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Contaminated fish consumption in California's Central Valley Delta ☆

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ABSTRACT

Extensive mercury contamination and angler selection of the most contaminated fish species coincide in California's Central Valley. This has led to a policy conundrum: how to balance the economic and cultural impact of advising subsistence anglers to eat less fish with the economic cost of reducing the mercury concentrations in fish? State agencies with regulatory and other jurisdictional authority lack sufficient data and have no consistent approach to this problem. The present study focused on a critical and contentious region in California's Central Valley (the Sacramento–San Joaquin Rivers Delta) where mercury concentrations in fish and subsistence fishing rates are both high. Anglers and community members were surveyed for their fish preferences, rates of consumption, the ways that they receive health information, and basic demographic information. The rates of fish consumption for certain ethnicities were higher than the rates used by state agencies for planning pollution remediation. A broad range of ethnic groups were involved in catching and eating fish. The majority of anglers reported catching fish in order to feed to their families, including children and women of child-bearing age. There were varied preferences for receiving health information and no correlation between knowledge of fish contamination and rates of consumption. Calculated rates of mercury intake by subsistence anglers were well above the EPA reference dose. The findings here support a comprehensive policy strategy of involvement of the diverse communities in decision-making about education and clean-up and an official recognition of subsistence fishers in the region.

1. Introduction

The present study provides critical data to support decision-making to reduce fish contamination, involve diverse stakeholder communities, and encourage safer fishing and eating patterns in California's Delta. The US Department of the Interior estimates that 10% of Californians engage in sport and subsistence fishing (USDI et al., 2003), many of whom fish in the watersheds of the Sacramento–San Joaquin Rivers Delta and San Francisco Bay. Subsistence fishing in areas with fish contamination creates the need for immediate policy initiatives, both to educate anglers about contamination and to speed the rate of remediation of the contamination. In California, fish contamination from mercury, polychlorinated biphenyls (PCBs), and other chemicals threatens fish consumption as a part of the daily diet. There has never been an economic evaluation of the cost of reducing fish contamination in California, though it is popularly thought to be high. Because of this perceived high cost of remediation, public agencies in California have proposed reducing fish consumption to reduce risk and exposure. There are actually several policy strategies that are available: (1) clean up environmental contamination in accordance with the Clean Water Act and California'a Porter-Cologne Act, (2) educate subsistence anglers about fish contamination, allowing them some choice, and (3) the combination of (1) and (2), developing pollution remediation plans that comprehensively deal with clean-up, new discharges, angler education, and inclusion of impacted communities. Currently, there is insufficient knowledge of fish consumption practices in California's Delta to make an informed choice among policy options.

California's growth was based initially on a gold-mining boom. Mercury mined in the Coast Ranges was used in the Coast and interior ranges to improve gold recovery (Alpers and Hunerlach, 2000). The watersheds of the Central Valley contain thousands of legacy mercury and gold mining features. Mercury also originates from natural geothermal activity, soil, atmospheric deposition,

Abbreviations: ANOVA, analysis of variance; CDFG, California Department of Fish and Game; CVRWQCB, Central Valley Regional Water Quality Control Board; FFQ, Food Frequency Questionnaire; PCBs, polychlorinated biphenyls; SAAC, Southeast Asian Assistance Center; SFEI, San Francisco Estuary Institute; TMDL, total maximum daily load; USDA, US Department of Agriculture; USEPA, US Environmental Protection Agency

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industrial and domestic waste-water, and unknown sources. Inorganic mercury enters the food chain primarily through bacteria-mediated mercury methylation (reviewed in Benoit et al., 2003) and bio-accumulates in organisms of higher trophic levels (Clarkson, 2002; Gilmour et al., 1998; May et al., 2000). Predatory fish (e.g., striped bass) tend to have the highest tissue concentrations of mercury (Wiener et al., 2003) and are favored by anglers.

Subsistence fishing is prevalent throughout the world, but tends not to be viewed as a behavior characteristic of urban communities. Urban California contains broad ethnic diversity, including many recently arrived immigrants who appear to have retained the cultural and economic practice of subsistence fishing. There is very high ethnic and language diversity in the Delta region of the Central Valley. Recently arrived Hmong, Cambodian, Vietnamese, Russian, and Mexican populations are common in Central Valley urban areas (Fujimoto, 1998). Many of these diverse communities relied on fishing as a cultural and economic practice in their countries of origin and have brought that practice with them. In addition, the social structure and accepted pathways of communication are quite different from the host culture (Fujimoto, 1998). This can make effective communication for education and/or decision-making particularly challenging—a problem that is poorly addressed in California state policy. There are also many California-born anglers and fish consumers in the Delta region who subsistence fish.

The Central Valley Regional Water Quality Control Board (hereafter the Regional Board) has developed a draft total maximum daily load (TMDL) for methyl-mercury in the Delta because of impairment to fish consumed by humans and wildlife (Central Valley Regional Water Quality Control Board, 2008). Because the consumption of fish by wildlife and humans is legally protected in these waters as a beneficial use under the Clean Water Act, legally, the state must develop a plan to resolve this impairment, which by strict definition means reducing mercury concentrations in fish. The Clean Water Act requires the development of TMDLs as science and policy guides for reducing particular types of waterway pollution. In the presence of subsistence fishing this is particularly challenging, because protecting their use would require potentially greater political and financial investments.

We used a food frequency questionnaire to study fish consumption patterns. Survey respondents were asked for a 30-day recall of fish intake from local waters and commercial sources. The vast majority of comparable studies using FFQs have reported accurate findings using this approach among a wide range of nationalities and ethnicities (Villegas et al., 2007; Quandt et al., 2007; Sullivan et al., 2006; Kuster et al., 2006; McNaughton et al., 2005). In cases where the FFQ has been less accurate, it tended to under-estimate actual consumption (Hudson et al., 2006; Lee et al., 2002). Anglers and community members were interviewed in English or the respondents' native language. A statistical description of fish consumption patterns is presented for the North Delta region of the Central Valley over 3 years (2005–2008), including information about individual fish species and ethnic communities. This information, combined with existing information about fish tissue concentrations of mercury is used as the basis for an exposure analysis. Findings are presented showing the diverse mechanisms through which anglers receive health related information. Finally, actual mercury exposure is compared to assumptions made in current policy-development for mercury remediation.

2. Methods

2.1. Study area

The study area comprised the North, South, and West Delta regions of the Central Valley, stretching from the cities of Sacramento and Stockton to the city of Fairfield (Fig. 1). The waterways included the Sacramento River (the largest in California), the Port of Sacramento Shipping Channel, Montezuma Slough, and the San Joaquin River. Specific sites for surveying along the Sacramento River were: Garcia Bend City Park, Freeport, Clarksburg, and Port of Sacramento shipping channel. These sites were chosen as sites likely to be popular with anglers after an expert review of CDFG creel survey data by river mile and pre-surveying site visits (Fig. 1). These areas were also chosen because fish tissue concentrations of mercury are high in the vicinity of the sites (within 10 river miles).

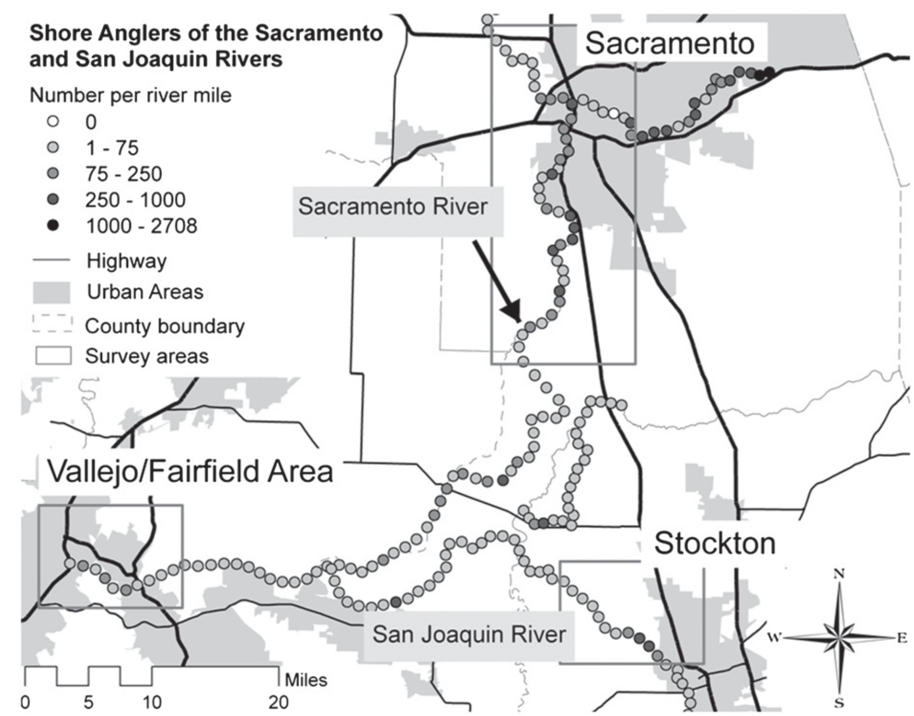

Fig. 1. Annual angling intensity in study area. Data from the California Department of Fish and Game creel survey program, 2000. Angler surveying areas for the present study.

2.2. Survey instrument, sample, and protocol

The survey instrument was designed to cover target fish species, fish consumption rates, health communication, and household demographics. It was designed in 2003 and 2004 in collaboration with the California Department of Public Health and the California Office of Environmental Health Hazard Assessment and is nearly identical to the instrument used in the recently published study of women attending clinics in Stockton, CA (Silver et al., 2007). There were 17 questions and the questionnaire took about 10 min to administer. Answers were recorded on the questionnaire, coded, and transferred to a computer spreadsheet. Fish filet models were used representing 3 different cooked weights of fish filet (1.5, 4.5, and 7.5 oz) in order to allow estimates of actual fish consumption rates.

Anglers were chosen for interviews as they were encountered along the river-bank by surveyors. All or the vast majority of anglers were interviewed as they were encountered, reducing bias in selection of the sampled population. However, the angler interviews were only conducted in English, which resulted in a failure to interview about 5% of those approached. 373 shore anglers were interviewed during biweekly to monthly site visits between September 2005 and June 2008. All days of the week were represented roughly equally in sampling; sampling was conducted primarily in the early morning and late afternoon when anglers were more likely to be present. In July and August, surveyors went into the field, but very few anglers were encountered when surveyors were present, which may be related to anglers fishing at different times of day, or night, during these hotter months. Encounters were initiated by the surveyor approaching the anglers and beginning a conversation about fishing. Anyone reporting that they had been previously interviewed was not interviewed again. On the vast majority of sampling days, all anglers observed fishing were interviewed. Community members were chosen for interviews based on prior knowledge of Southeast Asian Assistance Center (SAAC) staff that an extended family member fished, but without specific knowledge of how often they fished or ate fish. All such people identified by the SAAC staff were interviewed. SAAC staff live in the communities they serve and have access to households because of community familiarity with the organization. 137 community members were interviewed between December 2006 and June 2008.

Subjects were told that the survey was about fishing activity along the river and was being conducted to better understand what kinds of fish people were catching and eating. They were not told in advance that the survey was related to concerns about fish contamination.

2.3. Spatial and creel survey data

Fish contamination data up to 2006 were obtained from the California Regional Board, covering almost 30 years of measurements of mercury in various fish species, and from the San Francisco Estuary Institute (SFEI) for 2005–2007. Mean mercury concentrations (parts per million or micrograms/gram) were calculated for each target species using values for legal-sized or edible fish at or near the angler survey sites. In the case of striped bass, this corresponded to lengths >18 in, for sturgeon this corresponded to lengths >48 in and for all other fish species lengths >12 in, except sunfish, bluegill, and crappie where lengths >6 in were used.

Creel survey data covering 1999–2001 (the most recent and comprehensive available) were obtained from the California Department of Fish and Game in computer spreadsheets and in written reports to the US Fish and Wildlife Service. The survey covered fishing effort, types and numbers of fish caught, and location of fishing. The creel survey data were attributed to river mile points along the Sacramento River using ArcView 3.2 (Fig. 1). The river mile points were manually measured using ArcView 3.2 along the center-line of the river using geo-referenced digital photographs. These data were used to choose sites for surveying and to compare fishing activity of the surveyed population in this study with the creel survey population.

2.4. Survey data analysis

Fish consumption rates (g/day) were calculated for each individual based on 30-day recall of how much and how often individual types of fish (e.g., catfish) were eaten. Anglers were grouped by major race/ethnicity (e.g., Hispanic) according to Census Bureau classification. Minor ethnicity (e.g., Lao) was also recorded when the survey respondent provided sufficient information for the classification. Rates of mercury intake were calculated for individuals based on individual consumption rates determined through surveying for specific fish types and the regional mean mercury concentrations for those fish types, which is based on fresh weight. Because the cooked weight of fish, represented by the fish filet models used in surveying, is about 75% of the fresh weight, the calculated rates of mercury intake here are a conservative estimate of actual rates. Mean and 95th percentile fish and mercury consumption rates were calculated for all interviewees and median rates calculated for all recent consumers. Data were organized in MS Excel and all statistical analysis was done using the commercial software SPSS 16.0. Trends analysis was performed using the Seasonal Kendall test software developed by the US Geological Survey (Hirsch et al., 1982; Hirsch and Slack, 1984; Helsel et al., 2006).

3. Results

3.1. Context: fish contamination and angling intensity

Concentrations of mercury in commonly eaten fish were calculated using a combination of the Regional Board and SFEI datasets (Table 1). Fish sizes ranged from >6 in (bluegill) to >48 (sturgeon) and mean wet tissue concentrations ranged from 0.052 ppm (shad) to 0.772 ppm (largemouth bass) wet tissue weight.

Creel survey data collected by the California Department of Fish and Game (CDFG) indicate that the primary target fish species for all anglers, regardless of ethnicity, in the Northern region of the Central Valley Delta were striped bass, salmon, shad, and catfish (Murphy et al., 1999, 2000; Schroyer et al., 2001). This is similar to the targeted species in the present study (Table 2), with inter-ethnic differences in fish preferences. For all commonly caught fish there were mercury concentration data available in the study region (Table 1).

Table 1
Mercury concentrations of commonly eaten fish in the Northern Delta region, in size ranges sought by anglers.

Fish species (common name)	*N*	Mercury concentration		Length (in)	Location
		(Mean ppm)	SD		
Shad	19	0.052	0.023	> 15	AR, Delta
Bluegill	10	0.208	0.125	> 6	SR, SRSC
Carp	30	0.309	0.197	> 15	SR
Catfish	44	0.424	0.251	> 12	SR, Delta
Crappie	5	0.309	0.104	> 8	SR, Delta
Chinook Salmon	25	0.09	0.03	> 26	AR, FR, SR
Largemouth Bass	63	0.774	0.324	> 12	AR, SR
Sacramento Pike Minnow	42	0.763	0.525	> 12	AR, SR
Split-tail	1	0.37		16	SR
Sacramento Sucker	38	0.22	0.117	> 12	AR, SR
Rainbow Trout/Steelhead	12	0.061	0.014	> 18	AR, SR
Striped Bass	47	0.545	0.318	> 18	AR, Delta, SR
Sturgeon	11	0.271	0.241	> 48	SR
Sunfish	14	0.182	0.097	> 8	SR

AR=American River, FR=Feather River, SR=Lower Sacramento River. Data from the Central Valley Regional Water Quality Control Board database and San Francisco Estuary Institute reports online (http://www.sfei.org).

Table 2
Ethnicity-specific targeting of fish species. Shown are the fish species most commonly eaten and the fish species eaten in largest quantity. Ranks determined from survey for all respondents.

Ethnicity	Target	
	1st choice Frequency/amount	2nd choice Frequency/amount
African-American	SB/SB	CF/CF
SE-Asian	SB/SB	CF/CF
Lao	CF/SB	SB/SF
Hmong	SB/SB	CF/Stur
Asian/Pacific Islander	SB/SB	CF/CF
Hispanic	SB/SB	CF/CF
Native American	CF/LMB	CF/KS
White	SF/SB	SB/Stur
Russian	Carp/Carp	CF/CF

Carp=carp, CF=catfish, SF=sunfish, KS=Chinook salmon, LMB=largemouth bass, SB=striped bass, Stur=sturgeon.

In 2001, CDFG reported about 22,000 directly counted anglers at a survey rate of about one in every 4 days for all months of the year, but on different tributary rivers to the Delta (Schroyer et al., 2001). About 80% of those counted were fishing on the Sacramento River between the Feather River and the San Francisco Bay and other tributary rivers to the Delta. In 2001, of the approximately 1.2 million licensed anglers in California, 191,000 of them lived in 5 counties encompassing the Delta (Sacramento, San Joaquin, Solano, Yolo, and Contra Costa; data from the CDFG License Bureau). One interpretation of the 10-fold difference between the number of anglers counted by CDFG and the number of licensed anglers is that anglers fish about one of every 10 days on regional rivers. This is similar to the rate of fishing among anglers (one of every 4.5 days) and community members (one of every 10 days) in the present study.

3.2. *Rates of fish consumption*

Consumption rates for locally caught fish and commercially acquired fish were calculated for all respondents (Fig. 3 and Table 3). There was no significant relationship between day of the week when surveying occurred and ethnic group type, or fish consumption rate. Rates found for Southeast Asian community members were not significantly different from rates found for Southeast Asian anglers, but for other ethnic groups, community member consumption rates and angler consumption rates were significantly different. Because of this, most data analyzes on these two datasets were done separately. Consumption rates for anglers as a whole varied throughout the year, with peaks during the Fall, when both striped bass and salmon are returning to rivers to spawn (Fig. 3), and fishing activity is the highest (Fig. 2). There was no significant trend (P=0.78) in consumption of locally caught fish across the 3-year study period (2005–2008), when trend was corrected for seasonality using the Seasonal Kendall test (Hirsch et al., 1982; Hirsch and Slack, 1984; Helsel et al., 2006). The arithmetic mean and median consumption rates of *locally caught* fish were 27.4 and 17.0 g/day, respectively, for anglers—which are higher than and similar to the USEPA standard fish consumption rate of 17.5 g/day. Both the arithmetic mean and median consumption rates were used in the present study because they provide different types of information about behavior (Sechena et al., 2003). The mean and median rates of consumption of all fish (locally caught and commercial) were 40.6 and 24.1 g/day, higher than the combination of USEPA's average rate for fish consumption (17.5 g/day) and the USDA's average food intake rate for commercial fish (12.5 g/day). The corresponding mean fish consumption rates from the community member survey were 55.2 g/day (locally caught fish, median rate=21.3 g/day) and 63.4 g/day (total fish, median rate=28.4 g/day), with both types of rates being higher than the corresponding rates for anglers in the field ($P<0.05$, t-test), primarily because the majority of community members surveyed were Southeast Asians. Among the major ethnic groups, Southeast Asians ate the most locally caught fish, followed by African-Americans and Hispanics. However, there was no statistically significant difference in rates among the major ethnicities ($P>0.05$, ANOVA). Of the ethnic sub-groups, the Lao respondents had the highest mean total fish consumption rate (65.2 g/day) and locally caught fish consumption rate (57.6 g/day). Their rate of local fish consumption was significantly higher than the mean rate for all non-Lao anglers ($P<0.05$, t-test).

Women interviewed in community settings ate significantly more locally caught (54.1 g/day) and total (66.4 g/day) fish than male anglers (26.4 and 39.3 g/day; $P<0.05$, t-test) and identical amounts of commercially obtained fish. There was no statistically significant difference between male and female angler consumption rates ($P>0.05$, Table 3). There were no significant differences in consumption rates among age groups (Table 3). Rates of consumption for locally caught and total fish were significantly higher ($P<0.05$, t-test) for anglers from households with children, or from households with women of child-bearing age, than anglers from households without children or women of child-bearing age.

To represent the majority of the fish-consuming population, we also calculated the 95th percentile rates for locally caught, and total fish consumption and the corresponding mercury intake rates. By definition, 95% of fish consumers consume at or below the 95th percentile rate. These rates were compared to the rates used by the Regional Board for its Total Maximum Daily Load (TMDL) for methyl-mercury in the Delta region under different mercury load-setting "scenarios" corresponding to different assumed fish consumption rates (Central Valley Regional Water Quality Control Board, 2008). The scenarios were based on a range of consumption rates and were 17.5 g/day (scenarios A and C), 32 g/day (scenarios B and D), and 142 g/day (scenario E). All ethnicities and sub-ethnicities with sufficient "N" to calculate 95th percentile rates (exceptions=Russian and Native American) had locally caught and total fish intake rates greater than Regional Board scenarios A–D (Table 3). African-American, Lao, Vietnamese, Asian/Pacific Islander, and Hispanic anglers had 95th percentile rates greater than Regional Board scenario E (Table 3), which was the highest rate used by the Regional Board.

3.3. *Balancing locally caught and commercial sources of fish*

An important issue in understanding the economic and dietary decisions that subsistence fishing communities make when fish are contaminated, is the balance between buying and catching edible fish. Anglers and community members often consumed fish that they or someone they knew had caught as well as fish that they bought at markets or restaurants. For all ethnic groups and both genders combined, there was an inverse relationship between consumption rates of commercially acquired fish and locally caught fish (Fig. 4). There was a significant relationship between the frequency that anglers fished and the amounts of locally caught fish that they ate ($P<0.05$, Chi-square test).

3.4. *Rates of mercury consumption*

The combination of species-specific consumption rates and species-specific mercury concentrations was used to calculate the

Table 3
Mean and 95th percentile fish and mercury intake rates for different groups.

	N	Local fish intake		Local fish Hg intake		Total fish intake		Total fish Hg intake	
		Mean (g/d)	95th percentile (g/d)	Mean (μg Hg/d)	95th percentile (μg Hg/d)	Mean (g/d)	95th percentile (g/d)	Mean (μg Hg/d)	95th percentile (μg Hg/d)
Ethnicity									
African-American	32	31.2 [21.3]	242.3	15.7 [9.0]	127.8	48.3 [21.3]	252.0	20.8 [7.7]	130.6
Southeast Asian	152	32.3 [17.0]	129.4	14.0 [7.0]	62.8	42.8 [24.1]	180.2	17.1 [9.5]	74.7
Hmong	67	17.8 [14.9]	89.6	6.9 [6.2]	33.6	22.3 [19.1]	89.6	8.3 [8.3]	37.7
Lao	30	57.6 [21.3]	310.4	26.5 [10.5]	161.4	65.2 [24.1]	317.5	28.8 [9.5]	163.5
Vietnamese	33	27.1 [21.7]	152.4	11.9 [5.0]	77.4 [36.1]	55.4	249.3 [12.0]	20.4	105.9
Asian/Pacific Islander	38	23.8 [15.6]	148.3	9.8 [4.8]	40.4	46.1 [35.0]	156.4	16.5 [9.2]	49.5
Hispanic	45	25.8 [19.1]	155.9	10.8 [7.8]	48.1	36.3 [14.2]	169.5	13.9 [6.7]	54.1
Native American	6	6.5	ND	2.3	ND	69.9 [108.4]	ND	20.8 [33.3]	ND
White	57	23.6 [21.3]	138.9	8.8 [6.7]	43.8	34.7 [28.4]	139.2	12.1 [7.5]	46.8
Russian	17	23.7 [17.7]	ND	7.8 [5.6]	ND	36.1 [35.5]	ND	11.5 [9.6]	ND
All Anglers	373	27.4 [19.7]	126.6	11.4 [6.7]	51.5	40.6 [26.1]	147.3	15.4 [8.1]	56.6
Southeast Asian[a]	286	40.8 [17.0]	128.5	17.6 [7.3]	58.0	50.3 [25.5]	144.5	18.7 [7.9]	70.2
Hmong[a]	130	21.3 [14.9]	102.1	8.1 [4.6]	38.7	26.5 [17.0]	119.7	9.7 [4.5]	42.9
Lao[a]	54	47.2 [17.0]	265.8	20.4 [6.7]	117.8 [28.4]	54.4	267.0 [10.8]	22.6	118.8
Demographic Group									
Age									
18–34	143	32.0 [24.6]	138.9	13.0 [8.9]	55.6	44.9 [25.2]	151.5	16.8 [8.5]	66.7
35–49	130	22.7 [14.2]	120.5	9.8 [6.9]	51.2	36.8 [24]	143.9	14.0 [7.7]	57.5
> 49	87	30.6 [17.0]	207.0	12.8 [5.4]	92.3	44.3 [24.1]	217.2	17.0 [8.4]	95.4
Gender									
F	35	38.2 [22.5]	226.8	15.9 [8.4]	94.7	53.9 [24.6]	263.1	20.6 [8.2]	105.4
M	336	26.4 [19.5]	129.3	11.0 [6.5]	54.3	39.3 [26.1]	146.6	14.9 [8.1]	56.9
Household contains									
Woman 18–49 y-o	217	33.0 [21.2]	142.2	14.1 [7.3]	59.5	46.6 [7.3]	158.1	18.2 [8.8]	71.8
Children	174	35.1	142.8 [22.2]	15.4	61.2 [7.8]	49.2	171.9 [27.1]	19.6	78.3 [9.3]
Awareness									
0	172	24.7 [18.2]	121.6	10.4 [6.6]	51.9	35.5 [23.0]	143.5	13.7 [7.5]	56.6
1	44	42.8 [28.0]	361.1	19.5 [12.3]	187.5	52.9 [28.5]	361.1	22.5 [10.7]	187.5
2	115	28.4 [21.3]	139.6	11.0 [6.3]	61.2	45.8 [28.0]	151.7	16.2	63.3
3	35	12.2 [13.8]	62.4	5.1 [4.0]	32.1 [20.8]	28.1	95.6[6.0]	9.9	35.9
4	7	57.1 [36.1]	ND	24.3 [7.6]	ND	65.0 [39.0]	ND	26.7 [8.9]	ND

ND stands for "not determined" because of insufficient data. All data shown are for angler surveying, except for the data indicated as from combined angler and community surveys.
In the "mean" columns, the first value for a group is the arithmetic mean for all interviewees, the second value below it in "[ ]" is the median for recent consumers.

[a] Rates from combined angler and community surveys.

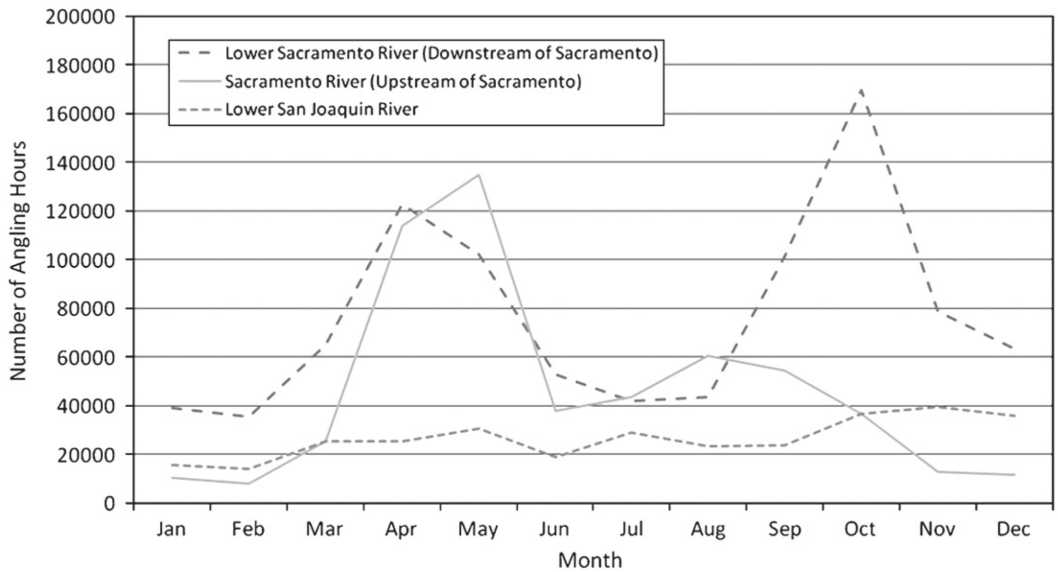

Fig. 2. Fishing intensity as angling hours varying by season and location on the Sacramento River and San Joaquin River. Data from the California Department of Fish and Game creel survey program, 2000.

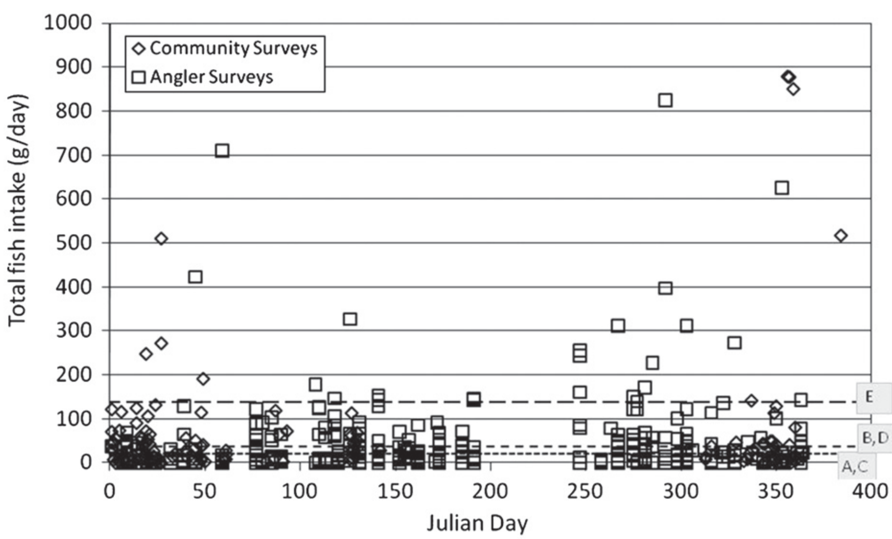

Fig. 3. Total fish consumption rates over the year (Julian Day 1=January 1). Each symbol represents an individual interviewee. The lines at the bottom represent the scenarios for fish consumption rates used by the Central Valley Regional Water Quality Control Board's TMDL for methyl-mercury in the Delta. A, C=17.5 g/day; B, D=32 g/day; E=142 g/day of fish consumed.

mercury intake rates of each surveyed angler and community member (Table 3, Fig. 5). Predictably, higher rates of mercury intake corresponded to higher rates of fish consumption because the types of fish consumed are similar across the range of consumption (Fig. 5), with the notable exception of two anglers (circled) who selectively consumed trout and salmon, which have low mercury concentrations in this region. Mean rates of mercury intake for individual ethnicities were compared to the USEPA reference dose (0.1 micrograms mercury/kg-body-weight/day) and to the grand mean of all intake rates. Approximately 5% of anglers had a mercury intake rate at least 10 times higher than the USEPA reference dose, the mercury intake rate 1/10 of the rate associated with measurable health impacts. The reference dose (7 micrograms/individual/day) was calculated using an average adult body-weight of 70 kg (Finley et al., 1994; USEPA, 1997). The mean total mercury intake rate for the whole sampled population is significantly greater than the USEPA reference dose ($P<0.05$, *t*-test). Similarly, the mean mercury intake rates for Southeast Asian, Vietnamese, Lao, and Asian/Pacific Islander were all significantly higher than the USEPA reference dose ($P<0.05$). For African-American, Lao, and Vietnamese anglers, 95th percentile local fish mercury intake rates were higher than 10 times the USEPA reference dose, and for these groups, as well as Southeast Asian anglers as a whole, the 95th percentile rates of mercury intake from total fish consumption were greater than 10 times the USEPA reference dose. Among ethnic groups, Lao and Vietnamese had mean mercury intake rates that were significantly higher than the grand mean rate for all anglers ($P<0.05$).

Anglers from households with children had mercury intake rates that were significantly higher ($P<0.05$) than the USEPA reference dose and higher than households without children

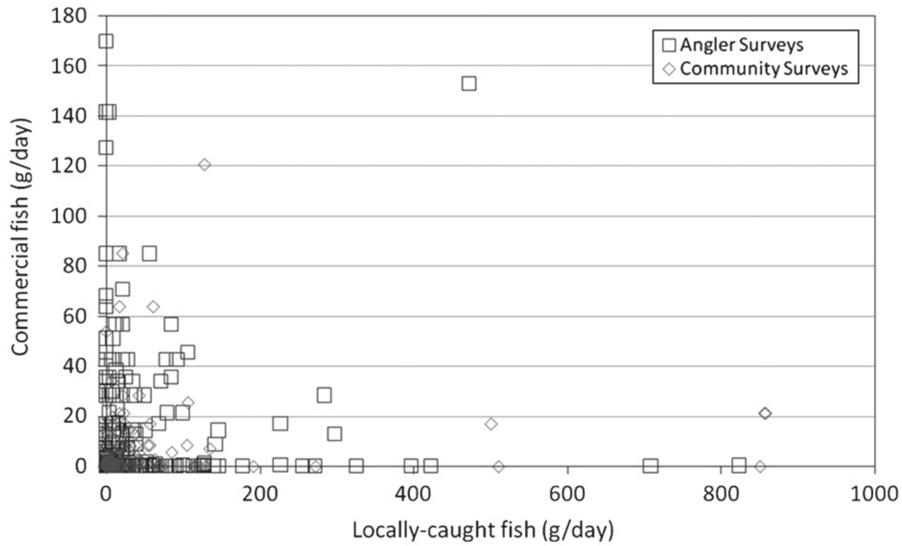

Fig. 4. Relationship between consumption rates for locally caught and commercially acquired fish.

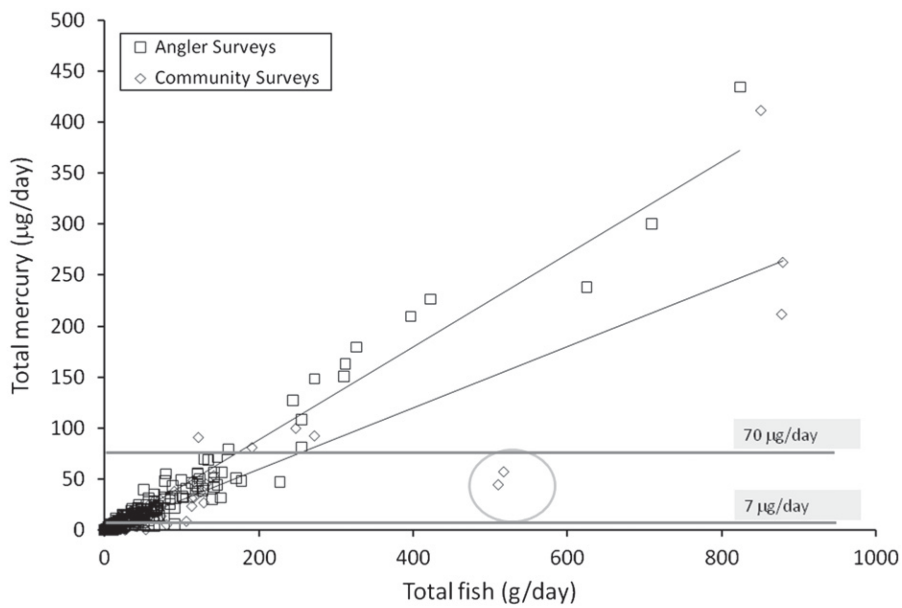

Fig. 5. Calculated mercury intake rates per interviewee compared to total fish consumption rate. The lines corresponding to 7 and 70 μg/day are the USEPA mercury reference dose for adults and ten times the dose, respectively. The circled pair of symbols represent surveyed community members who were consuming large amounts of low-mercury fish (salmon and trout). The upper line represents the least-squares regression fit for the angler survey results and the lower line, the corresponding fit for the community survey results.

(Table 3). Anglers from households with women of child-bearing age had higher rates of mercury intake than anglers from households without women of child-bearing age, but with only marginal significance ($0.05 < P < 0.10$).

The fish filet models used in surveying represented cooked fish, which has about 75% the mass and volume of fresh fish. Mercury concentrations are calculated and used here for fresh fish. Therefore, the mercury intake rates calculated here represent a conservative estimate of actual rates, where actual rates could be 1.33 times higher than those reported.

3.5. Awareness of fish contamination

Respondents were asked about their awareness of warnings about fish contamination and their responses coded according to accuracy and completeness of the response (range=0, no awareness, to 4, high awareness and accurate recall, Table 4). Angler awareness (Table 5) was highest among White respondents (mean=1.9), followed by Native Americans (mean=1.6), and African-Americans (mean=1.4). Awareness was also highest in middle-aged respondents (compared to other age groups) and higher in men than women. There was significantly lower ($P < 0.05$, *t*-test) awareness of warnings about fish consumption among Southeast Asians interviewed in community settings than for Southeast Asian anglers interviewed while fishing.

Awareness was compared to fish consumption and various demographic parameters (Table 3). Anglers that were more aware of warnings about fish contamination did not have statistically different rates of fish consumption or corresponding mercury intake than anglers with low awareness ($P > 0.05$, *t*-test). Awareness in households with children present (mean=0.97) was significantly ($P<0.05$, ANOVA) lower than in households without children (mean=1.2). There was no significant difference in awareness correlated to the presence or absence of a woman of child-bearing age in the household.

3.6. Pathways for communication of health information

Because state and local governments are considering informational campaigns about fish contamination and in some places have started them, we tested the fishing populations for awareness of this issue. Among African-Americans, Hispanics, Native Americans, and Russians, a sign at a fishing location was the main source of information about fish contamination (Table 5). Among Southeast Asians, Asian/Pacific Islanders, and Whites, television was the main source of information (Table 5). Secondary sources of information included friends and family and community clinics (Table 5). When sources of warnings about eating fish were compared among ethnicities, Asian, Southeast Asian, and White groups reported warnings from different sources than all other groups ($P<0.05$, Chi-square test). Similar results were found when trusted sources of health information were compared among groups. Asian, Southeast Asian, Hmong, and White groups reported trusting different sources for health information than all other groups ($P<0.05$, Chi-square test). There were no differences among age groups for trusted sources of health information. Males and females both recalled warnings primarily from television, but women also relied on friends and family as an important source.

The primary trusted source of health information for African-American, Southeast Asian, Asian/Pacific Islander, Hispanic, and White populations was health providers (Table 5). For Native Americans, family and friends were the primary source of health information (Table 5). Secondary sources for all groups included family and friends, television, radio, newspaper/magazines, and community centers (Table 5). For all age groups and genders, the primary source of health information was from medical providers. Secondary sources included family and friends and television.

Table 4
Coded awareness of health warnings about eating fish.

Code	Categories of responses
0	No awareness of health warnings
1	Report awareness of pollution, toxicity, some non-specified problem with fish
2	Awareness of one of the following: mercury contamination, OR specific contaminated fish species, OR specific recommended amounts of fish per time period, OR warnings about children and pregnant women fish consumption
3	Awareness of two of the issues in (2)
4	Accurate recall of mercury contamination, specific fish, frequency of consumption (1 meal/month), and warnings about children and pregnant women consumption

4. Discussion

This study shows that anglers in the Sacramento/San Joaquin Rivers Delta may be exposed to mercury in amounts well above the USEPA reference dose. This exposure is in part because the consumption rates of locally caught fish (primarily) are relatively high (compared to the USEPA average value), including being higher than the rates used by state agency staff to develop pollution control plans. In addition, the exposure is concentrated in non-white, primarily immigrant populations, though many ethnicities are affected. Rates of fish consumption vary seasonally, based primarily on fish availability, affecting the accuracy of mercury intake calculations from short-term studies.

4.1. Consumption rates compared to other studies

The fish consumption rates in the present study vary to some degree by ethnicity. This has been found to be true for a comparable study in a nearby area (Silver et al., 2007) and other areas. Fish consumption rates for certain ethnicities in the Delta region are similar to the rates found for Asian American and Asian Pacific Islanders in Washington (117.2 g/day; Sechena et al., 2003), for Yakama Nation members (58.7 g/day; Columbia River

Table 5
Mean awareness, sources of warnings about fish consumption, and trusted sources of health information for different groups of anglers.

Ethnicity	*N*	Awareness Mean (0=none, 4=high)	Source of warning 1st, 2nd choice	Trusted health sources 1st, 2nd choice
African-American	32	1.4	3, 4	1, 3
Southeast Asian	152	0.40	1, 4	1, 3
Hmong	67	0.58	1, 4	1, 3
Lao	30	0.67	1, 3	1, 5/10
Vietnamese	33	1.1	1, 4	1, 4
Asian/Pacific Islander	38	1.2	1, 4	1, 4
Hispanic	45	1.0	3, 1	1, 4
Native American	5	1.6	3, 4	3
White	57	1.9	1, 3	1, 3
Russian	17	0.8	3, 7	4, 7
All Anglers	373	1.1	1, 3	1, 3
Age				
18–34	83	0.9	4, 1/3	1, 4
35–49	82	1	1, 8	1, 4
>49	54	0.6	8, 1	1, 3
Gender				
F	23	0.6	1, 4	1, 3
M	198	0.9	1, 8	1, 3
Household				
With woman 18–49	142	1.13	1, 3	1, 3
With children	116	0.97	1, 3	1, 3

For warning sources: 1=television, 3=sign at fishing location, 4=friend or family, 7=community clinic, 8=other. For trusted sources of health information: 1=health care provider, 3=family or friend, 4=television, 5=radio, 7=newspaper or magazine, 10=community center.

Inter-Tribal Fish Commission, 1994), New Jersey adults (50.2 g/day; Stern et al., 1996), and the 99th percentile consumption rates found in national surveys (USEPA, 2001). The rates presented here are the first measured for local angling populations in the Delta.

The mean consumption rates observed for certain ethnic groups of Delta anglers (Table 3) are several times higher than the default consumption rate (17.5 g/day) the USEPA recommended for public agency planning, based on the 90th percentile rate from USDA nation-wide consumption surveys (USEPA, 2001). This consumption rate was used by the USEPA to set the target methyl-mercury concentration for fish tissue at 0.3 mg/kg fish tissue. The rates found here are also several times higher than the mean daily consumption rate (4.58 g/day) for the general US population (USEPA, 2002). These USEPA rates of consumption and the consumption rate calculated for San Francisco Bay anglers (95th percentile rate=32 g/day), are used by the Regional Board to set target fish tissue concentrations for the Delta through the TMDL process (Central Valley Regional Water Quality Control Board, 2008; described in more detail below). In all cases, the average and 95th percentile rates used in proposed pollution regulation are less than mean local fish consumption rates we found for Lao and the combined Southeast Asian fish consumers (Table 3). The consumption rates of locally caught fish that sometimes have multiple contaminants, especially near urban areas and near the San Francisco Bay, indicate that many fish consumers in the Delta have exposure levels of immediate public health concern.

4.2. *Mercury intake*

Few studies have calculated mercury intake from subsistence fishing using local measurements of mercury concentrations in fish (Stern et al., 1996). Other studies have compared fish consumption rates with mercury body load (e.g., blood; Cole et al., 2004). Our study provides the first accurate estimates of mercury intake for various populations eating multiple species of locally caught fish in California's Central Valley Delta, which can be compared in future studies to measured mercury body loads. These intake rates indicate that most fish consumers may be taking in greater than the USEPA maximum of 0.1 micrograms/kg-body-weight/day. About 5% of consumers are consuming more than 10 times the maximum recommended dose. This number could be higher by 1.33-fold because the rate of mercury intake was conservatively calculated (see Section 2). Certain ethnic groups are on average consuming several times greater than the USEPA reference dose. Ethnic group-specific 95th percentile rates for fish and mercury intake are higher than the highest rates used by the Regional Board for pollution control planning (Central Valley Regional Water Quality Control Board, 2008) and near to or greater than 10 times the USEPA reference dose. All of these findings pose complex, but straightforward policy questions about who should be protected and to what degree.

4.3. *Policy issues*

4.3.1. *Disproportionate health impacts of mercury intake*

The USEPA has determined that a dose of 0.1 microgram/kg body-weight/day of mercury is the maximum that children and women of child-bearing age should consume to protect fetal and child brain development (USEPA, 2004). This reference dose is approximately one tenth the intake rate that has been found to result in measurable health effects in various studies. For a 70 kg (154 lb) person (average adult body-weight), the rate would be 7 micrograms of mercury/day. Stern et al. (1996) calculated the mean rate of mercury intake for New Jersey adults, based on fish consumption rates (mean=50.2 g/day), as 7.5 micrograms of mercury/day.

In the present study, the rates of mercury intake were calculated for all respondents (Fig. 4) and are shown in Table 3 by ethnicity, gender, and age group. For none of the groups were calculated mean mercury intake rates from fish consumption less than the reference dose. The Lao respondents had the highest mean mercury intake rate (28.8 micrograms/day), 4 times higher than the reference dose. The vast majority of this mercury intake was from locally caught fish (26.5 micrograms/day). Of the different ethnic groupings, only Lao had mean mercury intake rates that were significantly higher than the reference dose (t-test, $P<0.05$).

4.3.2. *Impacts of state regulatory response*

In their interpretation of the Clean Water Act, the state has developed a draft TMDL for methyl-mercury in edible fish (Central Valley Regional Water Quality Control Board, 2008). The implementation is intended to be a combination of reduction of methyl-mercury in sediments and water column through waste-load allocations and changes in fish-eating behavior in at-risk human populations. The first phase of implementation includes developing education and outreach programs directed at communities eating fish from the Delta. The draft Delta TMDL states: "*Beneficial use protection in the case of mercury pollution, therefore, must be accomplished by a combination of cleanup and education. Education is a needed part of a TMDL implementation plan until effects of all mercury reduction efforts are reflected in fish tissue levels*." State agencies recognize this as a critical part of their overall strategy. For example, a New Jersey study found that a reduction in fish consumption rates was correlated with exposure to state warnings and advisories (Burger, 2008). This is intended to be the short-term "risk-reduction" program paralleling mercury controls, in order to protect human health until fish tissue targets (for mercury) are achieved. One danger of this approach is that TMDL attainment for humans may be achieved through changing human behavior (reducing fish consumption), rather than controlling mercury in the system. However, our study found no relationship between knowledge of fish contamination and fish consumption rates.

For subsistence fishing populations, simply trying to encourage less fish consumption may be infeasible and if successful, may pose heavy cultural and economic burdens on the population. In the case of the Delta methyl-mercury TMDL, if in a future TMDL amendment, fish consumption rates have dropped because of effective communication by agencies, then fish tissue target concentrations could be raised higher than they would have to be now to protect high-intake fish consumers. Because correcting impairment is the purpose of TMDLs under the Clean Water Act, it remains to be seen whether or not risk-reduction through fish consumption reduction can be legally defended as a TMDL implementation strategy. State responsibility also extends to protecting piscivorous birds and mammals. Fish tissue targets that take into account this responsibility may end up remaining relatively protective of high-intake human consumers as well.

4.4. *Effectively protecting beneficial uses*

A critical issue at the interface between state pollution policy and science is the method used to determine actionable risk. In this study and in most similar studies, the mean fish consumption rate is calculated to indicate the relative risk faced by consumers of contaminated fish. In many studies, the 90th or 95th percentile rates are also calculated as a way to track high-intake consumers. Consideration of 95th percentile rates of mercury intake is more protective of most of the population than measures of central tendency, is likely to lead to the most protective public policy, and is the strategy chosen by the Regional Board. The high 95th percentile mercury intake rates calculated for African-American, Southeast Asian, Lao, and Vietnamese put these groups at risk of measurable health effects from mercury consumption. Any policy response and pollution remediation plan (such as a Total Maximum Daily Load under the Clean Water Act) developed to deal with mercury contamination of edible fish in the Delta should include consideration of the 95th percentile rates.

In the staff report accompanying the TMDL and testimony to the Regional Board itself (Shilling, personal observation; CVRWQCB, 2008) staff suggest that the low fish tissue targets ($\sim$0.05 ppm) corresponding to the higher "subsistence" rates (142 g/day) are not realistic and instead suggest targets that are more attainable. In contrast to this assertion, current concentrations of mercury in American shad, rainbow trout, and other species in the Delta and tributary rivers are comparable to 0.05 ppm (Table 1 and unpublished data from the Regional Board). The more attainable targets suggested by the Regional Board (0.24–0.29 ppm; CVRWQCB, 2008) correspond to estimated fish consumption rates of 17.5–32 g/day, which are relatively low compared to fish consumption rates found for certain ethnicities in the present study. Because the estimated consumption rates used as the basis for TMDL standards do not account for high rates of fish consumption among certain groups, the TMDL is unlikely to be protective of beneficial uses and therefore may not be compliant with the Clean Water Act or California's Porter-Cologne Act.

4.5. Fish consumption patterns for health benefits

Balancing fish consumption for health benefits with concerns about contamination requires consideration of type and size of fish, frequency of consumption, and amount consumed. Species-specific contaminant concentrations, means that rates of contaminant intake can depend as much on total fish intake as on the pattern of fish species consumption. However, by changing patterns of consumption, it is possible to retain the value of eating fish from a health point-of-view, while avoiding the neuorological harm from mercury intake (Oken et al., 2005). In this case, consuming fish with lower mercury concentrations (smaller and/or low trophic level) can result in net health benefits (e.g., see Fig. 5). Because it is unlikely that many anglers and communities will stop or reduce fish consumption, patterns of consumption could be addressed. People could contribute to their exposure-reduction by eating fish in the palette of preferred types that are low in contaminants, by catching them from places known to have lower contaminant concentrations, and/or by focusing more on smaller fish that have lower concentrations of bioaccumulative toxins. Because anglers surveyed in this study showed willingness to eat fish species with low concentrations of mercury (e.g., salmon, shad, trout), it is possible that in general, changes in eating patterns are possible. However, ethnic-specific preferences for different species may pose a barrier to this type of change.

4.6. Community responsibility

In other areas where fish contamination has been approached from a public health perspective, the success of changing consumers' behavior has been variable. Based upon our findings, the learning process for this behavioral change is unlikely to originate directly from state agencies; rather trusted community sources (community organizations, family and friends, health providers) and certain mass media are likely to be more effective. This suggests that well-advertized community-based programs that develop and implement policies related to fish consumption behavior will be the most successful model. In the present study, there were inter-ethnic group differences in both the source of recalled warnings about fish consumption and for trusted sources of health information. A single cookie-cutter approach to communication of risk information may not be appropriate for the highly diverse angling communities of California's Central Valley Delta region. An approach that is more likely to reflect the needs and communication pathways of these diverse communities is one originating from the communities themselves and possibly initiated by trusted community organizations and community health providers (Shilling et al., 2008). In a recent study, Castello et al. (2008) provided evidence that the involvement of fishers in fishery management can result in significant improvements in fish populations and fishery quotas. A similar approach to fish contamination where impacted subsistence fishers were involved in solution-building would be a significant improvement over the current approach.

4.7. Environmental justice

The California Bay-Delta Authority has been the entity responsible for coordinating understanding of environmental problems in the Bay-Delta and coordinating and leading responses to these problems. This body has been criticized for its lack of inclusion of environmental justice practices (Shilling et al., 2009), lack of public input, and lack of clear connections between science and policy (Little Hoover Commission, 2005). Fish contamination is very much an environmental justice issue in the Bay-Delta and the Central Valley in general because of disproportionate impacts to the ethnically diverse fish consumers and the lack of involvement of these impacted consumers in decision-making. Community organizations that the authors have collaborated with have expressed interest and have active involvement in decision-making around attainment of target concentrations of mercury in fish. As will probably be the case for effective communication and community education about fish contamination, an effective strategy for attainment of mercury standards would be one that included the knowledge and activities of groups representing the impacted communities.

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