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Environmental Research 99 (2005) 403–412
Environmental Research
www.elsevier.com/locate/envres

Heavy metals in commercial fish in New Jersey

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Received 10 September 2004; received in revised form 6 January 2005; accepted 18 February 2005
Available online 6 May 2005

Abstract

Levels of contaminants in fish are of particular interest because of the potential risk to humans who consume them. While attention has focused on self-caught fish, most of the fish eaten by the American public comes from commercial sources. We sampled 11 types of fish and shellfish obtained from supermarkets and specialty fish markets in New Jersey and analyzed them for arsenic, cadmium, chromium, lead, manganese, mercury, and selenium. We test the null hypothesis that metal levels do not vary among fish types, and we consider whether the levels of any metals could harm the fish themselves or their predators or pose a health risk for human consumers. There were significant interspecific differences for all metals, and no fish types had the highest levels of more than two metals. There were few significant correlations (Kendall tau) among metals for the three most numerous fish (yellowfin tuna, bluefish, and flounder), the correlations were generally low (below 0.40), and many correlations were negative. Only manganese and lead positively were correlated for tuna, bluefish, and flounder. The levels of most metals were below those known to cause adverse effects in the fish themselves. However, the levels of arsenic, lead, mercury, and selenium in some fish were in the range known to cause some sublethal effects in sensitive predatory birds and mammals and in some fish exceeded health-based standards. The greatest risk from different metals resided in different fish; the species of fish with the highest levels of a given metal sometimes exceeded the human health guidance or standards for that metal. Thus, the risk information given to the public (mainly about mercury) does not present a complete picture. The potential of harm from other metals suggests that people not only should eat smaller quantities of fish known to accumulate mercury but also should eat a diversity of fish to avoid consuming unhealthy quantities of other heavy metals. However, consumers should bear in mind that standards have a margin of safety.

Keywords: Fish consumption; Risk; Arsenic; Lead; Mercury; Selenium

1. Introduction

Fish constitute an important source of protein for many people throughout the world, and fish consumption has increased in importance among health-conscious Americans because it provides a healthy, low cholesterol source of protein and other nutrients. Fishing is a also popular pastime (Toth and Brown, 1997; Burger et al., 1992, 1993; Burger, 2002; Knuth et al., 2003), including in urban areas (Burger et al., 2001a, 1999; Ramos and Crain, 2001). Fish provide omega-3 (n-3) fatty acids that reduce cholesterol levels and the incidence of heart disease, stroke, and preterm delivery (Anderson and Wiener, 1995; Daviglus et al., 2002; Patterson, 2002).

At the same time, levels of contaminants in fish are of considerable interest because of potential effects on the fish themselves or the organisms that consume them, including top-level receptors, including people. Contaminant levels, particularly methylmercury (MeHg) and polychlorinated biphenyls (PCBs), are sufficiently high in some fish to cause adverse human health effects

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0013-9351/$ - see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1016/j.envres.2005.02.001

in people consuming large quantities (Stern, 1993; IOM, 1991; Hightower and Moore, 2003; Hites et al., 2004). Methylmercury is reported to counteract the cardioprotective effects (Guallar et al., 2002) and to damage developing fetuses and young children (NRC, 2000). Fish consumption is the only significant source of methylmercury for the public (Rice et al., 2000). Maternal exposures can threaten the fetus because chemicals can be transferred across the placenta to the developing fetus (Gulson et al., 1997, 1998). Several groups have reported a positive relationship between mercury and/or PCB levels in fish, fish consumption by pregnant women, and deficits in neurobehavioral development in children (IOM, 1991; Jacobson and Jacobson, 1996; Lonky et al., 1996; Schantz, 1996; NRC, 2000, Stern et al., 2004, Schantz et al., 2003). There is also a decline in fecundity in women who consume large quantities of contaminated fish from Lake Ontario (Buck et al., 2000).

Much of the increasing concern about the safety of fish revolves around self-caught fish (both sport and subsistence fishing) from freshwater lakes and rivers, which are under consumption advisories in most states (EPA, 2004). Mercury accounts for most of these advisories, although PCBs, chlordane, dioxins, and dichlorodiphenyltrichloroethane are also important (EPA, 1996, 2002). The concern about contaminants in self-caught fish results partly from clear health mandates. States are responsible for issuing consumption advisories and promulgating regulations banning fishing in some waters.

Yet most people obtain their fish from fish markets and supermarkets (Burger et al., 2002b, 2004), making it important to know the levels of contaminants in these fish. Consumers cannot make informed decisions about what species of fish to eat if they do not know how contaminants vary among fish. In this paper, we examine the levels of elemental contaminants in 11 types of fish and shellfish commonly available in supermarkets and fish markets in New Jersey. There are few studies of mercury levels in commercial fish (but see Burger and Gochfeld, 2004) and fewer still that examine the levels of other metals.

Recently the US Food and Drug Administration (FDA, 2001, 2004a) issued a series of consumption advisories based on methylmercury that suggested that pregnant women and women of childbearing age who may become pregnant should avoid eating four types of marine fish, shark, swordfish, king mackerel, and tilefish, and should limit their consumption of all other fish to just 12 ounces per week (FDA, 2001). These recent FDA (2001, 2003) advisories have raised concern about the safety of fish available in supermarkets, yet there are very few data on contaminant levels in commonly available commercial fish, particularly for fish expected to have low levels. This paper partly addresses this deficit.

2. Materials and methods

2.1. Study site

Fish were collected by two methods: (1) a stratified sampling scheme for three target species (flounder, bluefish, and yellowfin tuna) that divided New Jersey into North, Central, South, and Shore regions and (2) a targeted approach in Central New Jersey that included six other types of seafood (Chilean sea bass, cod, croaker, porgie, red snapper, and whiting), shrimp (large and small), and scallops. The former sampling was aimed at examining whether contaminant levels varied by region of the state or type of market, while the latter was aimed at increasing the number of fish and shellfish types examined to test for interspecific differences. These additional species were among the most commonly available in the markets (Burger et al., 2004). We selected upscale and downscale towns in Central New Jersey and then selected two supermarkets and fish markets in each town from New Jersey's Seafood and Fish Index Page (www.ipindex.com/New%20Jersey/NJseafood.html; see Burger et al., 2004).

2.2. Protocol

Our overall protocol was to purchase fish and shellfish from supermarkets and fish markets and take them to the Environmental and Occupational Health Sciences Institute (EOHSI) of Rutgers University for metal analysis. At EOHSI, a 2-g (wet weight) sample of fish tissue was digested in ultrex ultrapure nitric acid in a microwave (MD 2000 CEM), using a digestion protocol of three stages of 10 min each under 50, 100, and 150 pounds/in^2 (3.5, 7, and 10.6 kg/cm^2) at 80 $\times$ power. Digested samples were subsequently diluted in 100 ml deionized water. All laboratory equipment and containers were washed in 10% HNO_3 solution and deionized water rinse prior to each use (Burger et al., 2001b).

Mercury was analyzed by the cold vapor technique using the Portable Zeeman Lumex (RA-915) mercury analyzer, with an instrument detection level of 0.2 ng/g and a matrix level of quantification of 0.002 μg/g. All other metals were analyzed with graphite furnace atomic absorption (GFAA), including arsenic, cadmium, chromium, lead, manganese, and selenium. Instrument detection limits on the GFAA were 0.2 ppb for arsenic, 0.1 ppb for cadmium, 1.0 ppb for chromium, 2.0 ppb for lead, 1.0 ppb for manganese, and 0.5 ppb for selenium. Matrix detection levels were about an order of magnitude higher. All concentrations are expressed in parts per million (ppm = μg/g) of total metal on a wet weight basis. In another study (Burger et al., 2001b) we found that the dry weight ranged from 23% to 33% of the corresponding wet weight (i.e., water content of 67–77%) for 11 types of fish from the Savannah River. Many studies have shown that almost all of the mercury in fish tissue is methylmercury, and 90% is a reasonable approximation of this proportion, which does vary somewhat among fish types and laboratories.

A DORM-2 Certified dogfish tissue was used as the calibration verification standard. Recoveries of 90–110% were accepted to validate the calibration. All specimens were run in batches that included blanks, a standard calibration curve, two spiked specimens, and one duplicate. The accepted recoveries for spikes ranged from 85 to 115%; no batches were outside of these limits. Also, 10% of samples were digested twice and analyzed as blind replicates (with agreement within 15%). For further quality control on mercury, a random subset totaling 12% of samples was sent to the Quebec Laboratory of Public Health. The correlation between the two laboratories was 0.92 ($P<0.0001$).

We used Kruskal–Wallis nonparametric one-way analysis of variance (generating a χ^2 statistic) to examine differences among fish types. We also used ANOVA on log-transformed data with the Duncan multiple range test to identify significant differences among species (SAS, 1995). Nonparametric Kendall correlations were used to examine relationships among metals. The level for significance was designated $P<0.05$.

3. Results

There were no consistent differences in metal levels among the three regions of the state nor as a function of type of market. Thus, the data were combined for the interspecific comparisons. There were interspecific differences in levels of all metals (Table 1). No single type of fish was consistently high for several metals. Flounder had the highest levels of arsenic; tuna had the highest levels of cadmium and mercury; shrimp had the highest levels of lead and manganese; and Chilean sea bass had the highest levels of selenium. The levels varied among species by an order of magnitude for most metals, except for manganese and mercury (Table 1).

There were few significant correlations among metals for the three fish species with the highest sample size (Table 2). That is, knowing that one metal was high (or low) did not predict what the other metals would be. Manganese and lead were the only metals that were positively correlated for all three species with the highest sample sizes. It is still important to have the correlations because, when other similar work is conducted with commercial fish, a pattern may emerge.

4. Discussion

4.1. Interspecific differences in metal levels in commercial fish

There were interspecific differences in levels of metals for all metals. However, the same fish metals did not have the highest values for more than two metals. We suggest that the differences are due to geography, trophic level, size, foraging method/location, and propensity of metals to undergo biomagnification in the food chain. That is, fish that are high on the trophic level might be expected to accumulate higher levels of bioaccumulative metals such as mercury (Campbell, 1994; Fairey et al., 1997; Burger et al., 2001a). Similarly, some metals bioaccumulate with size and age in fish (Phillips et al., 1980; Braune, 1987; Lange et al., 1994; Lacerda et al., 1994; Bidone et al., 1997; Burger et al., 2001b). Thus, it is not surprising that tuna, the largest and potentially oldest fish examined, had the highest levels of mercury (and cadmium) and that Chilean sea bass and bluefish had the next highest (both are also predators, although they are not as large or long-lived as tuna). It is surprising that cod, which are also intermediate-sized predators, did not have higher levels of mercury. All four of these species are mid-water-level predators on small- to intermediate-sized fish.

Flounder are bottom-feeding fish and had the highest levels of arsenic. This is based on a good sample size (55 fish) with small standard errors, suggesting that this reflects the levels in the population. Some commercial flounder are also caught regionally and so might reflect local/regional exposure from runoff.

Examining interspecific differences in fish obtained in markets is challenging because the fish come from many different geographic sources. For example, bluefish and porgies are usually locally caught, cod and flounder may have come from the northern Atlantic or northern Pacific, yellowfin tuna may have come from a wide range of tropical waters, and the shrimp may have been farm-raised or wild-caught. We were usually unable to obtain information from the markets about the sources of their seafood. We found that large shrimp (expected to have higher levels based on size and age) actually had lower levels of manganese and mercury than small shrimp, while small shrimp had an order of magnitude lower level of cadmium than large shrimp.

While sampling by purchasing fish in supermarkets makes it difficult to compare among types and to interpret levels because the geographical sources of the fish are unknown, it is the mix that consumers are exposed to when they purchase fish. Often information is not provided on either the exact species of fish (“Chilean sea bass” and “whiting” can each include several different species) or the catch location (Burger et al., 2004). When sales personnel are asked, they

Table 1
Metal levels (ppm, wet weight) in commercial fish from New Jersey markets: Sample size in parentheses

		Arsenic Mean ± std. err GM	Cadmium Mean ± std. err GM	Chromium Mean ± std. err GM	Lead Mean ± std. err GM	Manganese Mean ± std. err GM	Mercury Mean ± std. err GM	Selenium Mean ± std. err GM
Species	(N)							
Bluefish	(51)	0.26 ± 0.04 0.11 (D)	0.006 ± 0.002 0.003 (B,C)	0.25 ± 0.06 0.08 (A)	0.06 ± 0.01 0.04 (C)	0.23 ± 0.02 0.20 (D)	0.26 ± 0.02 0.23 (B,C)	0.51 ± 0.04 0.45 (C, D)
Chilean sea bass	(7)	1.7 ± 0.3 1.6 (B,C,D)	0.004 ± 0.001 0.002 (C)	0.08 ± 0.02 0.07 (B)	0.11 ± 0.01 0.11 (B,C)	0.16 ± 0.01 0.16 (D)	0.38 ± 0.06 0.35 (B)	1.02 ± 0.1 0.97 (A)
Cod	(7)	2.2 ± 0.5 1.9 (A,B)	0.0005 ± 0.0003 0.00009 (C)	0.34 ± 0.27 0.10 (A)	0.12 ± 0.01 0.12 (B,C)	0.29 ± 0.07 0.26 (C,D)	0.11 ± 0.01 0.11 (C)	0.70 ± 0.13 0.63 (B,C)
Croaker	(14)	1.9 ± 0.2 1.8 (B,C)	0.001 ± 0.0004 0.001 (C)	0.11 ± 0.02 0.09 (B)	0.09 ± 0.01 0.08 (B,C)	0.70 ± 0.23 0.38 (A,B)	0.14 ± 0.02 0.13 (B,C)	0.77 ± 0.1 0.69 (A,B,C)
Flounder	(55)	3.3 ± 0.4 2.4 (A)	0.01 ± 0.002 0.01 (B,C)	0.31 ± 0.09 0.09 (A)	0.06 ± 0.01 0.04 (C)	0.26 ± 0.03 0.21 (C,D)	0.05 ± 0.001 0.04 (C)	0.31 ± 0.03 0.26 (D, E)
Porgie	(16)	1.8 ± 0.17 1.7 (B,C)	0.004 ± 0.001 0.002 (C)	0.14 ± 0.046 0.08 (A)	0.14 ± 0.017 0.13 (B,C)	0.59 ± 0.09 0.45 (B,C)	0.10 ± 0.01 0.08 (C)	0.95 ± 0.1 0.86 (A,B)
Red snapper	(4)	0.23 ± 0.04 0.22 (D)	0.002 ± 0.001 0.001 (C)	0.15 ± 0.10 0.09 (A)	0.12 ± 0.01 0.12 (B,C)	0.15 ± 0.01 0.15 (D)	0.24 ± 0.01 0.24 (B,C)	0.91 ± 0.1 0.90 (A,B)
Scallops	(12)	0.81 ± 0.04 0.80 (B,C,D)	0.02 ± 0.003 0.02 (A,B)	0.04 ± 0.01 0.03 (B)	0.34 ± 0.1 0.22 (A)	0.11 ± 0.01 0.11 (D)	0.01 ± 0.001 0.01 (C)	0.05 ± 0.01 0.05 (E)
Shrimp (small)	(12)	0.53 ± 0.1 0.51 (C,D)	0.00013 ± 0.0001 0.00002 (D)	0.04 ± 0.01 0.03 (B)	0.29 ± 0.05 0.24 (A)	0.98 ± 0.3 0.57 (A)	0.02 ± 0.001 0.01 (C)	0.16 ± 0.03 0.14 (E)
Shrimp (large)	(12)	0.79 ± 0.1 0.57 (B,C,D)	0.004 ± 0.002 0.001 (C)	0.03 ± 0.01 0.03 (B)	0.17 ± 0.02 0.15 (B)	0.37 ± 0.13 0.24 C,D	0.01 ± 0.01 0.01 (C)	0.23 ± 0.03 0.19 (E)
Whiting	(16)	1.9 ± 0.4 1.4 (B,C)	0.009 ± 0.005 0.008 (B,C)	0.07 ± 0.014 0.05 (B)	0.09 ± 0.011 0.08 (B,C)	0.21 ± 0.03 0.19 (D)	0.04 ± 0.004 0.03 (C)	0.93 ± 0.1 0.72 (A,B)
Yellow fin tuna	(50)	1.0 ± 0.1 0.87 (B,C,D)	0.03 ± 0.005 0.02 (A)	0.20 ± 0.05 0.07 (A)	0.04 ± 0.01 0.02 (C)	0.15 ± 0.01 0.12 (D)	0.65 ± 0.1 0.44 (A)	0.75 ± 0.1 0.66 (A,B,C)
χ^2 (p)		159 (0.0001)	127 (0.0001)	30(0.002)	124 (0.0001)	73 (0.0001)	207 (0.0001)	145 (0.0001)

Shown are arithmetic mean with standard error, and geometric mean (GM). Letters that differ are significantly different among species.

usually have no idea where the fish came from and often do not know whether they were wild or farm-raised.

4.2. Comparison with FDA's total diet study

The US Food and Drug Administration conducts a Total Diet study based on a market basket survey of over 300 food types analyzed for both nutrient and toxic elements among other analytes. Data are available for arsenic, cadmium, lead, manganese, mercury, and selenium for canned tuna, fish sticks, haddock, shrimp, and salmon (FDA, 2004b). The data base reports the number of samples, number of nondetectables, mean, standard deviation, median, and maximum values for each analyte. The data underestimate the concentrations, because the analysis arbitrarily substitutes zero for

Table 2
Correlations among metals for three commercial fish species

	Bluefish	Flounder	Tuna
Arsenic with			
Chromium	0.24 (0.01)	NS	NS
Manganese	−0.21 (0.03)	0.19 (0.04)	NS
Mercury	NS	0.26 (0.007)	NS
Lead	−0.23 (0.02)	NS	NS
Selenium	−0.24 (0.01)	NS	NS
Cadmium with			
Chromium	NS	0.20 (0.03)	NS
Mercury	NS	NS	0.34 (0.0007)
Chromium with			
Mercury	NS	0.37 (0.0001)	NS
Lead	−0.25(0.01)	NS	−0.25 (0.01)
Selenium	−0.34 (0.0006)	NS	−0.20 (0.05)
Manganese with			
Lead	0.36 (0.002)	0.19 (0.05)	0.34 (0.007)
Lead with			
Selenium	0.22 (0.03)	NS	NS

Only significant correlations are given (Kendall tau).

all samples below the detection level rather than using more common conventions for left-censored data such as half the detection level. However, since most fish samples were above the detection limit, this source of bias was probably not important.

Our results for arsenic range from 0.23 to 3.3 ppm compared with FDA's 0.56 for salmon up to 5.54 ppm in haddock. Our cadmium results frange from 0.0001 to 0.01 ppm compared to <0.01 to 0.21 for FDA results. Our lead results were very similar across fish species with only a three-fold difference of 0.04–0.12, while FDA fish results were mainly in the 0.001–0.003 range. Both studies found an order of magnitude higher lead values in shrimp than in fin fish. Our manganese results were in the range of 0.1–1.0 (higher in shrimp than in fish), compared to FDA's results in the 0.07–0.16 range (not higher in shrimp). Mercury levels tended to be higher in the New Jersey sample (fish mainly in the 0.05–0.6 ppm range) compared to 0.004–0.16 in the FDA study. The two studies found very similar results for selenium (mainly in the 0.3–1.0 ppm range).

4.3. Risk to the fish and predators who consume them

Contaminants in fish can pose a health risk to the fish themselves, to their predators, and to humans who consume them. Although arsenic poisoning can occur, it is relatively rare in wildlife (Eisler, 1994). Most arsenic in seafood is organic arsenic which is less toxic than inorganic arsenic species (Eisler, 1994; ATSDR, 2000). Most laboratory studies dealing with chronic exposure do not examine the levels in the tissues consumed that result in lethality or other adverse effects. This suggests a critical need for studies that relate levels in prey organisms, levels in tissues, and dose to adverse effects. Arsenic is interesting because most studies deal with inorganic arsenic, yet the arsenic in fish is mainly organic (Eisler, 1994), making it difficult to examine effects.

Adverse effects from cadmium can occur in fish with dietary levels of 0.1 ppm (Eisler, 1985). Whole-body burdens of cadmium in fish from the United States overall average 0.03 ppm (wet weight), with the maximum being 0.22 ppm (Schmitt and Brumbaugh, 1990); current levels can range as high as 0.54 ppm in free-ranging fish (Burger et al., 2002a). Birds may be less sensitive to cadmium in their diet than mammals but are adversely affected at levels of 1.0 ppm in their diet (Eisler, 1994). Thus, there may be some cause for concern for top-level avian predators that eat some of these fish, perhaps as carrion.

Levels of 10 ppm of chromium in the diets of birds are considered to cause adverse effects in some wildlife species (Eisler, 1986). Levels in our commercial fish were well below these levels, suggesting that predators or scavengers would not be at risk from chromium if they ate them in the wild.

Lead is a neurotoxin that causes behavioral deficits in vertebrates (Weber and Dingel, 1997) and can cause decreases in survival, growth rates, learning, and metabolism (Eisler, 1988; Burger and Gochfeld, 2000). Levels of 50 ppm in the diet can cause reproductive effects in some predators, and dietary levels as low as 0.1–0.5 ppm are associated with learning deficits in some vertebrates (Eisler, 1988). In this study, the levels of lead in some species averaged within this range, suggesting that some sensitive predatory vertebrates may be impacted by the levels of lead in these fish.

There are remarkably few studies on the dietary effects of manganese on predators or on the adverse effects associated with particular tissue levels on the organisms themselves. Of the metals examined in this study, manganese is in most need of extensive laboratory and field studies. Although it is an essential trace element, it also exhibits toxicity (Burger and Gochfeld, 1995). Manganese, selenium, and chromium are essential trace elements, although all can cause toxicity at high doses. It is important that restrictions on intake not conflict with recommended dietary intake.

Mercury concentrations of 5 ppm (wet weight) in fish muscle can be associated with emaciation, decreased coordination, loss of appetite, and mortality in fish themselves (Eisler, 1987), while concentrations of 15 ppm are required for adverse effects in predators that eat the fish (Spry and Wiener, 1991; Wiener and Spry, 1996). In this study, none of the mercury concentrations reached these levels, suggesting that mercury does not pose a problem for the fish themselves. However, sensitive birds that consume fish can exhibit effects at dietary mercury concentrations of

0.05–0.5 ppm; for sensitive mammals, harmful effects occur at dietary levels of 1.1 ppm (Eisler, 1987; WHO, 1990, 1991). In this study of commercial fish, levels of mercury averaged up to 0.38 ppm in Chilean sea bass (a fish small enough to be eaten by predators) and up to 0.65 in tuna (a species generally large enough to have relatively few predators). Thus, it appears that some sensitive birds or mammals might be adversely affected if they consume the fish with the highest mercury levels. However, it is unlikely that any predators (such as birds or most mammals) would always obtain the largest fish (with the highest levels) to eat.

Although selenium is an essential micronutrient, it can be toxic at high levels (Coyle et al., 1993). A concentration of about 1 ppm (wet weight) in prey is the threshold for selenium toxicity in some fish, while muscle concentrations of 2.6 ppm are associated with adverse effects in the fish themselves (Lemly, 1993a, b); all of our values were well below this level, suggesting that selenium is not a problem for the fish themselves. However, selenium concentrations of 1 ppm in food are toxic to other wildlife that consume them (Lemly, 1993a), suggesting that some of the fish in this study (Chilean sea bass, porgie, red snapper, and whiting) may pose a problem to their predators.

4.4. Standards and guidelines for humans

We were surprised to find no uniform source of guidance or standards for most metal residues in fish tissue. There is no single reference for acceptable levels of most metals in marine or freshwater fish, whether self-caught or commercial. The following information was compiled from documents of the Codex Alimentarius Commission assembled under the aegis of the United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO) and from various national and state sources, including the US Environmental Protection Agency (EPA). Many of the standards were last revised in the early 1980s. The US FDA has an action level for methylmercury in fish (FDA, 2001) but not for any other metals; the level of 1.0 mg/kg (ppm wet weight) is a regulatory action level rather than a risk level. Originally the FDA had set 0.5 ppm as the action level, comparable to many other nations (see review in Burger and Gochfeld, 2004). The United Kingdom and the European Union have established criteria for certain metals in fish (e.g., the level for mercury is 0.5 ppm in edible fish, with up to 1 ppm allowed for certain "exempt" predatory fish species). China has set standards for methylmercury in canned fish (ppm wet weight) of 0.5 ppm (except that 1 ppm is allowed in shark, sailfish, tuna, pike, and other high-mercury level fish).

Understandably, standards change slowly in a country, and they take a long time to change across countries. In 1982, the European Commission set an Environmental Quality Standard for mercury; the mean concentration in mercury of a representative sample of fish shall not exceed 0.3 mg/kg (wet weight). The US EPA promulgated this value as an ambient water quality standard in EPA, 2001 (see http://www.epa.gov/fedrgstr/EPA-WATER/2001/January/Day-08/w217.htm).

There is relatively little information for other metals. The EPA has set arsenic tissue residues of 1.3 ppm fresh weight in freshwater fish as the criterion for human health protection (Eisler, 1994). Standards for cadmium are also sparse. Neither the United States nor the United Kingdom have published a standard or an action level for cadmium in fish. The Codex Alimentarius (2002) has standards or proposed standards for cadmium in mollusks (1.0 ppm) and crustacea (0.5 ppm). For cadmium the Joint Monitoring Programme established under the Oslo and Paris Commissions set a guideline of 0.2 ppm in fish and below 2 ppm in mussels.

The Codex Alimentarius (2002) specifies levels for lead in fish (0.2 ppm) and in mollusks (formerly 0.5 ppm but discontinued, Codex Alimentarius (2003)), but does not generally do so for most other metals. Some standards distinguish fish from crustacea and shellfish; others do not. Yet the Codex mission includes coordination of all food standards across nations.

Although the EPA Integrated Risk Information System (IRIS) data base does not specify values for fish or food in general, some relative inferences can be drawn by comparing the chronic oral reference doses. This is the dose (expressed in mg/kg-body weight/day) that can be consumed on a daily basis over a 45-year time span. "In general, the RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." (EPA IRIS data base).

Table 3 lists the EPA Reference Dose for metals derived from its IRIS data base. EPA has declined to set an RfD for lead because it finds no evidence of a threshold below which a nonharmful intake could be "allowed." The California Office of Environmental Health Hazard Assessment (OEHHA) has also set action levels for classifying waters as contaminated. The compilation of international metal-in-fish standards yields minimum, maximum, and median values (Nauen, 1983).

The dose of a toxic metal that one obtains from fish depends on the quantity of fish consumed. Based on a single weekly 8-ounce (228-g) meal, we calculated (Table 4) an "allowable concentration," the total metal intake per 8-ounce meal, and the average daily dose (mg of metal per kg of body weight per day). These allowable concentrations have been calculated to yield a dose just below the RfD (Table 4).

Table 3
EPA Reference Dose (risk-based), California Action level, and published international standards (compiled by FAO in 1982) www.swrcb.ca.gov/programs/smw/docs/9597/appendix_v.pdf

	EPA Chronic Oral RfD (mg/kg/day)	OEHHA California Action Level (μg/g)	International Standards (range) (μg/g)	International Standards (median) (μg/g)
Arsenic	0.0003	1.0	0.1–5.0 ($n = 11$)	1.4
Cadmium	0.01	3.0	0.05–2 ($n = 10$)	0.3
Chromium III	1.5	None	1.0 ($n = 1$)	1.0
Chromium VI	0.003	Not listed separately	—	—
Lead	None set	Not listed	0.5–10.0 ($n = 19$ mode = 2.0)	2.0
Manganese	0.14	Not listed	Not listed	Not listed
Mercury	0.0001	0.3	0.1–1.0 ($n = 28$, mode = 0.5)	0.5
Selenium	0.005	20	0.3–2.0 ($n = 3$)	2.0
Zinc	0.3	None	40–100 ($n = 6$)	50

Action levels and standards are given as μg/g (ppm) (wet weight basis) in fish tissue. The Codex Alimentarius has set a standard for lead in fish of 0.2 mg/kg. FAO published "Compilation of Legal Limits for Hazardous Substances in Fish and Fishery Products" (Nauen, 1983).

Table 4
Concentration in fish that would result in an exposure just at the Reference Dose (RfD) assuming a single 8-ounce fish meal per week

	Concentration in fish (mg/kg = ppm) (wet weight)	Amount consumed in one 8-oz (228 g) meal	Daily intake in mg/kg/day (compare with RfD in Table 3)
Arsenic[a]	0.6	1.37	0.00028
Cadmium	22	5.0	0.01
Chromium III	3200	730	1.49
Chromium VI	6	1.4	0.0028
Lead	No RfD set	NA	NA
Manganese	300	68	0.14
Mercury	0.22	0.05	0.0001
Selenium	10	2.28	0.0046
Zinc	600	137	0.28

[a]Assumes all is inorganic arsenic.

4.5. Exceedances in the commercial fish examined

Mercury is the best studied metal in fish tissue and is the one for which the US FDA has set an action level (1.0 ppm as methylmercury). While none of the species in this study had average mercury levels of 1.0 ppm, some individuals exceeded this value (discussed fully in Burger and Gochfeld (2004). Not surprisingly, yellowfin tuna had the highest geometric mean of 0.44 ppm (arithmetic mean 0.65 ppm) with 22% of individuals exceeding 1.0 ppm (allowing for an average methylmercury content of 90% of the total mercury, 18% of the tuna exceeded 1.0 ppm methylmercury). Most nations use a standard of 0.5 ppm, which was exceeded by 42% of yellowfin samples in our study; however, some nations allow an exemption for predatory fish (1 ppm), moreover, using the arithmetic average concentration, which represents the cumulative exposure better than the median or the geometric mean. We use the geometric mean to obtain better representation of levels in the fish by compensating for the skewing effect of the few fish with very high levels. But consumers of fish eat those fish and are exposed occasionally to those high levels. Thus, a person consuming 8 ounces (228 g) of bluefish, Chilean sea bass, or yellowfin tuna in a week would exceed the EPA Reference Dose for mercury.

Mercury in fish has received considerable attention, and one of the objectives of this study was to examine other metals that might be of concern. The geometric mean for arsenic in some commercial fish that we examined (Chilean sea bass, cod, croaker, flounder, porgie, and whiting) exceeded the OEHHA guideline of 1 ppm; some exceeded the median international standard of 1.4 ppm. However, a person could eat an 8-ounce fish dinner of any of these species, even cod, without exceeding the RfD. Remarkably, some of the fish in this study had arsenic levels of over 1.3 ppm (Chilean sea bass, croaker, flounder, porgie, and whiting), suggesting a need for a wide-scale evaluation of the effect of arsenic from commercial fish. Although much of the arsenic in shellfish is organic (lower toxicity), the proportion of organic vs total arsenic in finfish is not well characterized. Surprisingly, most of the laboratory data on effects are for inorganic arsenic (Eisler, 1994), making the conclusion that "humans beings appear to be one of the most susceptible species" (Eisler, 1994) difficult to interpret.

For cadmium the geometric mean in commercial fish was far below the median international standard of 0.3 ppm and was even below the lowest standard of 0.05 ppm for most species. Only yellowfin tuna and scallops (geometric mean of 0.02 ppm) exceeded this level. Seven of 11 samples exceeding 0.5 ppm were tuna.

Lead is one metal with a clear Codex Alimentarius standard of 0.2 ppm, which is lower than the lowest international standard at 0.5 ppm. In this study, levels of lead averaged above 0.2 ppm for scallops and shrimp. Average lead concentrations in small shrimp and scallops, but none of the finfish, exceeded this value. Twelve fish samples (3 flounder, 4 porgie, 3 bluefish, 1 tuna, and 1 croaker) exceeded 0.2 ppm, as did 4 scallop and 12 shrimp samples. We believe that lead levels bear further study in fish and shellfish.

Selenium is both toxic and essential. The few international standards range from 0.3 to 2.0 ppm. The mean levels of selenium in most species exceeded the former, but none exceeded 1.0 ppm as a mean value. Only one whiting reached 2.0 ppm selenium.

For chromium, an essential trace element which is not particularly abundant in fish tissue, there are virtually no toxicity standards. Average chromium levels were at least an order of magnitude below the lowest international standard (Hong Kong at 1.0 ppm). Several individual fish exceeded 1.0 ppm, and one bluefish and three flounder exceeded 2 ppm.

Manganese, likewise, is an essential element, for which we did not find standards in fish. Since manganese is subject to some internal regulation, it is probably not surprising that the geometric mean values are rather uniform across species, ranging from 0.15 to 0.45 ppm. Small shrimp had the highest levels of manganese. Overall only 5% of the samples exceeded 1 ppm, but the highest samples were shrimp and croaker.

4.6. Risk and the public

From a public health perspective, people are faced with making choices in markets about what fish to buy based on available knowledge, which usually includes identification of species or at least type, and knowing which kinds of fish have low levels of contaminants. Except for methylmercury (see FDA, 2003; Burger and Gochfeld, 2004) and PCBs, such information is generally unavailable.

Some markets, fish markets particularly (Burger et al., 2004), provide information on the locations where some fish were caught. This is more difficult when fish come from large suppliers and is nearly impossible with species such as yellowfin tuna that can be caught over a wide area of the ocean. And, as indicated above, even the name of the fish for sale may be misleading.

The data in this paper suggest that some species have relatively low levels of contaminants of concern, such as mercury, lead, and cadmium (e.g., flounder, porgie, and whiting). Small shrimp had higher levels of lead and manganese than larger shrimp. However, the same fish did not have either the highest levels of all metals or the lowest levels. Thus the greatest risk from different metals resided in different fish. Further, the species of fish with the highest levels of a given metal sometimes exceeded the guidance or standards for that metal. This suggests that the risk information given to the public, which mainly deals with the risk from mercury (and PCBs), does not present a complete picture. The potential of harm from other metals suggests that people not only should eat smaller quantities of fish known to accumulate mercury but also should eat a diversity of fish to avoid consuming unhealthy quantities of other heavy metals. Consumers should bear in mind that standards have a margin of safety but, conversely, that action levels are not necessarily risk based.

Contaminant information on this broad range of metals in commercial fish is generally not available to the public. Thus, we suggest that there is a need for more information on contaminant levels in fish from specific regions of the world and that the public should be provided with information on exact species identification, collection location, and growth method (farmed or wild-caught). Then data on contaminant levels in fish from particular regions of the world could allow people to make informed decisions about which fish to eat to reduce their risk from the contaminants.

For arsenic, bluefish tended to have the lowest levels and flounder the highest. Overall, 35% of samples exceeded 1.4 ppm, with several flounder samples exceeding 5 ppm, confirming the need for a better understanding of the ecodynamics and toxicokinetics of arsenic.

Acknowledgments

We thank A. Stern for his participation in other aspects of this study, T. Shukla and C. Dixon for laboratory assistance, and C. W. Powers, B. Goldstein, and B Friedlander for comments on the research. The research was supported by the Office of Science, Research, and Technology of the New Jersey Department of Environmental Protection, NIEHS Center Grant (ESO 5022), Consortium for Risk Evaluation with Stakeholder Participation (Department of Energy, Nos. DE-FC01-95EW55084, DE-FG 26-00NT 40938), and EOHSI. The views expressed in this paper are solely those of the authors.

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