Using A MicroExposure™ Monte Carlo Risk Assessment for Dioxin in Maine (USA) Fish to Evaluate the Need for Fish Advisories

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ABSTRACT

The presence of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) in fish downstream of pulp and paper mills has prompted some regulatory agencies to issue fish consumption advisories for a number of rivers and streams throughout the United States. In many cases, the basis for these advisories is a screening level risk calculation using conservative values for the various parameters in the risk equation. In nearly all cases, predicted risks are substantially overestimated. In an effort to address this deficiency, we developed probability distributions for each of the critical exposure factors (1-4) and incorporated these distributions into a MicroExposure™ Monte Carlo risk analysis.

INTRODUCTION

The risks associated with exposures to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) from the consumption of recreationally-caught fish are traditionally evaluated by conservatively calculating the dose received by a highly successful individual angler and estimating associated risks using simple algebraic equations (5). In most cases, a Lifetime Average Daily Dose (LADD) is estimated by relating default assumptions concerning TCDD levels in fish, quantity of fish consumed, angler's body weight, and angler's lifetime. The LADD is then multiplied by the carcinogenic potency to yield an estimate of risk. Using this traditional approach, the EPA has calculated single point estimates for the risks associated with eating fish downstream of bleached kraft pulp and paper mills (6). Based on these risk estimates, a number of regulatory agencies have issued fish consumption advisories for these rivers and streams.

Recently, several authors have demonstrated that the point estimate approach can result in substantial overestimates of exposure (7-10). In its new guidance on exposure assessment (11), EPA has reached the same conclusion, stating "the use of maximum or near-maximum values for each of the parameters in an exposure scenario will result in exposure estimates that are unrealistic." The new guidance recommends Monte Carlo analysis (MCA) as a method of deriving more realistic characterizations of highly exposed individuals (11).

Under MCA, the same equation is used to calculate the LADD as in the point estimate approach. However, instead of using point estimates for each of the equation parameters, MCA uses distributions of values. One recent development in MCA techniques is the MicroExposure™ MCA. This model is an adaptation of the synthetic life history approach developed by Price et al. (12), the mechanics of which are described elsewhere (13). Under MicroExposure modeling, the dose of TCDD received by an angler is defined as being equal to the sum of the doses received from eating individual fish. Data on individual levels of TCDD in fish are thereby incorporated into the analysis.

In this paper, estimates of the high end exposed (HEE) angler are developed by means of point estimates and MicroExposure MCA. While EPA (11) defines HEE as above the 90th percentile of dose, for the purposes of this study, HEE conservatively was assumed to be the 95th percentile of the dose distribution. The results of the two methods are contrasted and the MicroExposure model is used to propose estimates of exposure and associated risks for highly exposed anglers.

METHODS

Site-specific information on fish consumption practices in Maine (1) and TCDD levels measured in fish taken from river reaches directly below the discharge of Maine's pulp and paper mills (2-4) formed the basis of this analysis. Both 2,3,7,8-TCDD and 2,3,7,8-tetrachlorodibenzofuran (TCDF) were evaluated using a modified toxic equivalency (TEQ) approach because these two isomers are believed to account for more than 90 percent of the toxicity attributable to polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) in pulp and paper mill effluent (14).

Data on fish consumption, angler demographics, and angler behavior were obtained from the results of the Maine Angler Survey (1). This survey was performed in 1990 to determine the rate of intake of self-caught freshwater fish by recreational anglers in Maine. The survey was based on an end-of-year seasonal recall design that included both open water and ice fishing for the year 1990. The daily fish consumption distribution for fish caught from both moving waters (e.g., streams rivers) and still waters (e.g., ponds, lakes, reservoirs) was determined.

Figure 1 presents the distribution of fish ingestion rates for fish caught from freshwater moving waters. Among the findings of the survey was the observation that anglers tend to increase their level of fish consumption as they age. Age-specific estimates of consumption were developed for anglers twelve years of age and older, providing a basis for determining the age-specific rates at which anglers give up fishing.

During the last decade, several studies on the concentrations of dioxins and furans in fish in Maine rivers have been conducted (2-4, 16-18). Since the publication of the fish analytical results of the mid-1980s, many pulp and paper mills in Maine have replaced chlorine with chlorine dioxide as a bleaching agent in order to substantially reduce levels of TCDD and TCDF in their effluent. In turn, the levels of TCDD and TCDF in fish tissue have also declined. Because the databases developed by MRI (4) and Acheron (2,3) reflect current dioxin levels in fish, these data were used in this analysis. Skinless fillets of edible fish species collected downstream of pulp and paper mills on the nontidal portions of three Maine rivers -- the Androscoggin, Kennebec, and Penobscot -- were evaluated. Predominantly smallmouth bass and, to a lesser extent, largemouth bass, brown bullhead, brook trout, and brown trout comprised a database of 152 fish specimens, shown graphically by river in Figure 2.

Fish with nondetectable concentrations were conservatively assumed to have concentrations equal to one-half of the detection limit for that particular specimen. Results of approximately 10 percent of the TCDD analyses and 5 percent of the TCDF analyses were below the detection limit.

In this analysis, the product of the fish fillet mass and the TCDD concentration is equal to the mass of TCDD contained in the edible portion. This mass was then adjusted to reflect loss of TCDD during the cooking process (19). Using PCBs as an example, Sherer et al. (19) discussed the effects that cooking processes can have on persistent lipophilic compounds, such as TCDD, in edible fish tissue. Based on a comprehensive literature review, Sherer et al. (19) concluded that their results are likely to be applicable to other lipophilic compounds, such as chlorinated pesticides, dioxin and furans.

While mortality data for the general U.S. population were used in this analysis (20), the probability of moving was based on mobility data specific to New England (21). It was conservatively assumed that local moves would not influence an angler's fishing locale. Finally, the age-specific probability of an angler giving up fishing was developed from the results of the Maine Angler Survey (1). The assumed initial age of each angler considered in the model is based on the distribution of ages of licensed Maine anglers.

Both risk assessment methods used the same point estimate of the carcinogenic potency of TCDD [34,000 $(mg/kg\text{-}day)^{-1}$]. Although an in-depth treatment of this topic is beyond the scope of this study, the basis for the selected value is the 1990 PWG (22) reevaluation of the Kociba et al. (23) study and the application of the Linearized Multistage (LMS) model to calculate a cancer potency factor for TCDD of 9,700 $(mg/kg\text{-}day)^{-1}$ (24). However, the EPA, FDA, and Consumer Products Safety Commission (CPSC) recently reached a consensus on a method for cross-species scaling and proposed it as a uniform compromise policy position (57 Federal Register 24152, June 5, 1992). Incorporating this scaling approach with the results of the Keenan et al. (24) analysis yields a cancer potency factor of 34,000 $(mg/kg\text{-}day)^{-1}$.

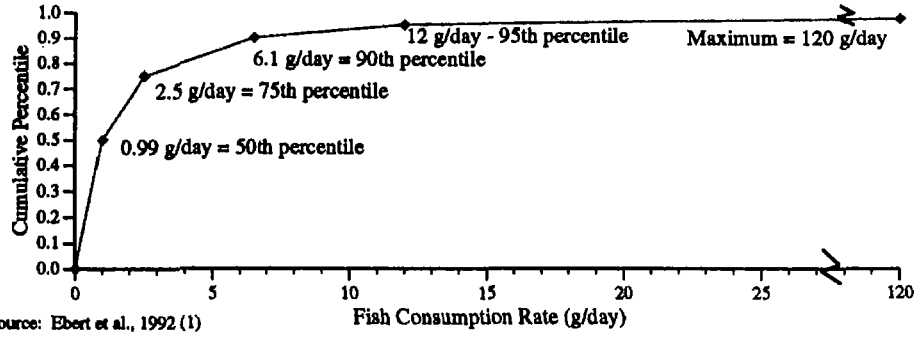
RESULTS AND DISCUSSION

Based on the above analysis, risks associated with HEE are predicted to be just under 10^{-5} using a point estimate approach and less than 5×10^{-7} using MicroExposure MCA (Figure 3). Because the MicroExposure model appears to provide the best means of characterizing the distribution of intakes for anglers, the estimates of potential risk generated through the use of this approach should be given greater credence than the results from the point estimate alternative. Therefore, the potential risks do not likely exceed 1×10^{-6}, even at the 99th percentile of exposure for this angling population.

These conclusions can be regarded as conservative for several reasons. First, the model assumes that an angler begins fishing at an early age and consistently fishes the rest of his life unless he either moves from the area or permanently gives up angling. It is far more likely that most anglers, even highly successful ones, experience temporary periods during which either they do not fish or they fish to a much lesser extent. Second, the model has used the assumption that 80 percent of all fish caught by the average angler are from affected rivers. Presently, pulp and paper mills are established on six Maine rivers, representing only a small percentage of all the available freshwater fishing resources in the state. Even if a typical angler lives close to an affected source, he or she would have many opportunities to fish on a large number of water bodies and would therefore take only a small fraction of their total catch from any single river reach. While it is beyond the scope of this study, future work should strive to refine the estimate of the fraction of fish caught in affected waterbodies. Third, the data on TCDD concentrations were based on fish caught immediately downstream from the pulp and paper mill effluent discharges. These TCDD concentrations represent the maximum levels likely to be detected in fish in an affected river. Fish caught elsewhere on a potentially affected river would likely contain lower concentrations of TCDD. Finally, we set the concentrations of TCDD or TCDF at one-half the detection limit in those fish samples found to be below the detection limit for these compounds.

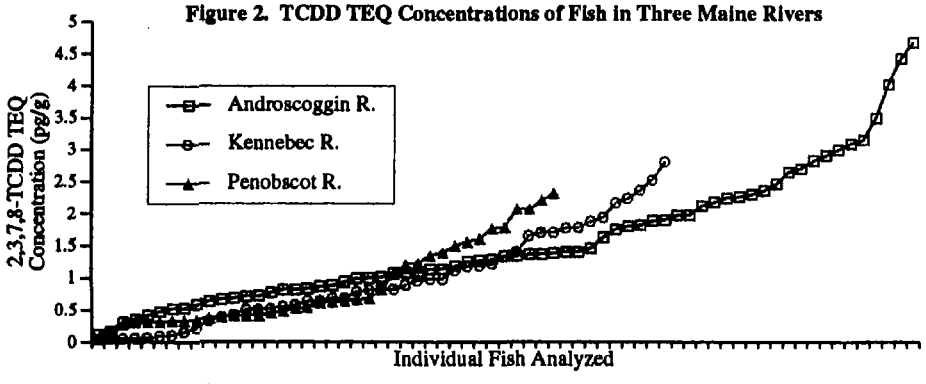
In summary, levels of TCDD equivalents in Maine fish that occur downstream of the discharge of pulp and paper mill effluent appear to pose an insignificant risk to the sports angler. These findings suggest that current fishing advisories on these Maine rivers may be lifted without presenting a health concern to anglers or their families. This finding is more clearly supported by the results of the MicroExposure model than by the other analysis which is associated with technical limitations and shortcomings. The findings of the MicroExposure model clearly demonstrate that all risks, even using conservative assumptions and at the 99th percentile of exposure, are 10^{-6} or less. Thus, it appears that the risks associated with eating recreationally-caught fish from rivers and streams downstream of Maine's pulp and paper mills are *de minimis*.

Figure 1. Frequency Distribution of Consumption Estimates from Rivers and Streams for Consuming Anglers Only



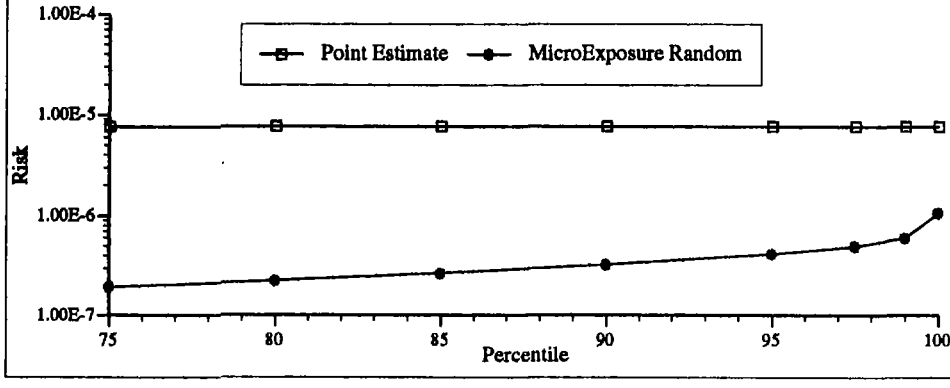
Source: Ebert et al., 1992 (1)

Figure 2. TCDD TEQ Concentrations of Fish in Three Maine Rivers



Note: One-half of the detection limit used for nondetects.

Figure 3. Distribution of HEE Risks from Two Different Exposure Models



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