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A Probabilistic Risk Assessment of *Cryptosporidium* Exposure Among Baltimore Urban Anglers

Jennifer D. Roberts

Health Scientist, ChemRisk, San Francisco, CA, USA

Ellen K. Silbergeld

Professor, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA

Thaddeus Graczyk

Associate Professor, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA

In some urban settings, recreational fishing in industrialized waterways may pose a substantial health risk due to the presence of pathogenic microbes such as *Cryptosporidium*, a pathogen that produces a moderate to fatal gastrointestinal illness in humans. This pilot study examined the risk of exposure to *Cryptosporidium* based on fish samples and hand wash samples taken from urban anglers. Information regarding fishing frequency and consumption were also collected through an interview questionnaire to further characterize this risk. There were a total of 56 anglers interviewed and 46 fish and hand wash samples collected (18 hand wash samples and 28 fish samples). It was determined that the mean probability of infection using the U.S. Environmental Protection Agency's (EPA) dose-response model for *Cryptosporidium* and the fish and hand wash samples was 0.11 and 0.81, respectively. Among the positive fish samples, this mean probability was found to be 0.41. Depending on a variety of confounding factors, such as immunity, pre-existing illnesses and other host specific factors, this probability indicated that on average 1 to 8 out of 10 anglers could become infected. The current fish consumption advisories in Maryland and elsewhere provide no apparent information in regard to any microbiological contaminant. This pilot study provided data for possible modifications and improvements to be made to policy and risk communication regarding the potential health risks due to *Cryptosporidium* exposure from fishing.

INTRODUCTION

Cryptosporidium is a protozoan parasite that is increasingly being recognized as a cause of serious symptoms resulting in a potentially lethal disease in exposed human populations (Graczyk et al., 1998a). The first two human cases of

C. parvum infection were reported in 1976 (Meisel et al., 1976; Nime et al., 1976) and most of the early case reports involved veterinarians or animal handlers. Major incidents of *Cryptosporidium* infection also occurred as a result of environmental contamination of municipal water supplies, such as the 1993 outbreak in Milwaukee, Wisconsin that affected over 50% of a population of 800,000 people and produced at least 69 deaths (Hoxie et al., 1997; Pan and Graczyk, 1997). This outbreak was suggested to have occurred due to contamination of municipal water with raw and untreated water. Other reports of *Cryptosporidium* infection were documented as a result of pathogen exposure in daycare centers and swimming pools (Hellard et al., 2000).

Until recently, it was believed that only two genotypes of *C. parvum*, were infectious to humans: the "human adapted" genotype I and the "animal adapted" genotype II (Graczyk et al., 1998a). The "animal adapted" or zoonotic genotype was identified in over 80 mammalian species. It is highly prevalent in ruminants, such as sheep and goats, and is readily transmissible to humans (Graczyk et al., 1996). The "human adapted" genotype is infectious to humans and cycled exclusively through the human population (Graczyk et al., 1998b, 2000a, 2000b). The "human adapted" genotype I is now known to be a separate species named *C. hominis*. There are currently at least 11 different species of *Cryptosporidium* that may infect all vertebrate groups, including fish (*C. nasorum*), reptiles (*C. serpentis* and *C. schneideri*), birds (*C. baileyi* and *C. meleagridis*), and mammals (*C. felis*, *C. wrairi*, *C. muris*, *C. andersoni*, *C. parvum* and *C. hominis*) (Morgan-Ryan et al., 2002).

Symptoms of cryptosporidiosis in exposed populations include profuse, watery diarrhea with mild to severe nausea, vomiting, headache and cramps; the diarrhea is cholera-like, with small amounts of mucus and little fecal material (Mahon, 2000). The fluid loss is severe and was reported to

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Address correspondence to Jennifer D. Roberts, ChemRisk, 25 Jessie Street, Suite 1800, San Francisco, CA 94105, USA. E-mail: jroberts@chemrisk.com

range from 3 to 17 L per day (Mahon, 2000). As a result, individuals exhibit signs of dehydration, weight loss, and electrolyte imbalance. There is a rapid onset and symptoms typically develop in 4 to 6 days after infection, but may appear anytime between 2 and 10 days after infection (USDA, 1998). Without proper treatment, cryptosporidiosis may result in death. In healthy individuals, cryptosporidiosis typically lasts from a few days to weeks and is resolved by a cell-mediated immune response (Mata et al., 1984). However, infected individuals may shed oocysts in their stool for months after all symptoms have disappeared.

Transmission occurs primarily via contact with mammalian feces that contain oocysts. Environmental sources of fecal *Cryptosporidium* oocysts include run-off from cattle and hog farms and sewage discharges that contain untreated human waste (Graczyk et al., 1997a). Once the oocysts are waterborne, fish may act as "phomites" or surface carriers of the oocysts. Furthermore, it was demonstrated that oocysts survive for relatively long periods of time in seawater (Fayer et al., 1998). It is therefore reasonable to assume that anglers in urban areas where significant animal or human sewage discharge occurs might be at an increased risk of *Cryptosporidium* infection, due to handling or consuming contaminated fish. However, to date most epidemiology studies and public health protection efforts have focused on recreational activities that involve direct contact with surface water (e.g., swimming at potentially impacted lakes or marine beaches). To our knowledge, there are no published estimates of quantitative risks of *Cryptosporidium* infection in urban anglers.

The purpose of this study was to assess infection risks to anglers in selected Baltimore urban areas. Like many industrialized urban watersheds on the East Coast, the Baltimore Harbor and its tributaries receive discharge from combined sewer overflows (CSOs). CSOs are designed to carry untreated sewage, domestic and industrial wastewater, and rainwater run-off to a sewage plant to be treated and discharged to a waterbody (EPA, 2002). However, if the amount of rain or snowmelt is heavy and the capacity of the sewage treatment system is exceeded, the untreated material in the CSOs may be discharged into the nearby streams, rivers or other waterbodies (EPA, 2002). CSO discharges have been linked to highly elevated pathogen levels in surface water bodies in other locations. For example, the lower Passaic River, in New Jersey, is a highly urbanized setting that contains 73 CSOs (Battelle, 2005). EPA estimates that 15,000 discharges annually release 1.2 gallons of untreated waste in the entire nation and the state of New Jersey estimates that it would cost \$4.4 billion to stop the overflow (GardenState EnviroNet, 2004). Numerous samples recently taken from various points mid-stream indicated that fecal coliform, fecal *Streptococcus*, and fecal *Enterococcus* were present at concentrations greater than 30,000 CFU/100 mL (ASI, 2003).

In this study, the risk of *Cryptosporidium* infection was evaluated in Baltimore urban anglers via microbiological analysis of fish and hand wash samples as well as through the collection of fish consumption data.

METHODS

Site Selection

Based on information obtained from community outreach programs (e.g. Baltimore Society of Friends) and local watershed associations, several popular angling locations in the Baltimore Metropolitan area were targeted for urban angler interviews and sample collection. Sites included Canton (Baltimore Harbor), Cox's Point (Back River), Lake Roland (Jones Falls), and Middle Branch (Figure I).

Questionnaire Interviews of the Urban Anglers

Informed consent was obtained from all of the participants and verbal interviews were given on site. Participants were given gift certificates to a local fast food restaurant post-interview. The interview contained questions that gathered information on demographics, fishing patterns, frequencies and locations, fish consumption behaviors, and awareness of fish consumption advisories including questions about the content of advisories such as the chemicals of concern. Data were collected for a total of 11 days throughout the 2002 and 2003 summer fishing seasons. The results of these self-reported questions provided information that was then used in the risk analysis component of this study.

Fish Samples

After each interview, participants were asked if they would be willing to provide us with one of their caught fish. Those who agreed were given another gift certificate. The fish were placed in sealable zip lock plastic bags containing a PBS (phosphate buffered saline) eluting fluid with 0.1% Tween 80, 0.1% SDS (sodium dodecyl sulfate), and 0.001% of an anti-foam agent (Graczyk et al., 1997a). The fish were then put in coolers on ice and transported within 3 hr to the Johns Hopkins University, Bloomberg School of Public Health for analysis. The fish were labeled based on the date, location and species of fish, and were analyzed under coded identification.

Hand Wash Samples

During the summer of 2002, it was observed that significant hand-to-mouth activity was occurring amongst some of the anglers. Therefore, hand wash sampling was added to the protocol during the summer of 2003. The sample collection protocol was evaluated and approved by the Johns Hopkins Bloomberg School of Health institutional review board. Post interview, participants were asked if they would be willing to rinse one hand (up to the wrist) in a zip lock bag containing

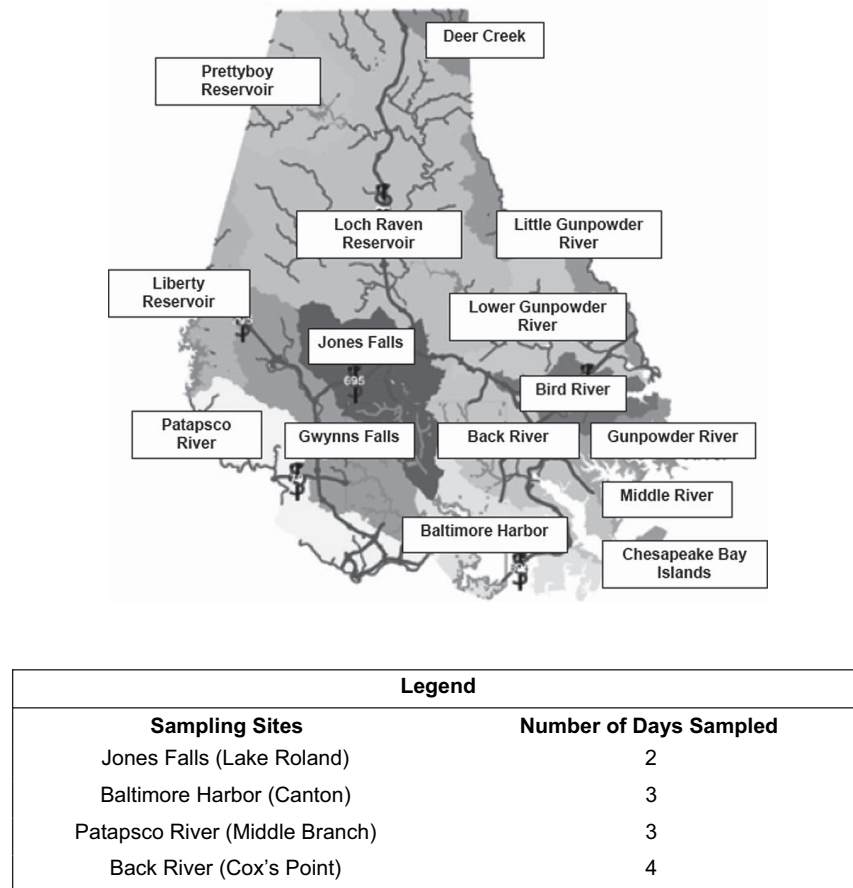


FIG. 1. Baltimore Watersheds.

Source: http://www.baltimorecountyonline.info/bin/t/o/ep_watershed_map_2006.jpg.

approximately 50 mL of PBS wash fluid with 0.1% Tween 80, 0.1% SDS, and 0.001% of an antifoam agent for approximately 5 to 10 sec. (Graczyk, et al., 1997a). Participants were informed of the safety of the solution and provided with a pre-dampened wipe to clean their hands afterwards.

Microbiological Analyses for *Cryptosporidium*

FISH (fluorescence *in situ* hybridization) in conjunction with immunofluorescent antibodies (IFA) assay were used for identification and viability assessment of *C. parvum* oocysts for both the fish and hand wash samples. The FISH oligonucleotide probes were synthesized by the DNA Analysis Facility of the Johns Hopkins University, Baltimore, MD, in 1.0 FM scale, purified by HPLC (high pressure/performance liquid chromatography), and 5' labeled with a single molecule of a fluorochrome. FITC-conjugated monoclonal IFA against the cell wall antigens of *Cryptosporidium* and *Giardia* from

MERIFLUOR™ *Cryptosporidium*/*Giardia* test kit (Meridian Diagnostic, Inc., Cincinnati, OH) were also used. Other investigators reported that the use of PBS yields a mean recovery efficiency of at least 44% (Graczyk et al., 1997b). IFA detected the monoclonal oocysts-reactive antibodies that were labeled with a compound that made the antibodies glow when observed microscopically under ultraviolet light. From each sample, 1ml of the PBS wash (total volume) from the surface of the fish and the hand wash was centrifuged and a slide was prepared for each sample using 100 µl of the centrifuged sample. Post collection of the fish samples, the surfaces of the fish were thoroughly wiped, not homogenized, in order to simulate hand contact by anglers rather than contact with fish flesh that may occur during cleaning and cooking. Each slide was independently examined by two researchers under ultraviolet light microscopy. Counts of oocysts were determined by viewing each slide using three separate area sections and then totaled. This count value then was used to calculate the total number of

oocysts per fish and the total number of oocysts per hand wash by multiplying by the total volume.

Data Analysis

The Intercooled STATA 7.0 statistical package as well as the Crystal Ball risk analysis software was used for the data analysis (StataCorp, 2001; Crystal Ball, 2000). STATA was used to analyze interview information and the Crystal Ball software was used for a Monte Carlo analysis to assess the probability of infection based on a probabilistic statistical approach.

Risk Analysis

The model for the probability of infection to *Cryptosporidium* for this study was based on EPA's dose-response model ($P_1 = 1 - e^{-rN}$) (Table I) (EPA, 2001; Rose et al., 1997; Haas et al., 1996). This exponential dose response model was developed following the Milwaukee outbreak to estimate the most likely level of contamination (Rose et al., 1997). This model uses a daily exposure, (N), of oocysts/person/day to determine the probability of infection (p), using the constant (r), fraction of ingested oocysts which must survive ingestion to establish infection. This (r) constant is organism specific and for *Cryptosporidium* it was determined as 0.0047 (95% CI [0.00215 – 0.00757]) (Rose et al., 1997; Haas et al., 1999). Since our exposure data were based upon monthly summary reports, the probability calculated was based on monthly exposures using a Monte Carlo analysis (Burmester and Von Stackelberg, 1991).

Two routes of exposure were quantified: (1) incidental ingestion following dermal contact with fish or surface water; and (2) fish consumption. The interview information was used to estimate monthly fish consumption rates and the frequency of fishing trips. The frequency of fishing trips per month was used to calculate monthly exposure. In short, the model used for this analysis involved two parameters, monthly exposure to oocysts (N) and the constant (r), the fraction of ingested oocysts which must survive ingestion to

establish infection. The calculation of (N) was based on the number of oocysts per fish and/or the number of oocysts per hand. In order to account for uncertainty, it was assumed that the distribution of oocysts was based on a Poisson distribution established by a distribution fit test that was conducted in the Crystal Ball program. The rate (λ) of the Poisson distribution was assumed to be the number of positive oocysts per slide of 100 μ l of the fish surface wash or hand wash. This value per 100 μ l was then extrapolated to the entire volume of fish and hand wash collected. With this information, the Monte Carlo simulation was performed using the Crystal Ball risk analysis software in order for the data to imitate a real-life scenario (Crystal Ball, 2000). Each simulation calculated multiple scenarios of the model using the imputed research data by repeatedly sampling values from the probability distributions for the uncertain variables. Monte Carlo analysis is a standard technique for simulating real-world situations involving elements of uncertainty. By using the Crystal Ball program, thousands of alternative scenarios or iterations are created that are then analyzed. The iteration is a three-step process in which a random number is generated for each assumption cell. One uncertainty variable is the number of oocysts/fish slide or oocysts/hand slide. The second uncertainty variable is the monthly exposure to oocysts (N) or oocysts/person/month and a third uncertainty variable is the constant (r). Using the Poisson distribution and the rate of positive oocysts per slide, a random number was generated with each iteration to then determine the oocysts/fish or oocysts/hand. Once this part of the iteration was completed, the monthly exposure was then determined. Using a triangular distribution which incorporates the likeliest, minimum and maximum values of the number of fish consumed/month or the number of fishing trips/month, another random variable was generated to determine the monthly exposure. These values of likeliest, minimum and maximum were based on the data collected from the angler questionnaires. Finally, a third random variable was generated based on the constant (r) and its 95% confidence interval. This assembly line process was repeated for each iteration within a Monte Carlo simulation

TABLE 1
Cryptosporidium Dose-Response Model

$P_1 = 1 - e^{-rN}$		
Model Parameters	Parameter Definition	Units
P_1	Probability of infection	--
r	Fraction of ingested oocysts which must survive ingestion to establish infection r = 0.00419 (95% CI [0.00215 – 0.00757])	infection/oocysts/person
N	Monthly exposure	oocysts/person/month

and the results were outputted for the forecast. By examining these multiple scenarios, the probability that an event or incident will or will not occur may be obtained. This forecast was based on the output of the model and the input of assumptions for each parameter of uncertainty. The benefit, here, is that this analysis does not rely on a single estimate or outcome.

RESULTS

Demographics of Participants

Fifty-six anglers agreed to participate in the study. Over 80% of the anglers approached agreed to participate; the most frequent reason given for refusal was lack of time. Approximately 80% of the participants were men and nearly 40% of the anglers were African American. Half of the anglers were age 50 or over and 13% reported that they had less than a high school diploma.

Within the timeframe of the previous 30 days, the anglers reported that they fished between 1 (minimum) to 30 (maximum) times, with an average of 14 (likeliest) visits. Forty nine % reported that they or a household member caught fish in the past month. On average, the anglers reported consuming 3 (likeliest) caught fish per month with a minimum being 1 and maximum being 5. Also, 50%, 4%, and 1% reported that they "always", "never" and "sometimes" cooked the fish, respectively. Forty-six % of the consuming anglers failed to respond to this question.

Data Summary

A total of 46 fish and hand wash samples were collected; 10 of 18 (56%) hand samples and 7 of 28 (25%) fish samples were positive for *Cryptosporidium* (Table II). Fish species were identified in 2003 and consisted of White Perch, Sunfish, White Bass, Little Minnow and Striped Bass. Although the results are not sufficiently robust to conduct statistical analyses, there are some apparent trends in the data that may reflect actual differences in oocyst prevalence. First, the frequency of detection of oocysts in fish samples was twice as high in 2003 (5/15, or 33%) than in 2002 (2/13, or 15%). Second, the frequency of oocyst detection on fish and hand samples at the Canton location (7/14, or 50%) was twice as much than at the Middle Branch location (4/16, or 25%). Third, the frequency of detection on the hand samples (56%) was more than double the detection frequency for the fish samples collected in 2002 and 2003 (25%). It is worth noting that in a few instances there were detectable oocysts on the hand samples, but not the fish samples, collected from anglers in 2003.

Risk Analysis

For the purposes of this analysis, the fish and hand wash samples were used to develop representative exposure concentrations

for the Monte Carlo analysis which performed 10,000 iterations. Two separate analyses were conducted: one with all samples and the other with only the positive samples (those with detectable viable oocysts). Since the limit of detection (LOD) for the FISH assay is a single *Cryptosporidium* oocyst in 100 μ l volume because such volume is used for testing, the samples that were found to be negative were analyzed as true negatives due to high sensitivity of this assay (Vessey et al., 1998; Graczyk et al., 2003). Among the positive samples, the arithmetic mean of the rate of positive oocysts per fish slide of 100 μ l was 5 oocysts and the mean of oocysts per hand slide was 10 (based on one angler hand). Among all the samples, the arithmetic mean of the rate of positive oocysts per fish slide of 100 μ l was 1 oocyst and the mean of oocysts per hand slides was 5.

Based on the positive fish samples, the Monte Carlo analysis determined that the mean probability of infection was 0.41, but that that maximum probability could reach 1 (Figure II). The probability of infection meant that infection may have occurred through any mechanism. This would involve any oral contact or ingestion of oocysts, such as hand-to-mouth contact or the ingestion of improperly cooked fish. The probability of all the 10,000 scenarios had a frequency distribution that was slightly skewed (0.1179). The probability of infection based on the positive hand wash samples was significantly higher with a mean of 0.91 (Figure III). The distribution was mainly skewed to the left (-49.61) and the kurtosis (2762.96) indicated a very thin tail. When all of the data were used the mean probability of infection based on the fish and hand wash sampled was 0.11 and 0.81, respectively (Figure IV, V). The maximum probability using all the fish samples was 0.78 and the maximum using all the hand samples was 1. Both frequency distributions were also found to be skewed, 1.28 for the fish samples and -4.95 for the hand samples.

Finally, a sensitivity analysis was performed from the Monte Carlo analysis to determine which parameter was the driving force of the outcome probability. Among the four outcome probabilities, the most sensitive parameter for three (total fish sample; total hand samples; positive fish samples) was the rate (λ) of the Poisson distribution, the number of positive oocysts per slide of 100 μ l of the fish surface wash or hand wash. The sensitivity of this parameter for the forecast probabilities of infection for the total fish samples, total hand samples and positive fish samples was 88%, 38%, and 45%, respectively. The most sensitive parameter (40%) for the positive hand samples' probability of infection was the (r) constant.

DISCUSSION

Under the Clean Water Act, state and federal fish consumption advisories are designed to provide advisory information to the public in regard to all potential risks due to contamination of caught fish. Many advisories provide information on the potential exposure to methyl mercury, pesticides and polychlorinated biphenyls (PCBs); however, currently there are no advisories providing information for the risks of exposure to

TABLE 2
Results of Fish Wash Samples (FS) and Hand Wash Samples (HS)

Sample	CollectionDate	Type	Description	CollectionLocation	Results	Number of Oocysts / 100 μ l of wash
1	8/27/2002	FS	Unknown	Canton	-crypto	0
2	8/27/2002	FS	Unknown	Canton	-crypto	0
3	8/25/2002	FS	Unknown	Cox's Point	-crypto	0
4	8/25/2002	FS	Unknown	Cox's Point	-crypto	0
5	8/25/2002	FS	Unknown	Cox's Point	-crypto	0
6	8/26/2002	FS	Unknown	Cox's Point	-crypto	0
7	8/24/2002	FS	Unknown	Lake Roland	+crypto	4
8	9/2/2002	FS	Unknown	Middle Branch	-crypto	0
9	9/2/2002	FS	Unknown	Middle Branch	-crypto	0
10	9/2/2002	FS	Unknown	Middle Branch	-crypto	0
11	9/3/2002	FS	Unknown	Canton	+crypto	5
12	9/3/2002	FS	Unknown	Canton	-crypto	0
13	9/3/2002	FS	Unknown	Canton	-crypto	0
14	8/23/2003	FS	Little Minnow	Middle Branch	-crypto	0
15	8/31/2003	HS	NA	Cox's Point	+crypto	5
16	8/23/2003	FS	White Bass	Middle Branch	-crypto	0
17	8/23/2003	HS	NA	Middle Branch	-crypto	0
18	8/23/2003	FS	White Bass	Middle Branch	-crypto	0
19	8/31/2003	FS	Sunfish	Cox's Point	+crypto	4
20	8/23/2003	HS	NA	Middle Branch	-crypto	0
21	8/23/2003	FS	Little Minnow	Middle Branch	-crypto	0
22	8/23/2003	HS	NA	Jones Falls	-crypto	0
23	8/31/2003	HS	NA	Cox's Point	-crypto	0
24	10/12/2003	FS	Unknown	Canton	-crypto	0
25	10/12/2003	HS	NA	Canton	+crypto	0
26	10/12/2003	HS	NA	Canton	+crypto	6
27	10/12/2003	FS	Striped Bass	Canton	+crypto	5
28	10/12/2003	HS	NA	Canton	-crypto	0
29	10/12/2003	FS	Striped Bass	Canton	+crypto	8
30	10/12/2003	HS	NA	Canton	+crypto	15
31	10/12/2003	FS	Striped Bass	Canton	-crypto	0
32	10/12/2003	HS	NA	Canton	+crypto	11
33	10/5/2003	FS	Unknown	Cox's Point	-crypto	0
34	10/5/2003	HS	NA	Cox's Point	+crypto	6
35	10/5/2003	HS	NA	Cox's Point	-crypto	0
36	9/27/2003	HS	NA	Middle Branch	+crypto	10
37	9/27/2003	FS	White Perch	Middle Branch	+crypto	5
38	10/5/2003	FS	Sunfish	Cox's Point	+crypto	3
39	10/5/2003	HS	NA	Cox's Point	-crypto	0
40	9/27/2003	HS	NA	Middle Branch	-crypto	0
41	9/27/2003	FS	White Perch	Middle Branch	-crypto	0
42	9/27/2003	HS	NA	Middle Branch	+crypto	4
43	9/27/2003	FS	White Perch	Middle Branch	-crypto	0
44	9/27/2003	HS	NA	Middle Branch	+crypto	20
45	10/5/2003	FS	Sunfish	Cox's Point	-crypto	0
46	10/5/2003	HS	NA	Cox's Point	+crypto	9

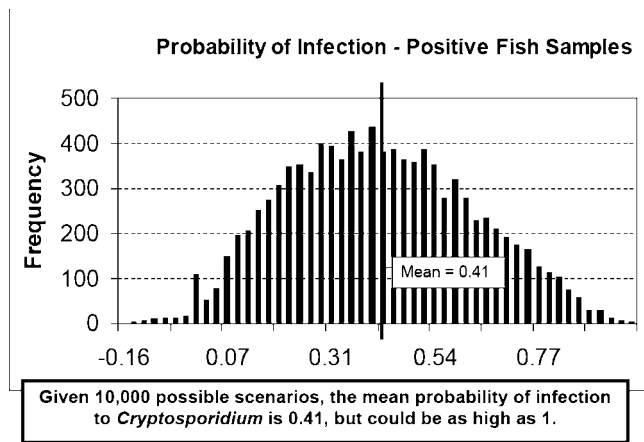


FIG. 2. Probability of infection based on positive fish samples and consumption.

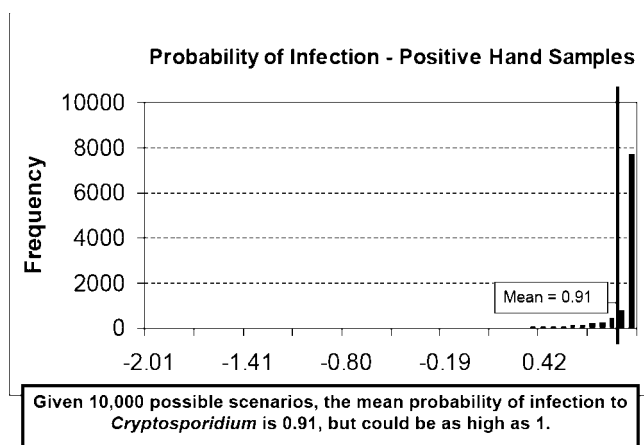


FIG. 3. Probability of infection based on positive hand wash samples and fishing.

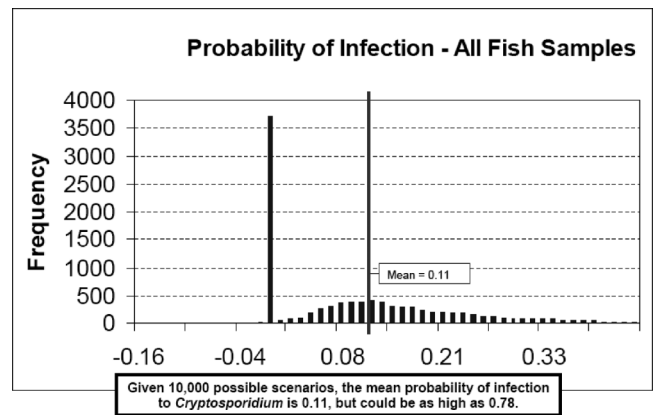


FIG. 4. Probability of infection based on total fish samples and consumption.

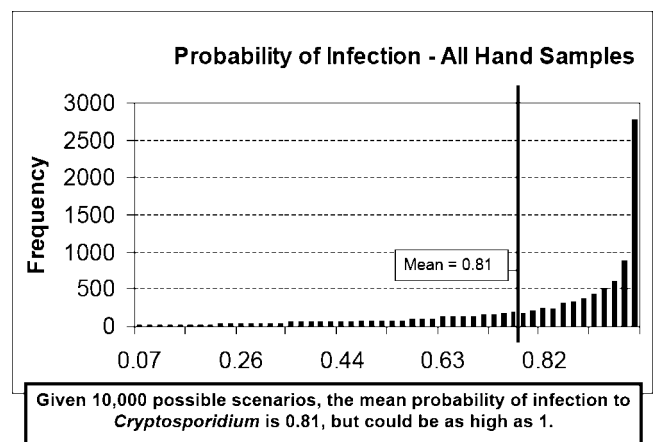


FIG. 5. Probability of infection based on total hand wash samples and fishing.

pathogens, such as *Cryptosporidium* or *E. coli*. *Cryptosporidium* in particular was shown to pose potentially significant adverse health risks, including fatalities, following environmental exposures (Hoxie et al., 1997; Pan and Graczyk, 1997). Even when symptoms have subsided, infected individuals may shed oocysts in their stool for months which poses a great public health threat (Mahon, 2000).

Cryptosporidium is just one of many pathogenic organisms that may be present in or on consumed fish (Haselow et al., 2001). This study indicates that the urban anglers may be at a risk for contracting cryptosporidiosis from exposures received while fishing and consuming caught fish. Based on the positive hand wash samples, it was estimated that the mean probability of infection was nearly one. A key factor in regard to the hand wash samples involves the transference of some or all of the

oocysts from the hand to the mouth depending on the number of mouthing events. Researchers have found that the number of mouthing or hand-to-mouth events among adults can be approximately 2 per hour or twice a day (Machaud et al., 1994; EPA, 2003). Given this variable along with the probability of infection, the risk of cryptosporidiosis among these anglers is significant especially considering the type of hand-to-mouth activities that anglers may engage in while fishing, such as smoking or eating. With the entire dataset the mean probability of infection based on the fish and hand wash samples was 11% and 81%, respectively. In any host, infection may be produced by one oocyst, but the probability that this will happen varies between hosts due to various confounding factors, such as immunity, age of the host, pre-existing illnesses and other host specific factors. These host-specific factors may also determine if the illness will progress from a subclinical or asymptomatic

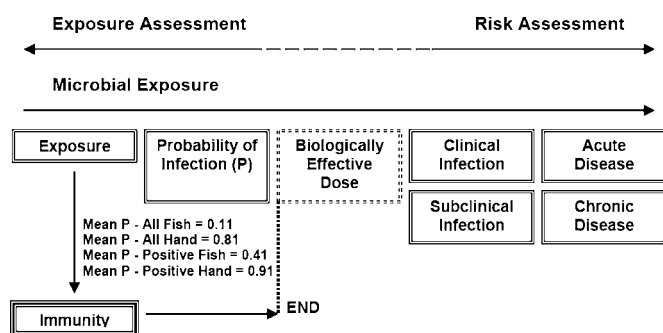


FIG. 6. Microbial Exposure-to-Disease Paradigm.

state and, in some cases, whether it will be acute or chronic in nature (Figure VI). With this Baltimore urban population, the risk of this probability was demonstrated to be high. To place this risk in perspective, the probability of infection to *Cryptosporidium* from fishing or consuming caught fish is higher among this sample than influenza, based upon estimates that 10–20% of U.S. residents may contract influenza each year (CDC, 2004). Although the probability of cryptosporidiosis in comparison to the common flu may not appear to be higher in the U.S., an important difference is that an immunocompetent individual may only display a case of severe diarrhea that eventually subsides. Unfortunately, a situation such as this may result in another un-reported or under-reported case. Therefore the number of actual cases of cryptosporidiosis is most likely being under-diagnosed and under-recognized. Hence, an important finding of this study is the identification of an under-recognized pathway of exposure to health risks via fishing. In addition to fish consumption, there is a high risk of pathogen exposure through fishing activity. The focus of attention in fish advisories directed at the dangers from consuming contaminated fish, and the nature of fish advisories is to only warn against consumption and not fishing. Yet, in the case of pathogens, the greater danger might occur just from fishing and not actually consuming the fish.

Based on the results of the interviewed questionnaire of the anglers, some were aware of a risk to human health from consuming contaminated fish, and specifically some anglers were aware of the dangers of consuming fish contaminated with mercury or other chemical pollutants. Despite the likelihood of some response bias among the anglers, not one angler mentioned being aware of the risk to exposure to pathogens. Risk perception among individuals plays an important role in the decision making processes (Burger et al, 1999a, 1999b). It is a public health responsibility to adequately communicate risks, and there is a need for the state and federal agencies to recognize the risk of pathogens especially in urban environments.

Although the findings of the research are valuable there was one main limitation, which was the potential for additional

certainty in the risk estimates due to the differences in infectivity among different strains of *Cryptosporidium* (Teunis et al., 2002). Other limitations were the small sample size, the lack of a fish or hand wash control or even the ability to match fish samples with hand wash samples from the same angler. With such a specific subpopulation, the size of the sample was limited by the water tides or rather the best times during the day for catching fish, the number of anglers present at specific times and the agreeability of the anglers to participate in the research. Unfortunately, with these types of limitations, it is difficult to identify a true prevalence of this risk. Yet even with these study limitations, this research is important because it is the first reported attempt to quantify exposure and risk of infection from handling or consuming fish contaminated with *Cryptosporidium*. By failing to recognize all of the potential routes of exposure to *Cryptosporidium*, many individuals are potentially in jeopardy of serious illness. It is important for anglers and the families and friends who handle the fish caught by the anglers to be aware of this risk such that the potential for another outbreak of *Cryptosporidium* be lessened. Even though this study focused on *Cryptosporidium*, the data are also applicable to other microbiological contaminants, such as *Giardia* which is often found with *Cryptosporidium*. With this type of pilot study other research can be conducted to continue to identify and evaluate the risk of pathogenic exposures due to angling activities. Additionally, future research that would identify disease outcome indicators in order to link exposure to disease would be highly recommended as the next step in understanding and communicating this potential risk.

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