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Risk to consumers from mercury in Pacific cod (*Gadus macrocephalus*) from the Aleutians: Fish age and size effects

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Abstract

While there has been considerable attention devoted to the risks to high level consumers from mercury in freshwater fish, relatively little attention has been devoted to saltwater fish. Although the U.S. Food and Drug Administration has issued advisories based on mercury for four saltwater species or groups of fish, there are few data on mercury levels generally, or on the risk these levels pose to the fish themselves or to consumers of marine fish. We examined total mercury levels in liver and muscle of Pacific cod (*Gadus macrocephalus*) collected from the northern Pacific and Bering Sea waters around Nikolski, Amchitka, and Kiska Islands in the Aleutian Chain (Alaska). We were interested in whether there were differences in mercury levels as a function of location, weight, length, and age of the fish, and what risk mercury posed to the food chain, including people. Fish were aged by examining otoliths, and we measured selenium because of its reported protective effects against mercury. Regression models indicated that 27% of the variation in levels of mercury was due to tissue examined and age, while 67% of the variation in levels of selenium was due to tissue, length, and age. Mercury levels were significantly higher in the muscle than the liver, and the reverse was true for selenium. Mercury levels were negatively correlated with selenium levels, and positively correlated with length, weight, and age. There were no gender differences in mercury or selenium levels. The mean levels of mercury in muscle (0.17 ppm wet weight) are within the range known to cause adverse effects in sensitive birds and mammals. Only 4% of the Pacific cod samples had mercury levels above 0.5 ppm, the action level promulgated by many states and countries, and none were above the 1 ppm action level of the U.S. FDA.
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1. Introduction

Fish are an important source of protein as well as recreation for many people (Toth and Brown, 1997; Burger, 2000, 2002), and fish are an important component of aquatic ecosystems, both freshwater and marine. High fishing rates occur in a wide range of cultures, including urban areas (Burger et al., 1999, 2001a, b; Bienenfeld et al., 2003), among Native Americans (Harris and Harper, 1998;

Burger, 1999), and in other parts of the world (Burger et al., 2003). Fish are an excellent, low-fat source of protein and provide many benefits, such as contributing to low blood cholesterol (Anderson and Wiener, 1995). Fish contain omega-3 (n-3) fatty acids that reduce cholesterol levels and the incidence of heart disease, stroke, and pre-term delivery (Daviglus et al., 2002; Patterson, 2002).

The levels of mercury in fish, however, are of considerable interest because of potential effects on the fish themselves, and on the top-level predators that consume them, including people (NRC, 2000; Consumer Reports, 2003). A major source of methylmercury for fish is from mercury that has been methylated after atmospheric transport and precipitation or runoff, followed by food

chain biomagnification (Monteiro et al., 1996; Downs et al., 1998). Fish consumption is the only significant source of methylmercury exposure for the public (Rice et al., 2000). Levels of methylmercury (MeHg) are sufficiently high in some fish to cause adverse human health effects in people consuming large quantities (IOM, 1991, 2006; Grandjean et al., 1997; Gochfeld, 2003; Hightower and Moore, 2003; Hites et al., 2004). Communities that rely on fish intake for daily nutrient sustenance may be at risk from chronic, high exposure to methylmercury (Grandjean et al., 1997) as well as other persistent organic pollutants. Methylmercury is reported to counteract the cardioprotective effect of omega-3 (Guallar et al., 2002; Rissanen et al., 2000; Salonen et al., 1995) and to damage developing fetuses and young children (NRC, 2000).

Prenatal exposure to methylmercury leads to significant behavioral deficits in infants, which led the World Health Organization to reduce the provisional daily intake of methylmercury from 0.47 to 0.23 µg/kg body weight/day (JECFA, 2003). At the same time, the U.S. Food and Drug Administration (U.S. FDA, 2001, 2005) issued a series of consumption advisories based on methylmercury that suggested that pregnant women and women of childbearing age who may become pregnant should limit their fish consumption, should avoid eating four types of marine fish (shark, swordfish, king mackerel, tilefish), and should also limit their consumption of all other fish to just 12 ounces per week (U.S. FDA, 2001, 2003). Considerable attention has been devoted to mercury levels in a wide range of freshwater fish, where lake pH can account for up to 70% of the variation in mercury levels (Haines et al., 1992, 1994; Watras et al., 1998), but less research has been devoted to marine ecosystems. Also risks from freshwater fish consumption are better studied than risks from marine fish (Legrand et al., 2005). This raises a question about the safe intake of large predatory marine fish.

In this study we examined the levels of total mercury and selenium in Pacific cod (*Gadus macrocephalus*) from the Aleutian Islands of Alaska, and were particularly interested in the potential risk from Pacific cod to top level predators, including humans. We report on selenium levels because selenium is thought to be protective for mercury exposure (Satoh et al., 1985). We were also interested in whether there were differences in mercury levels as a function of age and size of fish. Fish are an important dietary item of the people living in subarctic and Arctic regions (Berti et al., 1998; Egeland et al., 1998; Duchesne et al., 2004; Duhaime et al., 2004; Hansen et al., 2004), and contaminants are a concern (Chan and Receveur, 2000). This is especially true for people living on oceanic islands, such as the Aleutian and Pribilof Islands in the northern Pacific/Bering Sea region (APIA, 2002). Interviews with the residents of the Aleutian Chain indicate that 30–90% of the food consumed is subsistence food (Patrick, 2002), and Pacific cod is one of their preferred foods (APIA, 2002; Patrick, 2002; Hamrick and Smith, 2003). Since some of the fish analyzed in this report were caught by Aleut fishermen, the

fish represent those that would be consumed by subsistence people. Aleuts also cook whole fish in stews and soups.

Pacific cod are 1 of the top 25 commercially important species of the approximately 450 species of fish, shellfish, and crustacean species in the region (NRC, 1996). They are mainly bottom dwellers, broadly distributed in the North Pacific, and are common at depths of up to 300 m (mainly 50–300 m), particularly on the continental shelf and upper slope (Bakkala, 1984; Allen and Smith, 1988). Pacific cod migrate seasonally between the continental slope/shelf and along the continental slope (Simenstad et al., 1977). They range in age up to 25 years (Merrell, 1977; Munk, 2001), and are associated with Pacific halibut (*Hippoglossus stenolepis*) and other flounders (Simenstad et al., 1977). Pacific cod feed on benthic epifauna, shrimps and crabs, and juvenile fish, such as pollock (*Theragra chalcogramma*, Hood and Calder, 1981); in some places they eat mainly fish and crabs (Tokranov, 1992). Tokranov (1992) found that nearly 70% of the diet of Pacific cod was pollock, and the relative percent increased with size of the Pacific cod. Pacific cod are relatively high on an index of trophic level for the Bering Sea (Mito et al., 1999).

Pacific cod are eaten by larger fish such as halibut, by fur seals and whales, and of course, by people. Pacific cod were one of the seven species making up the bulk of the regional commercial fishery by the early 1980s, and Merrell (1977) correctly predicted that catches would continue to increase. The catch of Pacific cod in the eastern Bering Sea increased from the early 1960s to over 180 t by the late 1980s (NRC, 1996), and it remains an important commercial fish today. For example, in 2004, the catch for the Bering Sea/Aleutian Islands/Gulf of Alaska was 253,000 t (NMFS, 2007). Cod accounted for 11% of the biomass, and 16.4% of product value of the Alaskan ground fishery (NMFS, 2007).

2. Methods

Pacific cod were collected from Nikolski, Amchitka, and Kiska Islands, located in the Aleutian Chain (Fig. 1). These islands are approximately 1200–1500 km west of the tip of the Alaskan Peninsula. The latter two islands are part of a National Wildlife Refuge that was established in 1913 by executive order of President Taft (ATSDR, 2004). Nikolski is the oldest continuously inhabited community in North America.

Under appropriate permits from the State of Alaska's Department of Fish and Game (# CF-04-043), Pacific cod were collected in June and July 2004 by rod and reel or by trawling. At Amchitka and Kiska, small skiffs were based on the *Ocean Explorer*, while land-based skiffs were deployed at Nikolski. Fish were also collected between Amchitka and Kiska by trawling on the *Gladiator*, chartered by the National Marine Fisheries Service (NMFS). Pacific cod were collected by T. Stamm near Nikolski in May of 2005 using rod and reel from a skiff. Most fish were part of research by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) to examine radionuclide levels in marine biota for the Department of Energy (Powers et al., 2005).

While on the *Ocean Explorer*, we fished in the same manner and places as the local Aleut fishermen who were on the expedition. The *Gladiator* was conducting the Bottom Trawl Survey of the Aleutian Islands for NOAA/NMFS (National Oceanic and Atmospheric Administration), and Pacific cod samples were collected by a CRESP researcher from these trawls. Fish were immediately measured, weighed, and dissected, and samples of kidney, liver, and muscle were frozen for later analysis. Otoliths
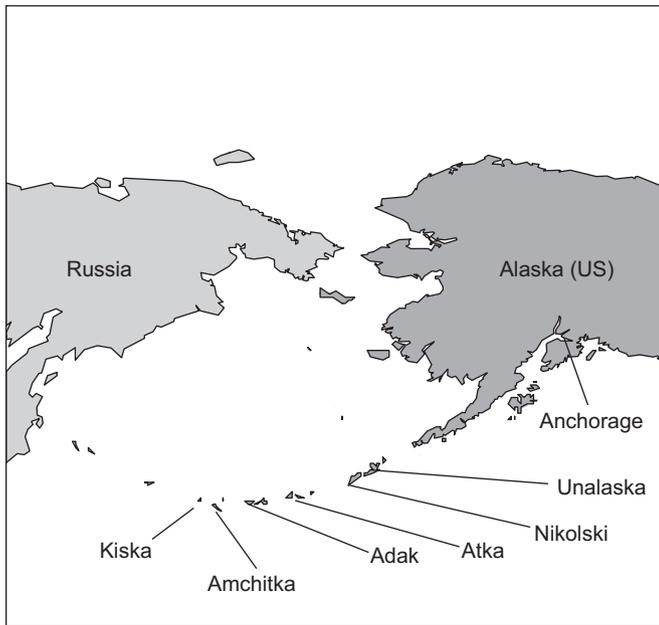
Fig. 1. Map showing the locations of sampling locations for Pacific cod.

were removed from 46 Pacific cod for later aging by Delsa Anderl of NOAA. Liver and kidney were collected as indicators of potential risk to the fish themselves, and muscle was taken as an indicator of risk to consumers, including humans.

Fish were shipped frozen 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 per square inch (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., 2001a).

Mercury was analyzed by the cold vapor technique using the Perkin Elmer FIMS-100 mercury analyzer, with an instrument detection level of 0.2 ng/g, and a matrix level of quantification of 0.002 µg/g. Selenium was analyzed by graphite furnace atomic absorption, with Zeeman correction. All concentrations are expressed in parts per million (ppm = µg/g) on a wet weight basis. 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, but not by age of the fish (Lansens et al., 1991). However, Bloom (1991) reported that over 95% of mercury present in fish is methylmercury, and that lower levels may have been biased by analytical and homogeneity variability.

A DORM-2 Certified dogfish tissue was used as the calibration verification standard. Recoveries between 90% and 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. Ten percentage of samples were digested twice and analyzed as blind replicates (with agreement within 15%). For further quality control on mercury, our laboratory periodically runs a random subset of samples in the Quebec Laboratory of Public Health; the correlation between the two laboratories is over 0.90 ($P < 0.0001$, see Burger and Gochfeld, 2004).

Multiple regression procedures were used to determine if tissue, length, weight, or age contributed to explaining the variations in amount of mercury in samples (PROC GLM, SAS, 1995). The procedure adds the variable that contributes the most to the R^2, then adds the next variable

that increases the R^2 the most, continuing until all significant variables are added. Thus variables that vary co-linearly are entered only if they add independently to explaining the variation. We used Kruskal–Wallis non-parametric one-way analysis of variance (generating a χ^2 statistic) to examine differences among tissues and size measurements. We also used ANOVA with Duncan Multiple Range test on log-transformed data to identify the significant differences (SAS, 1995). Kendall correlations were used to examine relationships among metals and size variables. The level for significance was designated as $P < 0.05$.

3. Results

The best regression models accounted for 27% ($r^2 = 0.27$) of the variation in mercury levels using tissue (muscle vs liver) and age, while 67% of the variation in selenium levels was explained by tissue, length, and age (Table 1). Location did not enter as a significant variable in the models for mercury.

Mercury levels ranged from 0.008 to 0.86 ppm in muscle, but ranged up to 1.25 ppm in the liver (Table 2). Although the average mercury levels were higher in the muscle than liver, the differences were relatively small. However, the mean selenium levels were nearly an order of magnitude higher in the liver than the muscle, and ranged up to 4.0 ppm (Table 2). Table 3 gives the percent of Pacific cod samples that were above various recognized action levels (see discussion below).

Table 1
Models for differences in metal in Pacific cod collected from Alaska

	Mercury	Selenium
Model		
F	8.40	46.00
df	3	3
P	0.0001	0.0001
r^2	0.27	0.67
Factors entering F (P)		
Tissue	16 (0.0001)	171 (0.0001)
Length	NS	4 (0.06)
Weight	NS	NS
Age	5 (0.03)	5.5 (0.02)

NS = not significant.

Table 2
Levels of mercury and selenium (ppm, wet weight) in Pacific cod from the Aleutians (Arithmetic mean + standard error)

	Muscle	Liver	$\chi^2(P)$
Sample size	140	141	
Mercury			
Arithmetic mean	0.17 ± 0.01	0.11 ± 0.01	29 (0.0001)
Geometric mean	0.13	0.08	
Range	0.008–0.86	0.014–1.25	
Selenium			
Arithmetic mean	0.18 ± 0.01	1.6 ± 0.06	203 (0.0001)
Geometric mean	0.17	1.38	
Range	0.009–0.602	0.068–4.005	

Mercury levels in muscle were more strongly correlated with age than weight, although the differences were not great (Table 4). Age was more strongly correlated with length than with weight. While mercury levels and age were positively correlated in muscle, they were not correlated in liver (Table 4). There were no significant correlations for selenium as a function of size or age in muscle, but there were significant negative correlations of with weight ($P < 0.0001$) and nearly significant ($P < 0.08$) in the liver (Table 4). Mercury and selenium were ($r = 0.12$ in muscle and 0.16 in the liver).

There were no significant gender differences in mercury or selenium levels.

4. Discussion

4.1. Mercury levels and trophic levels

Several factors affect mercury levels in fish, including trophic level, size, and age. Mercury levels are generally higher in higher trophic level fish (Jackson, 1991; Watras et al., 1998; Wiener et al., 2003). While juvenile Pacific cod can be eaten by a range of larger predatory fish, adult Pacific cod are generally too large to be prey although they can be eaten by large halibut, seals, and whales. Adult Pacific cod are relatively high on the food chain; they feed on benthic epifauna, shrimps and crabs, and juvenile fish, such as pollock (*T. chalcogramma*, Hood and Calder, 1981), although in some places they eat mainly fish and crabs (Tokranov, 1992). Tokranov (1992) found that nearly 70% of the diet of Pacific cod was pollock, and the relative percent increased with size of the cod. We also found adult pollock in the stomachs of some of the Pacific cod we collected. Pacific cod are relatively high on an index of trophic level for the Bering Sea (Mito et al., 1999).

Juvenile Pacific cod live in the kelp and eelgrass communities near shore (Dean et al., 2000), while older cod move offshore. Small juvenile cod may remain within vegetation beds for protection from predators (Heck and Orth, 1980), and they eat primarily copepods, invertebrate larvae, and small bivalves (Dean et al., 2000). Most of the Pacific cod caught in the present study were in relatively open water, at the edge of the dense kelp beds, and they were relatively large. We did not capture many juvenile Pacific cod. Most cod occur from 50 to 300 m depths, on or close to the continental shelf (Bakkala, 1984; Allen and Smith, 1988). If Pacific cod migrate between waters with different mercury concentrations, equilibrium in mercury levels in the muscle and liver may not be reached because of redistribution among tissues. Tagging studies, however, indicate that there is very little movement of Pacific cod among areas (DFO, 2006). In laboratory experiments with Atlantic cod (*Gadus morhua*), Julshamn et al. (1982) found that a muscle/liver ratio above 1 indicates equilibrium with the environment. Methylmercury concentrated in the muscle of *G. morhua* (Julshamn et al., 1982), although others have found higher levels in the liver (Chodyniecki et al., 1975).

Because of their position on the food chain, we had expected that Pacific cod would have levels of mercury in their muscle tissue that were intermediate to the other species of fish from this region. The Pacific cod from this study had higher levels (mean of 0.17 ppm in muscle) than low trophic level fish such as salmon (0.03–0.1 ppm, Zhang et al., 2001, anadramous). Further, the levels were lower than for sole (*Hippoglossoides elassodon*) and great sculpin (*Myoxocephalus polyacanthocephalus*) from Adak (0.3 ppm, Burger et al., 2007). Cod (either species) collected from supermarkets in New Jersey had mean levels of 0.11 ppm (Burger et al., 2005), similar to that reported by the FDA for commercial cod (0.11 ppm, U.S. FDA, 2005, species not distinguished). There have also been a number of studies of mercury in Atlantic cod, primarily of *G. morhua*; whose levels ranged from means of 0.01–0.33 ppm (Luten et al., 1987; Vos et al., 1986).

4.2. Mercury levels, fish size, and age

For some contaminants, particularly mercury, levels increase with the size and age of the fish (Lange et al., 1994;

Table 3
Percent of mercury and selenium levels above guidance or risk levels for muscle of Pacific cod from the Aleutians

	Mercury	Selenium
Sample size (*n*)	141	141
Percent above 0.3 ppm (EPA freshwater criterion)	13	7
Percent above 0.5 ppm (old FDA action level)	4	1
Percent above 1.0 ppm (present FDA action level)	0	0

Table 4
Correlation of size, age, and contaminant levels in Pacific cod from the Aleutians

	Mercury	Selenium	Length	Weight	Age
Mercury	–	0.12 (0.03)	0.37 (<0.0001)	0.38 (<0.0001)	0.45 (<0.0001)
Selenium	0.16 (0.005)	–	NS	NS	NS
Length	NS	−0.22 (0.0001)	–	0.84 (<0.0001)	0.74 (<0.0001)
Weight	NS	−0.28 (<0.0001)	0.84 (<0.0001)	–	0.66 (<0.0001)
Age	NS	−0.19 (0.08)	0.74 (<0.0001)	0.65 (<0.0001)	–

Correlations for muscle are above the diagonal and liver below. Given are Kendall τ correlations r (P).
NS = not significant.

Bidone et al., 1997; Burger et al., 2001a; Pinho et al., 2002; Green and Knutzen, 2003), however this is not always the case (Stafford and Haines, 2001). In some cases where there is a positive relationship in fish, size may explain only about 10% of the variation (Hopkins et al., 2001), but this was for a relatively small fish without great differences in size or age among individuals (*Gambusia holbrooki*). Similarly, at low mercury levels, the size relationships may not hold (see Park and Curtis, 1997). However, Trudel and Rasmussen (1997) found that elimination rate is negatively correlated with size, suggesting another reason for larger fish to have significantly higher mercury levels.

Few of these studies are with large marine predatory fish, however. Storelli et al. (2002) reported that size and mercury levels were highly correlated for swordfish (*Xiphias gladius*) and bluefin tuna (*Thunnus thynnus*) from the Mediterranean Sea. However, while yellowfin tuna (*Thunnus albacares*) showed a positive relationship between mercury and size (length and weight), albacore tuna (*Thunnus alalunga*) did not (Fiji, 2006) (Fig. 2). Luten et al. (1987) found a positive correlation between size and mercury content in Atlantic cod. For most fish, the age is unknown, and size is used as a surrogate for age (Boening, 2000). However, Braune (1987) found that in known-aged herring (*Clupea harengus harengus*), mercury level was more strongly correlated with age than with weight or length. We found no studies reporting size, age, and mercury levels for Pacific cod. However, increasing

mercury content with increasing age was shown for 16 Atlantic cod by Staveland et al. (1993; $r = 0.57$, $P < 0.02$).

In this study of Pacific cod, we found that age was the variable that first entered the regression model explaining variation in mercury levels. Growth rates in relation to age may account for differences. Simoneau et al. (2005) found that at a given length, faster growing walleye (*Sander vitreus*) had lower mercury concentrations than slower-growing fish.

Gender is another factor that can influence mercury levels in some fish. In some species, males have higher mercury levels than females of equal age (WHO, 1989), although Staveland et al. (1993) did not find this with Atlantic cod. We also did not find a gender-related difference in mercury levels in either muscle or liver of Pacific cod.

4.3. Risk to the food chain

In fish, dietary uptake probably accounts for more than 90% of the total uptake (Wiener et al., 2003). The assimilation efficiency for the uptake of dietary methylmercury in fish is probably 65–80% (Wiener and Spry, 1996). While most studies examine total mercury, methylmercury (the species of concern) comprises over 90% of the mercury in fish (Duffy et al., 1999). Methylmercury is a neurotoxin in fish, and at toxic levels can cause incoordination, diminished appetite, inability to feed, diminished responsiveness, lowered swimming activity, starvation, and mortality (Wiener et al., 2003). In the fish themselves, muscle levels of 5–20 ppm are associated with toxicity (Wiener et al., 2003). Differences in sensitivity relate to species of fish, bioavailability, and accumulation rate (Niimi and Kissoon, 1994). The mean mercury level of 0.17 ppm in Pacific cod in this study were well below these levels, indicating that the fish themselves are not at risk from mercury.

Much of the methylmercury in fishes relocates to skeletal muscle, which is protective for the fish itself, because the mercury exposure to the central nervous system is reduced (Wiener and Spry, 1996). This, however, makes it available to predators (including humans) that eat fish. Mercury toxicity is affected by temperature, salinity, dissolved oxygen, and water hardness (Boening, 2000). The critical effect levels for consumption by piscivorous mammal (0.1 ppm) and birds (0.02 ppm, Yeardley et al., 1998) are lower, although seabirds are generally less sensitive to high levels of cadmium and mercury than other birds (Furness, 1996). However, the mean mercury levels in the Pacific cod from the Aleutians (0.17 ppm in muscle) are within the range that might pose a problem for sensitive birds that scavenge Pacific cod along the shore, or for sensitive marine mammals.

Finally, the protective effects of selenium on mercury toxicity have been known for over a quarter of a century (Ganther et al., 1972; Kim et al., 1977), including in Atlantic cod (Ringdal and Julshamn, 1985). Levels of
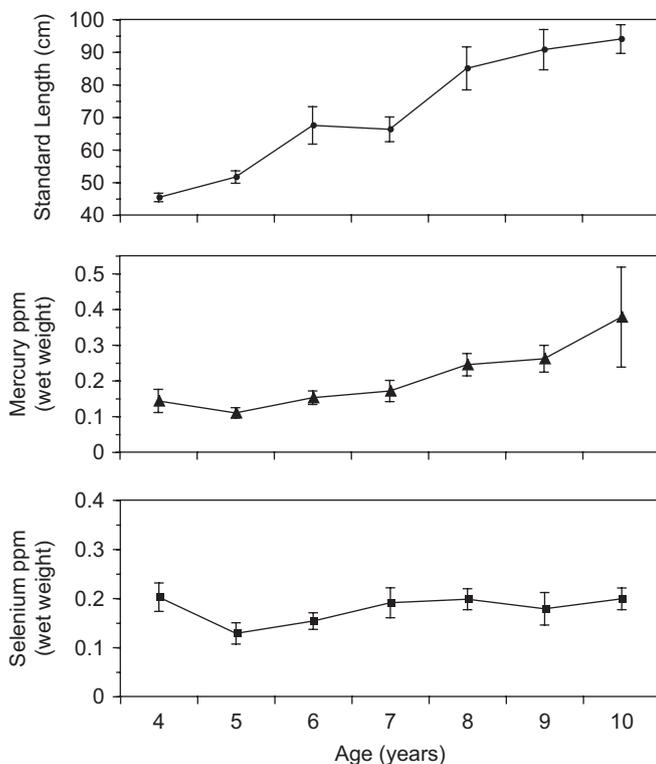

Fig. 2. Relationship of length (standard), selenium levels, and mercury levels (ppm, wet weight) as a function of age of Pacific cod, as determined by otoliths.

mercury and selenium are correlated in some studies (Eisler, 1985; Kuehl and Haebler, 1995; Wagemann et al., 1996), and we also found this to be the case for the Pacific cod in this study, although the correlation was not high ($r = 0.12$ for muscle and 0.16 for liver).

4.4. Risk to humans

The consumption of fish provides health benefits, but some fish have high mercury levels, contributing to possible adverse effects, particularly in fetuses and young children (see references in introduction). The discussion about the health benefits and risks from consumption of fish has mainly focused on recreational and subsistence fish, and only more recently on commercial fish (Burger and Gochfeld, 2004; Burger et al., 2004, 2005), although Yess (1993) reported on levels of canned tuna much earlier. While the definition of subsistence is arguable, fish comprise an important part of the diet of the people living in the Aleutian and Pribilof Islands in the northern Pacific/ Bering Sea region (Patrick, 2002; Hamrick and Smith, 2003). Providing these people with information about contaminants in the fish they consume is thus an important public health mandate. Further, Aleut fish consumption is complex: sometimes they cook the whole fish and eat most of it (if it is small), or they eat parts (fillets, liver). Thus computing risk is complex because Aleuts, and perhaps other subsistence people, are not consistent in either the sizes of fish or the parts they eat. More generally, Pacific cod are a fish of considerable commercial interest from the Aleutians, and unlike the Atlantic cod, the catch of Pacific cod is increasing (NRC, 1996), largely due to overfishing for other commercial species. Cod (both Atlantic and Pacific) are one of the top fish/shellfish consumed in the United States (NFI, 2004).

Methylmercury is one of the main contaminants of concern in fish. The U.S. FDA action level for methylmercury in fish is 1.0 μg/g (ppm w/w), but this is a regulatory action level, rather than a risk level (U.S. FDA, 2001). Originally, the FDA had set 0.5 ppm as the action level, comparable to many other nations (reviewed in Burger and Gochfeld, 2004). In contrast, the critical value for human consumption used by the U.S. EPA is 0.2 ppm (Rothschild and Duffy, 2002). 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 1 ppm is allowed in shark, sailfish, tuna, pike, and other high-mercury fish). 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 ppm (wet weight). The U.S. EPA (2001) promulgated 0.3 ppm as an ambient freshwater quality standard in 2001. Muscle in the Pacific cod in this study averaged about 0.17 ppm, with 13% of the cod having levels above 0.3 ppm.

Risk assessments for fish consumption generally examine chronic exposure, and not a single meal. However, Ginsberg and Toal (2000) have suggested that there may be risk during pregnancy for even a single-meal exposure, particularly for fish with levels of over 2.0 ppm. The risk from a pulsed exposure should also be examined, particularly its impact on a developing fetus at a critical developmental period. In the present study, no fillets of Pacific cod was above 0.86 ppm. We also reported the percent of fillets that were above 0.5 ppm because of the need to know the percent of times an exposure in a single meal may approach the tolerable daily intake (Berti et al., 1998). Providing information on risk from single-meal exposures, especially for pregnant women, is a risk communication challenge that we feel should be considered by the FDA. Egeland and Middaugh (1997) have called attention to the countervailing nutritional importance of fish, which increases the importance of identifying suitable local fish with low contaminant levels, especially during pregnancy. It is a matter of risk balance (Gochfeld and Burger, 2005; IOM, 2006).

While it is unlikely that an adult buying cod (of either species) from a supermarket will eat cod with only the highest levels consistently, the question is complicated for subsistence people. For example, we found that schools of Pacific cod tended to be the same size; thus a group of subsistence fishermen might in all likelihood bring back cod of the same large size from the same location during a series of fishing trips. Thus, it is possible for pregnant women to have several meals in a row from large-sized cod at the high end of mercury exposure. Further, many of the Aleuts we met froze fish for later consumption, prolonging the period of possible exposure. It was gratifying that most of the large Pacific cod did not have levels above 0.3 ppm, suggesting that on balance, most Pacific cod meals would not pose a risk, even from a single meal.

We caution that fish consumption is a matter of risk balancing (Egeland and Middaugh, 1997; Ponce et al., 2000; Gochfeld and Burger, 2005). There are clearly both benefits and risks from fish consumption, and the public should be provided with as much information as possible to allow them to maximize the positive health benefits, while minimizing the risks from contaminants (IOM, 2006). The availability of information on both the risks and benefits of specific species of fish from particular areas is key to making informed decisions about fish consumption. To be effective, development of risk communication tools should involve not only scientists, health professionals, and regulators, but the public as well (Jardine et al., 2003; Knuth et al., 2003; Burger et al., 2005).

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