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Do scientists and fishermen collect the same size fish? Possible implications for exposure assessment

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Abstract

Recreational and subsistence fishing plays a major role in the lives of many people, although most Americans obtain their fish from supermarkets or other commercial sources. Fish consumption has generally increased in recent years, largely because of the nutritional benefits. Recent concerns about contaminants in fish have prompted federal and state agencies to analyze fish (especially freshwater fish targeted by recreational anglers) for contaminants, such as mercury and polychlorinated biphenyls (PCBs), and to issue fish consumption advisories to help reduce the public health risks, where warranted. Scientists engaged in environmental sampling collect fish by a variety of means, and analyze the contaminants in those fish. Risk assessors use these levels as the basis for their advisories. Two assumptions of this methodology are that scientists collect the same size (and types) of fish that fishermen catch, and that, for some contaminants (such as methylmercury and PCBs), levels increase with the size and age of the fish. While many studies demonstrate a positive relationship between size and mercury levels in a wide range of different species of fish, the assumption that scientists collect the same size fish as fishermen has not been examined. The assumption that scientists collect the same size fish as those caught (and eaten) by recreationalists or subsistence fishermen is extremely important because contaminant levels are different in different size fish. In this article, we test the null hypothesis that there are no differences in the sizes of fish collected by Aleut fishermen, scientists (including divers), and commercial trawlers in the Bering Sea from Adak to Kiska. Aleut fishermen caught fish using rod-and-reel (fishing rods, hook, and fresh bait) from boats, as they would in their Aleutian villages. The scientists collected fish using rod-and-reel, as well as by scuba divers using spears up to 90 ft depths. A fisheries biologist collected fish from a research/commercial trawler operated under charter to the National Oceanographic and Atmospheric Administration (NOAA). The fish selected for sampling, including those caught commercially in the Bering Sea, represented different trophic levels, and are species regularly caught by Aleuts while fishing near their villages. Not all fish were caught by all three groups. There were no significant differences in length and weight for five species of fish caught by Aleuts, scientists, and fisheries trawls, and for an additional 3 species caught only by the Aleut and scientist teams. There were small, but significant, differences in the sizes of rock greenling (*Hexagrammos lagocephalus*) and red Irish lord (*Hemilepidotus hemilepidotus*) caught by the scientist and Aleut fishermen. No scientists caught rock greenling using poles; those speared by the divers were significantly smaller

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than those caught by the Aleuts. Further, there were no differences in the percent of males in the samples as a function of fishing method or type of fishermen, except for rockfish and red Irish lord. These data suggest that if scientists collect fish in the same manner as subsistence fishermen (in this case, using fishing rods from boats), they can collect the same-sized fish. The implications for exposure and risk assessment are that scientists should either engage subsistence and recreational fishermen to collect fish for analysis, or mimic their fishing methods to ensure that the fish collected are similar in size and weight to those being caught and consumed by these groups. Further, total length, standard length, and weight were highly correlated for all species of fish, suggesting that risk assessors could rely on recreational and commercial fishermen to measure total lengths for the purpose of correlating mercury levels with known size/mercury level relationships. Our data generally demonstrate that the scientists and trawlers can collect the same size fish as those caught by Aleuts, making contaminant analysis, and subsequent contaminant analysis, representative of the risks to fish consumers.

Keywords: Mercury; Fish; PCBs; Risk; Size

1. Introduction

Subsistence fishing and recreational fishing are important aspects of the culture of many groups of people throughout the world, especially in regions where the fishing season extends many months. Fish consumption has generally increased in the United States over the last few years, largely because of the perceived nutritional benefits of eating fish and the availability of a wide range of fish in supermarkets and fish markets. Fishing is a popular pastime, and fish are an important source of protein for many people (Toth and Brown, 1997; Burger et al., 1992, 1993; Burger, 2002; Knuth et al., 2003), even in some metropolitan areas (Burger et al., 1999, 2001a; Ramos and Crain, 2001). Fish provide omega-3 (n-3) fatty acids, which reduce cholesterol levels and the incidence of heart disease, stroke, and preterm delivery (Anderson and Wiener, 1995; Daviglus et al., 2002; Patterson, 2002). These benefits are particularly for cold water fish from regions such as the Bering Sea and North Pacific.

Recently, however, there has been widespread concern about possible adverse health effects from consuming fish with contaminants, particularly methylmercury and polychlorinated biphenyls (PCBs). Contaminant levels are sufficiently high in some fish to cause adverse human health effects in people consuming large quantities (Stern, 1993; Institute of Medicine (IOM), 1991; Hightower and Moore, 2003; Hites et al., 2004), counteracting the cardioprotective effects (Guallar et al., 2002) and damaging developing fetuses and young children. Concern is particularly high for developing fetuses because chemicals can be transferred across the placenta to the fetus during maternal exposure (Gulson et al., 1997, 1998). There is a positive relationship between mercury and PCB levels in fish, fish consumption by pregnant women, and deficits in neurobehavioral development in children (Institute of Medicine (IOM), 1991; Sparks and Shepherd, 1994; Jacobson and Jacobson, 1996; Lonky et al., 1996; Schantz, 1996; National Research Council (NRC), 2000). There is also a decline in fecundity in women who consume large quantities of contaminated fish from Lake Ontario (Buck et al., 2000). Balancing risks and benefits has been of particular importance for native peoples of Alaska (Egeland et al., 1998; Duffy and Jewett, in press).

The responsibility for protecting the health of its citizens rests with the states, and state agencies are responsible for issuing fish consumption advisories intended to inform the public about possible risks from consuming fish of certain species, or in certain amounts, or from certain water bodies. The number of fish advisories issued by states due to chemicals, such as mercury and PCBs, has increased over the last several years (Environmental Protection Agency (EPA), 2002, 2004). Recently the US Food and Drug Administration ((FDA), 2001, 2003) issued a series of consumption advisories for marine fish based on methylmercury, recommending that pregnant women and women of childbearing age who may become pregnant should avoid eating four types of fish—shark, swordfish, king mackerel, and tilefish—and should limit their consumption of all other fish to just 12 oz per week (Food and Drug Administration (FDA), 2001).

Continued issuance of advisories depends, on having information on contaminant loads in the fish that subsistence and recreational fishermen are catching. Such fishermen do not readily give up their fish, and catch too few in a short enough period of time to provide sufficient samples for chemical or radiological analysis. Thus, biologists usually collect fish by a variety of methods that involve electroshocking, netting, seining, and spearing (by divers), rarely supplemented by rod-and-reel.

In this article, we examine the sizes of fish caught by subsistence fishermen (using fishing rods), by biologists (using rods and by spearing), and by a fishery biologist on a commercial trawler chartered by the National Oceanographic and Atmospheric Administration (NOAA) as part of its biennial fish survey. We tested the null hypothesis that there are no differences, as a function of type of fishing effort, in the size and weight of several species of fish caught in the Bering Sea from Adak Island to Kiska Island in the Aleutian chain that runs from Alaska to Russia. All species we sampled are part of the subsistence diet of the local Aleuts and can serve as bioindicators of marine ecosystem exposure, and some are used in commercial fisheries of the region. Although these results are directly applicable to subsistence fisherman in the Aleutians, the general principle of examining our assumptions about fish size is germane to fish consumption studies elsewhere.

The determination that scientific sampling, usually designed to be representative of a resource (Environmental Protection Agency (EPA), 2000), reflects fish of the same weight and size as those caught by subsistence fishermen is important. This assumption forms the basis for risk assessments and for subsequent fish advisories. Given that for some contaminants, such as mercury, there is a positive relationship between fish size and mercury levels, any systematic bias upward or downward in the size of fish caught by scientists would similarly bias the risk assessments. Data on the size and weight of fish collected by either recreational or subsistence fishermen are extremely rare. This is certainly true for the Aleuts. Although, there is an implicit assumption that recreational fishermen collect fish within the legal size limit, this has not been examined, and may not be applicable to subsistence fishermen. Although, there are some studies that compare commonly used science-based methods for collecting sediments and fauna (Burger, 1983; Warwick and Clarke, 1991; Kramer et al., 1994; Somerfield and Clarke, 1997), comparisons of traditional or recreational fishing and science-based sampling have not been done.

This study is part of a Consortium for Risk Evaluation with Stakeholder Participation (CRESP) project evaluating the potential risk to marine ecosystems and human health from the three underground nuclear test shots detonated at Amchitka Island from 1965 to 1971 (Kohlhoff, 2002; Department of Energy (DOE), 2002a, b; Consortium for Risk Evaluation with Stakeholder Participation (CRESP), 2003; Burger et al., 2005). The main project, which will run many months or even years if other contaminants are also examined, involves collecting specimens ranging from kelp and sea urchins to marine birds that can serve as indicators of the health of the marine ecosystem and that are subsistence foods of the Aleuts. The CRESP project also includes limited collection of water/sediment samples and examination of some physical parameters that might influence exposure routes in the marine ecosystem.

2. Study site and methods

Our study was conducted in the Bering Sea and North Pacific waters from Adak to Kiska Island in the Aleutian Island chain. The marine resources of the region provide the base for the subsistence lifestyle of the Aleutian and Pribilof islanders (Patrick, 2002). The region has very high oceanic productivity, and is very rich biologically, hosting populations of several endangered and threatened marine mammals, large seabird colonies, and important fish populations (Merritt and Fuller, 1977; Estes, 1978; National Research Council (NRC), 1996). A large proportion of the commercial fish consumed in the United States comes from the Northern Pacific and Bering Sea fishery (Alaska Fisheries Science Center (AFSC), 2003). For example, Dutch Harbor in the Aleutians had the highest tonnage of fish landings in the world in 2002.

Our overall protocol was to collect fish using different collectors (scientists, Aleuts) and different methods (fishing poles, spears while diving, trawling). Fish were collected from 21 June through 8 August 2004 from docks (Adak Harbor, Constantine Harbor on Amchitka), from small boats (from Adak to Kiska), and from two fishing trawlers (*Ocean Explorer* and *Gladiator*, from Amchitka to Kiska). Three methods were used: rod-and-reel (scientists, Aleuts), spearing (scientist divers), and trawling (scientists on a NOAA trawl). Scientists and Aleuts sometimes fished together in the same or adjacent small skiffs, and sometimes fished separately. In most cases, instructions were to catch and retain whatever fish were available (no instructions were generally given about species or size of fish). Some attempt was made while on the *Ocean Explorer* to collect about the same number of fish around all the islands (especially Amchitka and Kiska), and during the final few days Aleuts were asked to try and fish for rock greenling and Irish lords (all scientific names of fish are given in Table 1) because the divers had obtained these species by spearing.

To ensure that our CRESP trawl sampling was representative of the NOAA trawl, we compared the sizes of fish for our sample with those of the fish captured overall. There were no significant differences in weight or condition for fish of the same size, except for Atka mackerel; the NOAA scientists collected smaller fish than did the CRESP scientist on board ($P<0.002$, t test).

Size variables were compared using the nonparametric analysis of variance (PROC NPAR1WAY in SAS with Wilcoxon option). This yields a χ^2 statistic, comparing distributions of responses by different independent variables (Statistical Analysis System (SAS), 1995). We performed Pearson correlations on log-transformed data.

3. Results

For 7 of the 11 species of fish that we caught, there were no length or weight differences as a function of either collector type or method (Table 1). However, there were weight differences for two species (rockfish, yellow Irish lord) and length and weight differences for two (red Irish lord, rock greenling) (Table 1). Standard length and total length were highly correlated for all species, as were total length and weight (Table 2). This suggests that environmental assessors need take only one of these measurements, and that risk assessors could rely on recreational and subsistence fishermen to measure the total length or the weight of a fish for the purpose of relating it to contaminant levels in known-sized fish.

There were no differences in the percentages of males captured as a function of fishing method or fishermen type, except for rockfish and red Irish lord (Table 1). The commercial NOAA trawl caught only male rockfish, compared with less than 50% for the other fishing methods. The Aleuts caught only 7% male red Irish lords, compared with 52% for the scientist team.

Table 1
Comparison of fish sizes as a function of collectors and methods for fish from the Bering Sea (Adak to Kiska)

	Scientist team[a]	Aleut	NOAA trawl	χ^2 (*P*)
Atka Mackerel	$n=2$	$n=4$	$n=30$	
(*Pleurogrammus monopterygius*)				
Total length (cm)	44±	42±2	40±0.5	NS
Standard length (cm)	39±	36±1	35±0.5	NS
Weight (g)	997±	615±32	642±22	NS
% male	100	67	53	NS
Dolly Varden	$n=10$	$n=49$		
(*Salvelinus malma*)				
Total length (cm)	32±1	31±1		NS
Standard length (cm)	28±0.5	28±1		NS
Weight (g)	290±15	325±32		NS
% male	60	54		NS
Flathead sole	$n=17$	$n=22$		
(*Hippoglossoides elassodon*)				
Total length (cm)	40±1	38±1		NS
Standard length (cm)	34±1	32±1		NS
Weight (g)	605±41	575±30		NS
% male				
Great Sculpin	$n=13$	$n=14$		
(*Myoxocephalus polyacanthocephalus*)				
Total length (cm)	49±2	50±2		NS
Standard length (cm)	42±2	44±2		NS
Weight (g)	2032±216	2306±392		NS
% male	100	50		NS
Pacific Halibut	$n=3$	$n=14$	$n=7$	
(*Hippoglossus stenolepis*)				
Total length (cm)	84±40	81±7	62±15	NS
Standard length (cm)	75±36	73±6	53±13	NS
Weight (g)	15 917±14 751	10 782±2775	5740±3399	NS
% male	0	25	57	NS
Pacific Cod	$n=54$	$n=72$	$n=10$	
(*Gadus macrocephalus*)				
Total length (cm)	60±3	61±2	64±5.0	NS
Standard length (cm)	55±3	56±2	60±4.0	NS
Weight (g)	4590±833	3881±664	3451±702	NS
% male	42	34	50	NS
Rock Sole	$n=41$	$n=5$	$n=15$	
(*Lepidopsetta bilineata*)				
Total length (cm)	33±1	35±2	37±1	NS
Standard length (cm)	28±1	30±1	30±1	NS
Weight (g)	448±29	501±73	515±36	NS
% male	28	0	33	NS
Rockfish[b]	$n=33$	$n=69$	$n=5$	
(*Sebastes* spp)				
Total length (cm)	37±1	37±1	40±1	NS
Standard length (cm)	33±1	32±0.5	34±1	NS
Weight (g)	889±49	842±40	1104±62	6 (0.04)
% male	33	45	100	7.8 (0.02)
Rock Greenling	$n=83$	$n=57$		
(*Hexagrammos lagocephalus*)				
Total length (cm)	33±0.4	35±1		9 (0.003)
Standard length (cm)	29±0.4	31±1		10 (0.001)
Weight (g)	507±15	604±25		9 (0.002)
% male	37	30		NS

Table 1 (*continued*)

	Scientist team[a]	Aleut	NOAA trawl	χ^2 (*P*)
Red Irish Lord (*Hemilepidotus hemilepidotus*)	*n* = 34	*n* = 27		
Total length (cm)	28±1	34±1		24 (0.0001)
Standard length (cm)	24±1	28±1		21 (0.0001)
Weight (g)	434±27	662±58		15 (0.0001)
% male	52	7		13 (0.0003)
Yellow Irish Lord (*Hemilepidotus jordani*)	*n* = 42	*n* = 47		
Total length (cm)	41±1	40±0.48		NS
Standard length (cm)	34±1	33±0.51		NS
Weight (g)	956±63	796±32		6 (0.04)
% male	54	45		NS

[a]Scientist team comprises divers and surface fishermen.
[b]Scientist and Aleuts collected Black Rockfish *Sebastes melanops*, NOAA trawler collected Dusky Rockfish *Sebastes ciliatus* .

Table 2
Correlation of size and weight for fish collected in the Bering Sea Region

Fish	*n*	Standard length and total length	Total length and weight
		r (*P*)	*r* (*P*)
Atka Mackerel	34	0.95 (0.0001)	0.84 (0.0001)
Dolly Varden	59	0.90 (0.0001)	0.84 (0.0001)
Flathead sole	39	0.96 (0.0001)	0.93 (0.0001)
Great Sculpin	27	0.98 (0.0001)	0.92 (0.0001)
Pacific Halibut	24	0.99 (0.0001)	0.94 (0.0001)
Pacific Cod	135	0.99 (0.0001)	0.92 (0.0001)
Rock Sole	60	0.85 (0.0001)	0.84 (0.0001)
Rockfish	107	0.87 (0.0001)	0.91 (0.0001)
Rock Greenling	135	0.94 (0.0001)	0.87 (0.0001)
Red Irish Lord	61	0.99 (0.0001)	0.87 (0.0001)
Yellow Irish Lord	89	0.94 (0.0001)	0.91 (0.0001)

4. Discussion

The Environmental Protection Agency (2000) issues guidance for sampling and analysis of contaminants in fish for risk analysis and risk communication. The guidance generally encompasses our experience, except that recommended species do not necessarily reflect those harvested locally. The recommendation to approximate the size of fish harvested is sound, but does not take into account differences imposed by different collecting methods or different types of fishermen.

4.1. Size and sex differences

In this study, there were no size differences (lengths or weights) for four species of fish caught by the scientist team, Aleuts, and NOAA trawl biologist, and no differences between three additional species caught only by the scientist team and Aleuts. There were weight differences in two other fish (rockfish, yellow Irish lord) and length and weight differences in two other species of fish (rock greenling, red Irish lord). The possible causes of these differences are worth exploring.

The rockfish collected by the scientist team and Aleuts were black rockfish (*Sebastes malanops*), whereas those collected on the NOAA trawl boat included dusky rockfish (*Sebastes ciliatus*), although they look very similar (Kramer and O'Connell, 2003). Thus it is not surprising that the weights differed, although the lengths did not. All the rock greenling collected by scientists were collected by the scientist divers, and they were significantly smaller than those collected by Aleuts, although the differences were very small. This suggests that collecting fish while diving may not mimic the collection of fish by subsistence fishermen.

The reasons for the differences in size of red Irish lords, however, are unclear. Unlike most of the other species, red Irish lords collected by scientists included those obtained by rod-and-reel and by spearing while diving; there was no significant difference in size as a function of these methods.

However, red Irish lord was a fish that was targeted for capture by the Aleuts to match the sample the divers caught. Thus, the Aleuts went to a place where they specifically hoped to find Irish lords, rather than simply going to a place where the fishing was good. This targeted effort needs to be considered when comparing fish caught by fishermen (who presumably always target) and scientists.

The question of the sex of the fish collected is interesting, largely because scientists often do not report the sex of the fish collected or analyzed for heavy metals or other contaminants. There were no differences in the percentages of males in the samples for 9 of the 11 species of fish with respect to either fishing method or fisherman type. However, the NOAA trawl caught only male rockfish, and the Aleuts caught fewer males compared with the scientist team.

4.2. Implications for exposure and risk assessment

The question of whether scientists collect the same size fish as those caught by either recreational or subsistence fishermen is both trivial and profound. It is trivial because scientists could presumably collect the same size fish as fishermen if they used the same methods and kept only those fish that the fishermen would keep. This, however, presumes that the scientists have data on the size of fish that the fishermen catch (and take home to eat for those interested in risk assessment) an assumption that is not tested, largely because such data are not routinely collected by resource managers, regulators, or scientists. Further, it is assumed that fishermen keep only those fish that are within the legal size limits (set by states), but this is not generally studied. Further, it is unlikely that subsistence fishermen do so, and indeed they may take all fish caught or prefer fish of a particular size.

Whether scientists and fishermen collect fish of the same size is profound because of its implications for the exposure assessment phase of risk assessment. Scientists often catch fish by electroshocking (which results in all fish being collected regardless of size), leaving them to decide which fish to analyze for contaminants or radionuclides of concern. The decision on which fish to analyze often is made by either selecting all fish above the legal size limit or selecting fish of a particular size. The latter decision is sometimes made to control variation in contaminant levels among species of fish or for technical reasons (when whole counts are made it is difficult to homogenize large fish). For compositing purposes, fish need to be of similar size (EPA Guidance 2000); hence scientists might select the most common size, rather than the size preferred for eating. Thus, scientists sometimes select fish smaller than those fishermen normally catch.

Because for some contaminants, such as mercury, levels increase with the size and age of the fish (Lange et al., 1994; Bidone et al., 1997; Burger et al., 2001a; Green and Knutzen, 2003), it is critical in risk assessment that scientists examine contaminants in fish of the same size (and thus the same contaminant levels) as those caught and eaten by fishermen. Further, the linear relationship is not always positive; radiocesium levels are higher in some small fish than in larger individuals of the same species (Burger et al., 2001b). Thus, three possible relationships need to be considered for risk assessment of different contaminants: larger fish can have higher levels (mercury), lower levels (radiocesium), or no consistent differences (for some fish, some contaminants). Thus, risk assessors should clearly collect the appropriate sizes of fish that are eaten by recreational or subsistence fishermen.

Another implication for exposure assessment that became apparent after spending several weeks with Aleuts, who routinely fish for subsistence foods, were subtle size preferences. There were individual preferences, as well as general preferences, for specific sizes of fish. For example, all Pacific halibut caught are taken back to the Aleut villages to eat, according to our Aleut fishermen. However, the Aleut fishermen preferred intermediate-sized halibut (about 80–150 lb) for themselves, rather than smaller or larger ones. Thus, they froze fillets from the 80- to 100-lb halibut to take back to their relatives, rather than fillets from the 35- to 50-lb fish (which they stated were "too soft") or the larger ones (which were "too tough"). On the *Ocean Explorer*, freezer space was limited, and we could save only what was preferred, whereas when Aleuts fish for themselves close to their villages, all fish are taken back. Further, Aleuts preferred to eat small red Irish lords (because they are eaten whole). These two preferences may reflect the age of the fish (older fish are tougher to eat); halibut from the Bering Sea region are known to live up to 55 years, and other groundfish live 100+ years (Munk, 2001). It is not, however, that fish of other sizes are not taken back to the villages for consumption, but rather that the fishermen themselves (usually men) are not eating these fish. Thus, women, children, and elders (who no longer fish) are eating them as well.

Another aspect that may not be as relevant for fishermen in coastal areas around the continental United States is the potential to catch really large fish. That is, in this study, we caught halibut ranging from 3 to 4 lb, to more than 100 lb, certainly a wide range of sizes. This large size range for any one species is unlikely to occur in either freshwater streams and lakes or coastal bays and estuaries. Methodologically, having fish of such different sizes makes compositing difficult; EPA guidance (Environmental Protection Agency (EPA), 2000) suggests compositing fish of nearly identical size. Thus, scientists may routinely make simplifying decisions and analyze only one or two different size (and thus age) classes or, in some cases, may simply choose to analyze contaminants in relatively small fish.

While it remains imperative for risk assessors to gather site-specific information on fish size, contaminants in fish, and consumption patterns, the importance of testing our general assumptions about exposure cannot be underestimated. The human relationship between fish size and some contaminants underscores this.

Finally, it is worth noting that ecologists who are interested in understanding resource use, competition among species, and potential exposure to contaminants examine both the species and size of fish (or other prey) that individuals capture for themselves or their offspring (e.g., Safina and Burger, 1988; Burger and Gochfeld, 1991). Thus, ecological risk assessors can go to the literature and determine the size of prey fish a particular species eats, and relate the prey to contaminant levels in similarly sized fish derived from toxicological studies. It is remarkable to us that similar studies are not routinely conducted with recreational and subsistence fishermen.

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References

Alaska Fisheries Science Center (AFSC), 2003. Alaska fisheries. Available at: *wysiwyg://www/afsc/noaa.gov/species/pollock.htm*.

Anderson, P.D., Wiener, J.B., 1995. Eating fish. In: Graham, J.D., Wiener, J.B. (Eds.), Risk versus Risk: Tradeoffs in Protecting Health and the Environment. Hardvard University Press, Cambridge, MA.

Bidone, E.D., Castilhos, Z.C., Santos, T.J.S., Souza, T.M.C., Lacerda, L.D., 1997. Fish contamination and human exposure to mercury in Tartarugalzinho River, Northern Amazon, Brazil: a screening approach. Water Air Soil Pollut. 97, 9–15.

Buck, G.M., Vena, J.E., Schisterman, E.F., Dmochowski, J., Mendola, P., Sever, L.E., Fitzgerald, E., Kostyniak, P., Greizerstein, H., Olson, J., 2000. Parental consumption of contaminated sport fish from Lake Ontario and predicted fecundability. Epidemiology 11, 383–388.

Burger, J., 1983. Determining sex ratios from collected specimens. Condor 85, 503.

Burger, J., 2002. Consumption patterns and why people fish. Environ. Res. 90, 125–135.

Burger, J., Cooper, K., Gochfeld, M., 1992. Exposure assessment for heavy metal ingestion from a sport fish in Puerto Rico: Estimating risk for local fishermen. J. Toxicol. Environ. Health 36, 355–365.

Burger, J., Gaines, K.F., Gochfeld, M., 2001a. Ethnic differences in risk from mercury among Savannah River fishermen. Risk. Anal. 21, 533–544.

Burger, J., Gaines, K.F., Stephens Jr., W.L., Boring, C.S., Brisbin Jr., I.L., Snodgrass, J., Peies, J., Bryan, L., Smith, M.H., Gochfeld, M., 2001b. Radiocesium in fish from the Savannah River and Steel Creek: potential food chain exposure to the public. Risk. Anal. 21, 545–559.

Burger, J., Gochfeld, M., 1991. The Common Tern: Its Breeding Biology and Behavior. Columbia University Press, New York.

Burger, J., Gochfeld, M., Kosson, D., Powers, C.W., Friedlander, B., Eichelberger, J.E., Barnes, D., Duffy, L.K., Jewett, S.C., Volz, C.D., 2005. Science, policy, and stakeholders: Developing a consensus science plan for Amchitka Island, Aleutians, Alaska. Environ. Manage. 35, 557–568.

Burger, J., Staine, K., Gochfeld, M., 1993. Fishing in contaminated waters: Knowledge and risk perception of hazards by fishermen in New York City. J. Toxicol. Environ. Health 3, 95–105.

Burger, J., Stephens, W., Boring, C.S., Kuklinski, M., Gibbons, J.W., Gochfeld, M., 1999. Factors in exposure assessment: Ethnic and socioeconomic differences in fishing and consumption of fish caught along the Savannah River. Risk Anal. 19, 427–438.

Consortium for Risk Evaluation with Stakeholder Participation (CRESP), 2003. Amchitka Independent Assessment Science Plan. CRESP, Piscataway, NJ. Available at: *http://www.cresp.org*.

Daviglus, M., Sheeshka, J., Murkin, E., 2002. Health benefits from eating fish. Comments Toxicol. 8, 345–374.

Department of Energy (DOE), 2002a. Modeling Groundwater Flow and Transport of Radionuclides at Amchitka Island's Underground Nuclear Tests: Milrow, Long Shot, and Cannikin, DOE/NV-11508-51. Nevada Operations Office, Las Vegas.

Department of Energy (DOE), 2002b. Screening Risk Assessment for Possible Radionuclides in the Amchitka Marine Environment, DOE/NV-857. Nevada Operations Office, Las Vegas.

Duffy, L.K., Jewett, S.C. Mercury in fish of Alaska, with emphasis on subsistence foods. Science Total Environ., in review.

Egeland, G.M., Feyk, L.A., Middaugh, J.P., 1998. The Use of Traditional Foods in a Healthy Diet in Alaska: Risks in Perspective. State of Alaska Division of Public Health, Juneau.

Environmental Protection Agency (EPA), 2000. Guidance for Assessing Chemical Contaminant Data for Use In Fish Advisories, vol. 1: Fish Sampling and Analysis, third ed. Office of Water, Washington, DC. Available at: *http://www.epa.gov/ost/fishadvice/volume1/index.html*.

Environmental Protection Agency (EPA), 2002. Update: National Listing of Fish and Wildlife Consumption Advisories. US Environmental Protection Agency, Cincinnati, OB. Available at: *vysiwyg//104/http//www.epa.gov/ost/fish/advisories/general.html*.

Environmental Protection Agency (EPA), 2004. Update: National Listing of Fish and Wildlife Consumption Advisories. US Environmental Protection Agency, Cincinnati, OB. Available at: *vysiwyg//104/http//www.epa.gov/ost/fish/advisories/general.html*.

Estes, J.A., 1978. Sea otter predation and community organization in the Western Aleutian Islands, Alaska. Ecology 59, 822–833.

Food and Drug Administration (FDA), 2001. FDA Consumer Advisory. Available at: *http//www.fda.gov/bbs/topics/ANSWERS/2000/advisory.html* (accessed 1 December 2001).

Food and Drug Administration (FDA), 2003. FDA Consumer Advisory. Available at: *http//www.fda.gov/bbs/topics/ANSWERS/2000/advisory.html* (accessed 1 January 2004).

Green, N.W., Knutzen, J., 2003. Organohalogens and metals in marine fish and mussels and some relationships to biological variables at reference localities in Norway. Mar. Pollut. Bull. 46, 362–377.

Guallar, E., Sanz-Gallardo, I., van't Veer, P., Bode, P., Aro, A., Gomez-Aracena, J., Kark, J.D., Riemersma, R.A., Martin-Moreno, J.M., Kok, F.J., for the Heavy Metals and Myocardial Infarction Study Group, 2002. Heavy metals and Myocardial Infarction Study Group: Mercury, fish oils, and the risk of myocardial infarction. N. Eng. J. Med. 347, 1747–1754.

Gulson, B.L., Jameson, C.S., Mahaffey, K.R., Mizon, K.J., Korsch, M.J., Vimpani, G., 1997. Pregnancy increases mobilization of lead from maternal skeleton. J. Lab. Clin. Med. 130, 51–62.

Gulson, B.L., Mahaffey, K.R., Jameson, C.W., Mizon, K.J., Korsch, M.J., Cameron, M.A., Eisman, J.A., 1998. Mobilization of lead from the skeleton during the postnatal period is larger than during pregnancy. J. Lab. Clin. Med. 131, 324–329.

Hightower, J.M., Moore, D., 2003. Mercury levels in high-end consumers of fish. Environ. Health Perspect. 111, 604–608.

Hites, R.A., Foran, J.A., Carpenter, D.O., Hamilton, M.C., Knuth, B.A., Schwager, S.J., 2004. Global assessment of organic contaminants in farmed salmon. Science 303, 226–229.

Institute of Medicine (IOM), 1991. Seafood Safety. National Academy Press, Washington, DC.

Jacobson, J.L., Jacobson, S.W., 1996. Intellectual impairment in children exposed to polychlorinated biphenyls in utero. N. Engl. J. Med. 335, 783–789.

Knuth, B., Connelly, N.A., Sheeshka, J., Patterson, J., 2003. Weighing health benefits and health risk information when consuming sport-caught fish. Risk Anal. 23, 1185–1197.

Kohlhoff, D.W., 2002. Amchitka and the Bomb: Nuclear Testing in Alaska. University of Washington Press, Seattle.

Kramer, D.E., O'Connell, V.M., 2003. Guide to Northeast Pacific Rockfishes. Alaska Sea Grant Bulletin No. 25, Fairbanks.

Kramer, K.J.M., Brockmann, U.H., Warwick, R.M., 1994. Tidal Estuaries: Manual of Sampling and Analytical Procedures. Balkerna, Rotterdam.

Lange, T.R., Royals, H.E., Connor, L.L., 1994. Mercury accumulation in largemouth bass (*Micropterus salmoides*) in a Florida lake. Arch. Environ. Contam. Toxicol. 27, 466–471.

Lonky, E., Reihman, J., Darvill, T., Mather Sr., J., Daly, H., 1996. Neonatal behavioral assessment scale performance in humans influenced by maternal consumption of environmentally contaminated fish. J. Great Lakes Res. 22, 198–212.

Merritt, M.L., Fuller, R.G. (Eds.), 1977. The Environment of Amchitka Island, Alaska, Report NVO-79. US Technical Information Control, Energy Research and Development Administration.

Munk, K.M., 2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and considerations of age determination. Alaska Fish. Res. Bull. 8, 121–122.

National Research Council (NRC), 1996. The Bering Sea Ecosystem. National Academy Press, Washington, DC.

National Research Council (NRC), 2000. Toxicological Effects of Methylmercury. National Academy Press, Washington, DC.

Patrick, R., 2002. How local Alaska native communities view the Amchitka issue. In: Proceedings of the Amchitka Long-Term Stewardship Workshop. CRESP, University of Alaska, Fairbanks.

Patterson, J., 2002. Introduction: comparative dietary risk: balance the risks and benefits of fish consumption. Comments Toxicol. 8, 337–344.

Ramos, A.M., Crain, E.F., 2001. Potential health risks of recreational fishing in New York City. Ambulat. Pediatr. 1, 252–255.

Safina, C., Burger, J., 1988. Prey dynamics and the breeding phenology of common terns. Auk 105, 720–726.

Schantz, S.L., 1996. Developmental neurotoxicity of PCBs in humans: what do we know and where do we go from here? Neurotoxicol. Teratol. 18, 217–227.

Somerfield, P.J., Clarke, K.R., 1997. A comparison of some methods commonly used for the collection of sublittoral sediments and their associated fauna. Mar. Environ. Res. 43, 145–156.

Sparks, P., Shepherd, R., 1994. Public perception of the potential hazards associated with food production: an empirical study. Risk Anal. 14, 799–808.

Statistical Analysis System (SAS), 1995. SAS Users' Guide. Statistical Institute, Cary, NC.

Stern, A.H., 1993. Re-evaluation of the reference dose for methylmercury and assessment of current exposure levels. Risk Anal. 13, 355–364.

Toth Jr., J.F., Brown, R.B., 1997. Racial and gender meanings of why people participate in recreational fishing. Leisure Sci. 19, 129–146.

Warwick, R.M., Clarke, K.R., 1991. A comparison of methods for analyzing changes in benthic community structure. J. Mar. Biol. Assoc. UK 71, 225–244.