in PCB concentrations between genders of six warmwater fish species in Lake Logan Martin, Alabama, USA. Chemosphere 68:1707-1715.

US EPA (United States Environmental Protection Agency). 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume 2: Risk Assessment and Fish Consumption Limits, Third edition. United States Environmental Protection Agency, Office of Water.

Van den Berg, M., L. Birnbaum, A.T.C. Bosveld, B. Brunstrlim and 20 other co-authors. 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs, for humans and wildlife. Environmental Health Perspectives 106: 775-792.

Van den Berg, M., L.S. Birnbaum, M. Denison, M. DeVito, W. Farland, M. Feeley, H. Fiedler, H. Hakansson, A. Hanberg, L. Haws, M. Rose, S. Safe, D. Schrenk, C. Tohyama, A. Tritscher, J. Tuomisto, M. Tysklind, N. Walker, and R.E. Peterson. 2006. The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicological Sciences 93:223-241.