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Mercury levels and potential risk from subsistence foods from the Aleutians

Joanna Burger [a,b,*], Michael Gochfeld [b,c], Christian Jeitner [a,b], Sean Burke [a,b], Tim Stamm [d,e], Ronald Snigaroff [e,f], Dan Snigaroff [e,f], Robert Patrick [e], Jim Weston [g]

[a] *Nelson Biological Laboratory, Division of Life Sciences, Rutgers University, 604 Allison Road, Piscataway, NJ 08854-8082, USA*
[b] *Environmental and Occupational Health Sciences Institute and Consortium for Risk Evaluation with Stakeholder Participation, Piscataway, NJ 08854, USA*
[c] *Environmental and Occupational Medicine, UMDNJ-Robert Wood Johnson Medical School, Piscataway, NJ 08854, USA*
[d] *Nikolski, Aleutian Chain, Alaska, USA*
[e] *Aleutian/Pribilof Island Association, Anchorage, Alaska, USA*
[f] *Atka, Aleutian Chain, Alaska, USA*
[g] *University of Mississippi, University, Mississippi 38677-1848 USA*

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Abstract

Considerable attention has been devoted to contaminants (mainly PCBs and mercury) in subsistence foods (particularly fish) from various parts of the world. However, relatively little attention has been devoted to examining mercury levels in a full range of subsistence foods from a particular region. While managers and scientists compute risk based on site-specific data on contaminant levels and consumption rates, a first step in making risk decisions by subsistence peoples is knowledge about the relative levels of mercury in the foods they eat. This study examined levels of mercury in subsistence foods (edible components) from several islands in the western Aleutians of Alaska, including algae (4 species), invertebrates (9 species), fish (15 species) and birds (5 species). Samples were gathered by both subsistence hunters/fishers and by scientists using the same equipment. Another objective was to determine if there were differences in mercury levels in subsistence foods gathered from different Aleutian islands. We tested the null hypotheses that there were no interspecific and interisland differences in mercury levels. Because of variation in distribution and the nature of subsistence hunting and fishing, not all organisms were collected from each of the islands. There were significant and important differences in mercury levels among species, but the locational differences were rather small. There was an order of magnitude difference between algae/some invertebrates and fish/birds. Even within fish, there were significant differences. The highest mean mercury levels were in flathead sole (*Hippoglossoides elassodon*, 0.277 ppm), yellow irish lord (*Hemilepidotus jardani*, 0.281 ppm), great sculpin (*Myoxocephalus polyacanthocephalus*, 0.366 ppm), glaucous-winged gull (*Larus glaucescens*, 0.329 ppm) and its eggs (0.364 ppm), and pigeon guillemot (*Cepphus columba*, 0.494 ppm). Mercury levels increased with increasing weight of the organisms for limpets (*Tectura scutum*), and for 11 of the 15 fish species examined. Nine of the 15 fish species had some samples over the 0.3 ppm level, and 7 of 15 fish had some samples over 0.5 ppm. For birds, 95% of the pigeon guillemot muscle samples were above the 0.3 ppm, and 43% were above 0.5 ppm. While health professionals may argue about the risk and benefits of eating fish, and of eating alternative protein sources, the public should be provided with enough

* Corresponding author. 604 Allison Rd. Rutgers University, Piscataway, New Jersey, 08854-8082, USA. Tel.: +1 732 445 4318; fax: +1 732 445 5870.

E-mail address: burger@biology.rutgers.edu (J. Burger).

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information for them to make informed decisions. This is particularly true for subsistence people who consume large quantities of self-caught foods, particularly for sensitive sub-populations, such as pregnant women. We argue that rather than giving people blanket statements about the health benefits or risks from eating fish, information on mean and maximum mercury levels should also be provided on a wide range of subsistence foods, allowing informed decisions, especially by those most at risk.
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1. Introduction

Increasingly public health officials, the public, scientists and managers are concerned about contaminants in a range of self-caught or harvested foods. Hunting, fishing and gathering are still important lifestyles in many places in the World, particularly in poor communities or where small villages are isolated. Fishing, for example, is an important part of rural culture and tradition, particularly where the fishing season extends for many months, or where fishing is a necessary part of a subsistence lifestyle (Harris and Harper, 1997; Rothschild and Duffy, 2002; Toth and Brown, 1997).

Fish are an excellent, low-fat source of protein for humans that provides many benefits, such as omega-3 (n-3) fatty acids that reduce cholesterol levels and the incidence of stroke, heart disease, and pre-term delivery (Daviglus et al., 2002; Patterson, 2002). However, contaminants, such as PCBs and mercury, are sufficiently high in some fish and seafood to pose a potential health risk to consumers, particularly fetuses, neonates, and developing infants (Guallar et al., 2002; Gochfeld, 2003; Hites et al., 2004; IOM, 1991; NRC, 2000). Methylmercury (MeHg) counteracts the cardioprotective effects of omega-3 fatty acids (Guallar et al., 2002). In some countries and for some subsistence peoples, the significant source of methylmercury for the public is fish consumption (Rice et al., 2000). Fish and shellfish consumption is a classic case of risk balancing (comparing alternative risks and benefits), particularly when alternative protein sources (such as red meat) are considered (see papers in Am J. Prev. Med., Vol. 29, 2005). Yet individuals cannot make risk balancing decisions without information on the benefits and risks of a wide range of foods. For Alaska, Egeland and Middaugh (1997) have argued that the benefits of maintaining a subsistence diet outweigh the risks from contaminants.

Often contaminants of concern are evaluated in fish, and rarely shellfish, but a full range of subsistence foods are not usually analyzed due to the difficulty of obtaining specimens, the cost of analysis, and the belief that contaminants are generally low in organisms that are lower on the food chain. Yet in many subsistence communities, people eat a range of foods, including algae, shellfish and other invertebrates, fish, birds and mammals. Marine algae and kelp products are used in the human diet in many places, including the Arctic (Chan et al., 1995), in Canada (Sharp et al., 1988), and in Asian countries (Phaneuf et al., 1999; VanNetten et al., 2000). Shellfish and fish are clearly important worldwide as a food source. Birds and bird eggs are a seasonally important food source (Blanchard, 1994), and in some regions, birds are dried for use later. Yet despite the range of subsistence foods used in many cultures, there are few studies that have examined mercury levels in these foods (but see Marcotrigiano and Storelli, 2003).

In this study mercury levels were examined in a range of subsistence foods collected from Nikolski, Adak, Amchitka and Kiska Islands in the Aleutian chain of Alaska. As with other subsistence Alaskans, fish and other subsistence foods are part of the Aleut diet all year (Rothschild and Duffy, 2002). Subsistence foods examined include kelp and other algae, shellfish and other invertebrates, fish, and birds and bird eggs. This study did not include marine mammals, although there have been a number of studies of contaminants in mammals, some even from this region (Beckmen et al., 2002; Hobson et al., 2004). The study assumes that one way to reduce risk from contaminants, such as mercury, is to provide the subsistence hunters and fishermen, and the people who cook and prepare the food, with data on contaminant levels. Such data can be used to make informed decisions about whether and when and how much of a particular item to hunt and consume. Information about such risk–risk decisions is routinely provided by the media and medical press aimed at the lay public (e.g. Prevention Magazine, January 2002; Chicago Tribune articles, Roe and Hawthorne, 2005; Consumer Reports, 2006). This study has the additional advantage that all subsistence foods samples were collected by Aleuts in their traditional manner, and some were also collected by scientist. Further, it can serve as a baseline for future studies from this region.

Risk assessors generally spend time determining risk with the use of site-specific information on both contaminant levels and consumption rates. Consumption data, however, are notoriously difficult to obtain, particularly for small and isolated communities, for people with high consumption of harvested foods, for communities where subsistence foods vary seasonally and yearly (depending on local populations of plants or animals), and for closed communities where people do not talk to strangers. Such communities often are not amenable to invasive collection of blood or other tissues for direct analysis of mercury exposure, as is occurring among urban anglers (Gobeille et al., 2006). Risk assessors often resort to the use of default exposure assumptions in examining the risks from fish consumption (Marien and Stern, 2005).

Consumers can receive information about seafood safety from their health care providers, from state or federally-issued health advisories, or from friends or relatives. A recent poll of health professionals (N=1423) indicated that 55% of MDs and 60% of nurses advocate moderate consumption of seafood within recommended guidelines (6–24 oz/week, depending upon risk factors, MedScape, 2006). Further, only 14% of MDs advocated consumption of any amount of seafood, and 28% of MDs did not discuss seafood consumption with their patients.

Another approach risk managers can take to lowering potential risk from contaminants is to provide the communities themselves with information on contaminant levels in different subsistence foods and methods of reducing risk through species selection, avoiding some parts of fish, and different cooking methods. This paper addresses the question of variation in mercury levels in a range of subsistence foods of the Unangan (=Aleut) peoples living in the Aleutian Islands. Considerable time and attention has been devoted to contaminants in mainland Alaskan subsistence communities (Carpenter et al., 2005; Duffy et al., 1999), as well as other Native Americans (DeCaprio et al., 2005). However, data are not available for Aleutian communities despite some similarities in subsistence lifestyles of Native peoples.

A series of studies from Harvard (Willett, 2005) examined the benefits of fish consumption on a wide range of public health endpoints, and concluded that where there are potential risks and benefits, both risk and benefit information should be provided. Recently an Institute of Medicine (IOM, 2006) study concluded that for most people, the health benefits of eating fish and shellfish clearly outweigh any risks from contamination by toxic chemicals. However, Aleuts and other subsistence peoples are not most people, and pregnant Aleuts who live on remote islands with no access to supermarkets rely heavily on subsistence foods. This paper provides them with information on mercury levels in a wide range of subsistence foods, and illustrates the importance of wise choices among such foods, particularly for pregnant women. Actual food choices, however, will be based on a number of factors, including food preferences and cultural mores.

2. Methods

Subsistence foods were collected in July and August 2004 from the Aleutian islands of Adak (52° N lat; 176° W long), Amchitka (51° N lat;179° E long) and Kiska (51° N lat;177° E long, Fig. 1), and in spring 2005 from Nikolski (52° N lat; 168° W long). Salmon samples were also collected from Atka (52° N lat; 174° W long) in August 2003. Amchitka and Kiska Islands are part of the Alaska Maritime National Wildlife Refuge that was established in 1913 by executive order of President Taft (ATSDR, 2000). There are small Aleut communities on Adak (ca 200), Nikolski (ca 38) and Atka (ca 100), but Amchitka and Kiska are currently uninhabited although they are traditional Aleut homelands. Further, fishermen from Atka sometimes go as far as Amchitka to catch some fish, particularly halibut. Nikolski is the oldest continually-occupied community in North America (Black, 1974; Schlung, 2003). There are twice-weekly flights to Adak, Atka, and Nikolski, which can bring food, although most commercial food arrives by ship. Inclement weather often results in cancellations of both planes and ships, and schedules vary from year to year, making the delivery of fresh foods problematic. Adak and Atka have harbors, but Nikolski does not.

Algae, invertebrates and fish were collected from Adak, Amchitka, and Kiska under appropriate permits from the State of Alaska's Department of Fish and Game (# CF-04-043), and birds and eggs were collected under permits from the State of Alaska and the U.S. Fish and Wildlife Service (# 04-079 and MB086658-0). Fish were collected from all four islands either from land or boat, with rod and reel by Aleuts and by scientists, and with trawling and underwater spearing by scientists while on the trawlers, Ocean Explorer or Gladiator. While underwater spearing is not an Aleut practice, we also wanted to compare these methods with more traditional ones. Aleuts from Nikolski and Adak were on the expedition to Amchitka and Kiska, and collected samples in all locations, in the traditional manner used in their villages. There were few differences in the types and sizes of fish collected by Aleuts and scientists (Burger et al., 2006a).

Algae was collected by hand from the intertidal region by Aleuts and scientists; invertebrates were generally

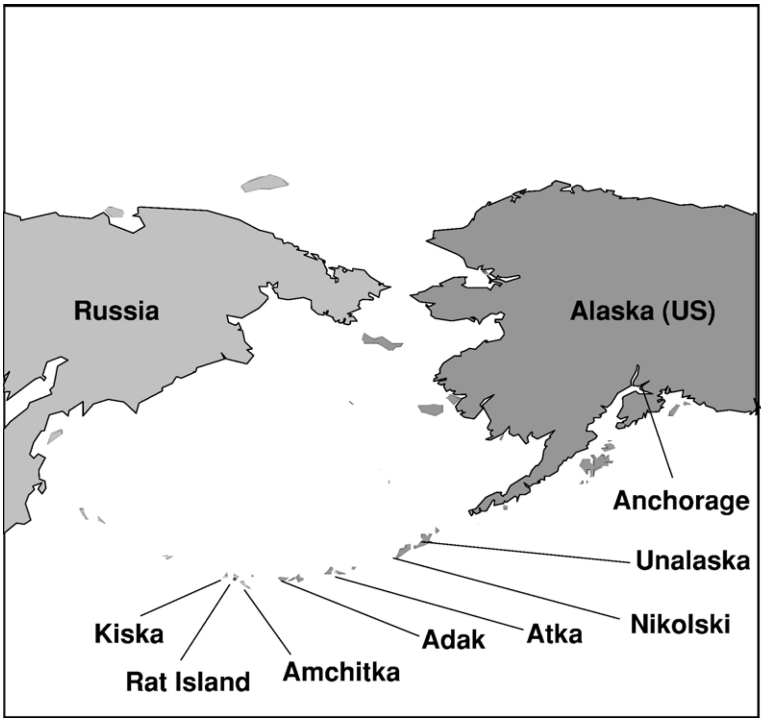

Fig. 1. Map of Aleutians showing key Aleut villages and site of collection of samples.

collected by Aleuts, and birds were shot by both Aleuts and scientists. Fish were caught with a rod and reel in all study sites, although not all species were collected at all sites. Fish and birds were immediately measured, weighed and dissected, and samples of muscle were frozen for later analysis. Algae and invertebrates were measured and weighed, and appropriate soft tissues were frozen. All samples were given a unique number and had Chain of Custody forms with the following information recorded: specimen number, species, age class where appropriate, date, island, location from that island, collector, and preparator. All samples were shipped frozen to the Environmental and Occupational Health Sciences Institute (EOHSI) of Rutgers University for metal analysis.

Samples collected at Adak, Atka and Nikolski were collected only for this study, but samples collected at Amchitka and Kiska 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 (Burger et al., 2006a,b, 2007a). Levels of all anthropogenic radionuclides examined were well below safe human health risk guidance levels (Powers et al., 2005). Scientific names for all species examined in the present study are given in Table 1. Bald eagle is the only species in Table 1 that is never eaten by Aleuts, but it is presented for comparative purposes.

Since all samples collected at Nikolski, and many of the samples collected from Adak and Atka were collected by subsistence hunters and fishermen as part of their regular activities, it was difficult to obtain the same number of samples of each species from each place. We selected samples for analysis randomly from each location where samples were collected. At EOHSI, a 2 g (wet weight) sample of tissue was digested in ultrex ultrapure nitric acid in a microwave (MD 2000 CEM), using a digestion protocol of three stages of ten minutes each under 50, 100 and 150 pounds per square inch (3.5, 7, and 10.6 kg/cm^2) at 70× power. Digested samples were subsequently diluted to 25 ml with deionized water. Instruments 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 0.0002 ppm, and a matrix level of quantification of 0.002 ppm. All concentrations (total mercury) are expressed in parts per million (ppm = ug/g) on a wet weight basis. We use ppm throughout because that is the term used by state and federal agencies when communicating with the public generally, and when discussing risk from fish consumption. Normally, people do not dry foods completely before eating them (except for salmon and some algae). We have

Table 1
Mercury levels (ppm, wet weight)(μg/g) of species collected from the Aleutian Islands, Alaska

Common name	Scientific name	Trophic Level	*n*	Max	Mean±SE	Duncan letter grouping	Correlation with weight
Algae							
Kelps (brown algae)	*Hedophyllum sessile*	Primary producer	15	0.001	0.001±0.000	(C)'	[a]
Kelps (brown algae)	*Fucus distichus*	Primary producer	22	0.002	0.001±0.000	(B,C)	[a]
Sea lettuce	*Ulva latuca*	Primary producer	12	0.003	0.002±0.000	(A)	[a]
Kelps (brown algae)	*Alaria nana*	Primary producer	52	0.039	0.005±0.001	(A,B)	[a]
Invertebrates							
Green sea urchin	*Strongylocentrotus polyacanthus*	Grazer	30	0.016	0.005±0.001	(F)	0.2 (NS)
Limpet	*Tectura scutum*	Grazer	10	0.022	0.009±0.002	(E)	0.7 (0.009)
Chiton	*Cryptochiton stelleri*	Grazer	20	0.021	0.010±0.001	(E)	−0.5 (0.003)
Blue mussel	*Mytilus trossulus*	Filter feeder	148	0.040	0.016±0.001	(D)	0.04 (NS)
Rock jingle	*Pododesmus macroschisma*	Filter feeder	20	0.026	0.018±0.001	(C,D)	0.0 (NS)
Oregon triton	*Fusitriton oregonensis*	Grazer	36	0.096	0.024±0.004	(C,D)	0.05 (NS)
Octopus	*Octopus dofleini*	Predator	5	0.064	0.038±0.011	(B,C)	0.8 (NS)
Golden king crab	*Lithodes aequispina*	Grazer/scavenger	14	0.070	0.043±0.005	(B)	0.02 (NS)
Red king crab	*Paralithodes camtschaticus*	Grazer/scavenger	5	0.205	0.101±0.027	(A)	0.2 (NS)
Fish (muscle)							
Sockeye salmon	*Oncorhynchus nerka*	Predator	15	0.066	0.042±0.005	(H)	[a]
Atka mackerel	*Pleurogrammus monopterygius*	Predator	19	0.077	0.046±0.004	(F,G,H)	0.3 (0.07)
Pacific ocean perch	*Sebastes alutus*	Predator	17	0.139	0.048±0.009	(G,H)	0.6 (0.0006)
Northern rock sole	*Lepidopsetta polyxystra*	Predator	15	0.133	0.068±0.007	(D,E,F,G)	−0.02 (NS)
Walleye Pollock	*Theragra chalcogramma*	Predator	12	0.215	0.074±0.018	(E,F,G,H)	0.5 (0.02)
Rock sole	*Lepidopsetta bilineate*	Predator	27	0.247	0.092±0.011	(C,D,E,F)	0.4 (0.007)
Rock greenling	*Hexagrammos lagocephalus*	Predator	84	0.493	0.099±0.010	(D,E,F,G,H)	0.3 (0.0002)
Dolly varden	*Salvelinus malma*	Predator	75	0.552	0.114±0.013	(E,F,G,H)	0.05 (NS)
Red irish lord	*Hemilepidotus hemilepidotus*	Predator/scavenger	57	0.335	0.130±0.010	(C,D)	0.3 (0.003)
Pacific halibut	*Hippoglossus stenolepis*	Predator	24	0.928	0.158±0.044	(C,D,E)	0.4 (0.003)
Black rockfish	*Sebastes melanops*	Predator	68	0.506	0.167±0.015	(B,C)	0.4 (<0.0001)
Pacific cod	*Gadus macrocephalus*	Predator	142	0.859	0.173±0.011	(B,C)	0.4 (<0.0001)
Flathead sole	*Hippoglossoides elassodon*	Predator	39	0.517	0.277±0.013	(A)	0.1 (NS)
Yellow irish lord	*Hemilepidotus jordani*	Predator/scavenger	68	0.944	0.281±0.024	(A,B)	0.2 (.01)
Great sculpin	*Myoxocephalus polyacanthocephalus*	Predator	27	1.096	0.366±0.058	(A)	0.5 (0.0002)
Birds							
Tufted puffin	*Fratercula cirrhata*	Predator (small fish)	21	0.257	0.121±0.016	(D)	0.03 (NS)
Common eider	*Somateria mollissima*	Predator (mussels)	20	0.182	0.123±0.008	(C,D)	0.1 (NS)
Bald eagle (chicks)	*Haliaeetus leucocephalus*	Predator/scavenger (large fish)	2	0.224	0.128±0.097	(D)	[a]
Common eider egg	*Somateria mollissima*	Predator (mussels)	51	0.409	0.191±0.010	(C)	
Glaucous-winged gull	*Larus glaucescens*	Predator/scavenger	32	0.851	0.329±0.030	(B)	0.05 (NS)
Glaucous-winged gull egg	*Larus glaucescens*	Predator/scavenger	21	0.808	0.364±0.037	(A,B)	
Pigeon guillemot	*Cepphus columba*	Predator (invertebrates/ small fish)	21	0.855	0.494±0.037	(A)	−0.2 (NS)
Mammal							
Sea lion muscle	*Eumetopias jubatus*	Predator	1		1.03		
Sea lion liver	*Eumetopias jubatus*	Predator	1		69.5[b]		

Given are arithmetic means±SE (total mercury) with Duncan values in parentheses (species sharing the same Duncan letter do have no significant difference in mercury at .05 level). All species were eaten by Aleuts except bald eagle.
[a]Measurements not taken.
[b]This value was measured several times from newly digested samples.

found that dry weight in freshwater fish ranged from 23 to 33% of the corresponding wet weight (i.e., water content of 67–77%, Burger et al., 2001b), and in the cold-water fish examined in this study, they ranged from 18 to 24%). In algae from this study, dry weight ranged from 11 to 19% of wet weight, and in bird eggs, it ranged from 45 to 52%. Many studies have shown that almost all of the mercury in fish and avian tissue is methylmercury, and 90% is a reasonable approximation of this proportion, which does vary somewhat among types, laboratories,

Table 2
Mercury levels (ppm, wet weight)(μg/g) of Aleut foods collected from 6 islands (east to west) in Alaska

Species	Nikolski	Atka	Adak	Amchitka	Rat Island	Kiska	$X^2(p)$
Algae							
Hedophyllum sessile				0.001±0.000 (A)		0.001±0.000 (A)	0.2 (NS)
Fucus distichus				0.001±0.000 (A)		0.001±0.000 (A)	1.5 (NS)
Sea lettuce (*Ulva* sp)				0.002±0.000 (A)		0.002±0.000 (A)	0.6 (NS)
Alaria nana			0.007±0.002 (A)	0.002±0.001 (B)		0.007±0.002 (A)	8.2 (0.01)
Invertebrates							
Green sea urchin			0.007±0.001 (A)	0.004±0.001 (B)		0.003±0.000 (B)	12.3 (0.002)
Limpet				0.009±0.002			
Chiton			0.015±0.001 (A)	0.005±0.000 (B)			14.3 (0.0002)
Blue mussel			0.016±0.001 (A)	0.013±0.002 (A)		0.014±0.001 (A)	3.2 (NS)
Rock jingle				0.018±0.002 (A)		0.018±0.002 (A)	0.0 (NS)
Oregon triton			0.037±0.009 (A)	0.025±0.004 (A)		0.011±0.001 (B)	13.1 (0.001)
Octopus				0.038±0.011			
Golden king crab				0.053±0.006 (A)	0.039±0.006 (A)		2.0 (NS)
Red king crab					0.101±0.027		
Fish							
Sockeye salmon		0.035±0.007 (A)	0.049±0.008 (A)				1.9 (NS)
Atka mackerel				0.045±0.006 (A)	0.050±0.008 (A)	0.045±0.006 (A)	0.5 (NS)
Pacific ocean perch				0.064±0.011 (A)		0.019±0.005 (B)	8.2 (0.004)
Northern rock sole				0.069±0.012 (A)	0.067±0.008 (A)		0.004 (NS)
Walleye pollock			0.098 (A)	0.028±0.005 (A)		0.109±0.028 (A)	7.2 (0.03)
Rock sole			0.095±0.023 (A, B)	0.070±0.019 (B)		0.110±0.014 (A)	4.9 (0.08)
Rock greenling	0.053±0.009 (A)		0.120±0.026 (A)	0.107±0.012 (A)		0.074±0.027 (A)	6.9 (0.07)
Dolly varden	0.024±0.005 (B)		0.023±0.008 (B)	0.157±0.016 (A)			25.2 (<0.0001)
Red irish lord				0.123±0.009 (A)		0.174±0.043 (A)	0.7 (NS)
Pacific halibut				0.324±0.134 (A)	0.078±0.001 (A)	0.095±0.013 (A)	3.2 (NS)
Black rockfish	0.160±0.069 (A)			0.168±0.017 (A)		0.166±0.036 (A)	0.008 (NS)
Pacific cod	0.153±0.022 (B)		0.316±0.070 (A)	0.201±0.017 (A, B)		0.111±0.012 (B)	19.0 (0.0003)
Flathead sole			0.276±0.013				
Yellow irish lord	0.248±0.036 (A)		0.042±0.038 (B)	0.235±0.026 (A)		0.391±0.052 (A)	10.9 (0.01)
Great sculpin			0.323±0.058 (A)	0.453±0.159 (A)		0.456±0.272 (A)	0.4 (NS)
Birds							
Tufted puffin				0.107±0.023 (A)		0.135±0.023 (A)	0.5 (NS)

Table 2 (*continued*)

Species	Nikolski	Atka	Adak	Amchitka	Rat Island	Kiska	$X^2(p)$
Birds							
Common eider				0.125±0.012 (A)		0.122±0.012 (A)	0.1 (NS)
Bald eagle (chicks)				0.031		0.224	
Common eider egg				0.184±0.008 (A)		0.207±0.024 (A)	0.5 (NS)
Glaucous-winged gull			0.352±0.047 (A)	0.359±0.056 (A)		0.269±0.048 (A)	1.5 (NS)
Glaucous-winged gull egg			0.380±0.055 (A, B)	0.254±0.047 (B)		0.471±0.071 (A)	6.2 (0.04)
Pigeon guillemot				0.448±0.035 (A)		0.545±0.067 (A)	1.7 (NS)
Mammal							
Sea lion muscle				1.03			
Sea lion liver				69.50			

Given are arithmetic means±SE (total mercury) with Kruskal–Wallis Chi Square values and p values. Duncan values are given in below. (Shared Duncan letter means no difference among islands at 0.05 level).

and seasons (Jewett et al., 2003). Appropriate ratios of methylmercury to total mercury for saltwater invertebrates need to be determined.

A DORM-2 Certified dogfish tissue was used as the calibration verification standard. Recoveries between 90–110% were accepted to validate the calibration. All specimens were run in batches that included blanks, a standard calibration curve, 2 spiked specimens, and one duplicate. The accepted recoveries for spikes ranged from 85% to 115%; no batches were outside of these limits. 10% 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 1) on two different mercury instruments within our own lab (Lumex and Perkin Elmer), and 2) in the Quebec Laboratory of Public Health. The correlation between the two EOHSI instruments, and between the EOHSI equipment and the Quebec laboratory is over 0.90 ($P<0.0001$, see Burger and Gochfeld, 2004).

Kruskal Wallis non-parametric one way analysis of variance (generating a X^2 statistic) was used to examine differences among species of subsistence foods. ANOVA with Duncan Multiple Range test on log-transformed data was used to identify the significant differences between islands (SAS, 1999). The level for significance was designated as $P<0.05$, although values of $P<0.10$ are given for comparison (larger sample sizes might have resulted in significance).

3. Results

There were significant interspecific differences in mean mercury concentrations within and among species groups (Table 1). Concentrations in all algae were an order of magnitude lower than all fish, and were two orders of magnitude lower than some fish and some birds. Red king crab has the highest mean mercury concentrations among invertebrates; mean concentrations were over twice as high as those in golden king crab (Table 1). Among fish, salmon, mackerel and ocean perch had the lowest levels, and flathead sole, yellow irish lord, and great sculpin had the highest mean concentrations (Table 1). Among birds, pigeon guillemot had the highest mean concentrations, followed closely by gulls and their eggs (Table 1).

Overall, the correlation between weight and length was high. Thus, the correlations between weight and mercury concentrations are presented in Table 1. Weight was significantly correlated with mercury levels for limpets and for 11 of the 15 fish species examined.

Although there were some significant differences in mean mercury concentrations among islands, the differences were generally not great and there was no clear pattern (Table 2). For fish, where levels could be high enough to be important for consumers, the highest levels were usually at either Adak or Amchitka. Differences among islands become more important as the overall mean levels are higher, as in some fish. Levels were sometimes three times higher at one island than another. For example, mean concentrations in Pacific cod were three times higher on Adak than at Kiska, but in yellow irish lord these differences were reversed. There were no interisland differences for birds (Table 2).

One way to consider mercury concentrations in subsistence foods is to examine the percent of samples above regulatory action or guidance levels (Table 3).

Table 3
Percent of invertebrates, fish, and birds with total mercury levels above regulatory action levels

Species	%> 0.2 ppm	%> 0.3 ppm	%> 0.5 ppm	%> 1 ppm
Invertebrates				
Red king crab	20	0	0	0
Fish				
Walleye pollock	8	0	0	0
Rock sole	7	0	0	0
Rock greenling	13	2	0	0
Red irish lord	19	2	0	0
Dolly varden	17	9	1	0
Pacific halibut	13	13	8	0
Black rockfish	32	18	1	0
Pacific cod	33	13	4	0
Flathead sole	82	33	3	0
Yellow irish lord	60	35	12	0
Great sculpin	59	48	30	4
Birds				
Tufted puffin	24	0	0	0
Common eider egg	53	14	0	0
Glaucous-winged gull egg	71	52	5	0
Glaucous-winged gull	72	56	13	0
Pigeon guillemot	95	95	43	0

This provides some indication of the likelihood that a given meal of a subsistence food would be above the action level (Table 3). Great sculpin and pigeon guillemot were the species with the highest percentage of samples above 0.5 ppm. The significance of the action levels is examined in the discussion below.

4. Discussion

4.1. Trophic level differences in mercury

The route of uptake of mercury differs for the organisms examined: 1) algae take up metals in proportion to the external concentration in surrounding water (Phillips, 1990), 2) invertebrates also take up metals from the water and also their food, 3) fish take up metals primarily from food, but also from water, and 4) birds take up metals through food. Thus, algae and invertebrates would be expected to have lower levels of contaminants, and fish and birds would show a food chain relationship, where organisms higher on the food chain should have higher levels.

In this study, mercury levels were one or two orders of magnitude lower, depending upon species, in algae and invertebrates than in fish and birds, suggesting a trophic level relationship. Within recognizable food chains, top-level predators had higher levels of mercury. Thus, octopus had higher levels than lower level invertebrates or algae. King crabs, invertebrates that are scavengers (and thus can eat higher trophic level carrion), had higher mercury levels than the other invertebrates. Gulls and eagles that eat fairly large fish had higher levels than the fish they eat, which in turn had higher levels than invertebrates. Finally, the one sea lion tested at the request of Aleut hunters, had higher levels than the fish (it eats many of these species).

However, habitat also played a role. Mercury levels in inshore predatory species, reflecting metals derived from inshore foraging habitats, were higher than those of organisms with a wider home range. Of birds, pigeon guillemot and eagle muscle had the highest levels of mercury. Eagles generally remain close to land, picking up fish and carrion along the coast, and guillemots forage closer to shore than puffins. Of fish, inshore, bottom-dwelling fish had the highest levels (flathead sole, irish lords), and species that spend more time at sea (salmon, Atka mackerel) had the lowest levels. This even held true for brown kelp (*Alaria nana*) that grew at deeper depths than the other algae, and had lower levels than the more intertidal species.

There were some interesting findings that bear comment: 1) *Alaria nana* had higher levels than the other algae, 2) red king crab had higher levels than golden king crab, 3) some bottom-dwelling fish, such as sculpin and sole, had the highest levels of any fish, and 4) pigeon guillemot, the smallest fish-eating bird examined, had the highest levels of mercury. We expected pigeon guillemot to have the lowest levels among birds because they eat smaller fish, however, these birds had levels in muscle that were twice as high as other birds. We cannot account for this difference based on either prey fish eaten or habitat where they feed. The other differences, due to habitat and trophic level, bear consideration in terms of risk to consumers, including people.

During our expedition the Aleut hunters conducted one subsistence hunt for a sea lion, and subsequently requested that a sample be tested for food safety. The level in the liver, checked several times with newly digested material, was 70 ppm, which was two orders of magnitude higher than samples from any of the other species. This information was specifically requested by the Aleuts because liver is considered a delicacy by some. Similar levels have been found in liver of sea lions from California (74.1–96 ppm, Buhler et al., 1975; 38–64 ppn, DeLong et al., 1973) and from Oregon (91–249 ppm, Buhler and Mate, 1971). However, Buhler et al. (1975) reported that only 1.6 to 3.7% of the mercury in the liver was MeHg, while almost 100% of the mercury in muscle was MeHg. This results in the amount of MeHg in the liver being similar to that in the muscle, thus producing about the same risk.

4.2. Locational and size differences

Most of the samples in this study came from Amchitka, Kiska, and Adak, with a few additional samples from Atka and Nikolski. There were however, some significant locational differences in mercury concentrations that could have risk implications for the species themselves, and for consumers that eat them: 1) levels in ocean perch were three times higher at Amchitka than Kiska, 2) levels in chiton were three times higher at Adak than Amchitka, 3) levels in dolly varden were seven times higher at Amchitka than Adak. The latter is probably due to habitat; half of the dolly varden at Amchitka were collected in a land-locked lake (Cannikin) that had exposure during military occupation, and Cannikin Lake was created by the nuclear detonation (Kohlhoff, 2002). Military activities could have resulted in mercury contamination. However, the differences among the samples taken from the marine environment showed relatively small inter-island differences, which is useful in terms of exposure to organisms that eat them, including humans.

4.3. Human exposure

The organisms examined in this study were selected because they were Aleut subsistence foods, but they are also important to the general population. The importance of fish and shellfish in diets generally, as well as in subsistence diets, has been well documented. Moya (2004) noted that Native American populations have higher consumption rates of fish than recreational anglers, but did not deal with algae, shellfish or other invertebrates (such as octopus). Kelp and other algae form part of a subsistence diet for many Native Alaskans (Garza, 2005). Marine algae products are also used in the human diet in other places, particularly in Canada (Sharp et al., 1988), in Asian countries (Phaneuf et al., 1999; VanNetten et al., 2000), and particularly in the Arctic where kelp contributes significantly to the total metal intake (Chan et al., 1995). In every Aleut village visited as part of this project people asked about contaminants in algae, and mentioned the various ways they prepare it; in Unalaska non-Aleuts also asked about contaminants in algae. In addition, dried algae tablets have appeared recently in health food stores in North America (VanNetten et al., 2000). Marine algae is also used as feed for livestock, for soil manure, for abstracting iodine, and for colloid production (e.g. in agar, Caliceti et al., 2002).

Obtaining information on consumption patterns is difficult in Native American communities such as the Aleutians because they are isolated and may be reticent about their diets, sometimes are wary about mentioning foods that other people do not eat or are not legally allowed to eat, and low population levels make it difficult to obtain an adequate sample from small and remote villages. For example, Nikolski had a total population of 38 at the time of our visit. A study in False Pass, Alaska, found that residents used a minimum of 59 kinds of wild resources, including 19 kinds of fish, 13 kinds of marine invertebrates, 12 kinds of birds and their eggs, and 11 kinds of mammals (Fall et al., 2006). All households used wild resources. Individual households averaged 22.6 kinds of wild resources, and 95% gave away portions of their catch. Every household used salmon, other fish, marine invertebrates and wild plants, and 90% used birds and land mammals (Fall et al., 2006). Individual species frequencies of household use were: sockeye salmon (95%), halibut (95%), octopus (90%), chitons (85%), dolly varden (75%) and king crab (75%), to name a few (Fall et al., 2006). In a report on subsistence food use in Unalaska and Nikolski, Hamrick and Smith (2003) reported that the most frequently consumed foods were halibut, salmon (several species), seal oil, cod, and king crab.

In our visits in the Aleut villages, we also heard that every household ate wild foods. Fish seemed to be the staple item, although they relished marine mammals and birds when available. Teen-agers, a group not normally interviewed in consumption studies, were more forthright about some of the foods they shot and ate, including small shorebirds. The most complete information will be gathered by resident subsistence hunters themselves. One advantage of this study was that Aleuts from the villages collected many of the organisms, and provided information on the types of species consumed, the parts eaten, and cooking practices (or lack thereof in the case of fish eggs, some shellfish). In an overview of fish consumption rates in the United States, Moya (2004) summarized the data sets that were available on Native American populations, and noted that none were from Alaska. Despite the information on consumption behavior from the Aleut villages described above, quantitative data are lacking.

A second problem with determining consumption patterns of subsistence people is seasonal variation in availability of different foods. Many species of birds are migratory, and fish may be migratory or simply move offshore, making them less available. Understanding consumption patterns based on these differences among Native American communities is made more difficult when villages are remote.

Finally, preferences play a role in consumption, and these preferences act on top of availability. For example, the Aleuts on the expedition liked and ate rock greenling all year, but ate other fish (such as sculpin) only when nothing else was available (or they had a bad fishing day); they preferred octopus, halibut or sea lion over other available fish. These kinds of preferences that are dependent upon the biology and idiosyncracies of given seasons make determinations of consumption patterns both difficult, and unrealistic in terms of risk issues. That is, in the normal course of events, a developing fetus may be exposed to very different foods in a given month because of differences in presence, availability (can they catch it), and preferences.

4.4. Risk to humans

The available published information on Aleut consumption, and our informal surveys in the villages we visited, suggest that Aleuts are eating subsistence foods every day, that they eat large quantities of fish (especially salmon), and that their diet varies seasonally depending upon availability and individual choices (see above). For example, it is relatively easy to gaff salmon in streams close to town, requires more effort to go out for halibut, and considerably more time and effort to hunt marine mammals. Further, most households have freezers, allowing them to eat fish and game all year; others have smoke houses for salmon and other fish. Halibut and sea lion are large and the excess is frozen for later consumption.

Methylmercury is one of the main contaminants of concern in fish. The USFDA action level for methylmercury in fish is 1.0 ppm (ug/g, w/w), but this is a regulatory action level, rather than a risk level (FDA, 2001, 2003, 2005). In contrast, the level that would trigger a one meal per week 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 mercury in fish muscle of 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 US EPA (2001) promulgated 0.3 ppm as an ambient freshwater quality standard in 2001, but this value was developed using consumption levels (7 μg/day for a 70 kg person) that are far less than those of the Aleuts.

Table 3 shows the percent of the samples for each fish and bird species that exceeded the different action levels. The percent of fish samples above 0.5 ppm is also important so that people are aware of the percent of times an exposure in a single meal may approach the tolerable daily intake (Berti et al., 1998). As is clear, there is a great deal of difference among the subsistence fish and birds that affect exposure. Several fish samples exceeded the level of 0.3 ppm at least a third of the time, while three of the birds did so (Table 3).

Risk assessments are based on chronic exposure, and not on 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. While the risk from a pulsed exposure has not been specifically examined, particularly with respect to its impact on a developing fetus at a critical developmental period, we suggest that information on maximum values should be routinely presented. In the present study, for example, a woman would exceed the 2.0 threshold in a single day if she ate sea lion muscle twice a day or sea lion liver once a day. However, she would be over the 2.0 threshold if she happened to eat any number of fish that were at the high end of mercury levels three times a day (or larger quantities of these fish or birds twice a day), including cod, sculpin, irish lords or halibut, and guillemot or gull eggs. These are not unreasonable amounts for the Aleuts we met and interviewed. An Aleut woman could easily have two meals of fish, birds, or sea lion that were at the high end of the variation. For example, a large fish (with high levels) might be eaten at consecutive meals, giving a pulse of high mercury for the day. We suggest that the high single-meal exposure for subsistence peoples should be expanded to a high single-day exposure scenario, since subsistence people often eat part of the same organisms at several meals in the same day.

Finally, we suggest that providing Aleuts and others with information on levels of mercury, as well as dangerous threshold levels for sensitive populations, will allow them to make their own risk management decisions. Aleuts and others living in remote regions of the world make risk decisions all the time, concerning, among other issues, where and how to hunt, and where and how to fish, when to conduct these activities (depending upon rough weather or sea conditions). We believe that providing them with risk information is the key to allowing them to make informed risk decisions.

5. Conclusions

There are a number of public health implications of this study. A series of studies from Harvard (Willett,

2005) that examined the positive benefits of fish consumption on public health noted that a recent decrease in fish consumption was "probably influenced" by fears about mercury, and concluded that where there are potential risks and benefits, both risk and benefit information should be provided. Egeland and Middaugh (1997) argued that for Alaskans the benefits of maintaining a subsistence diet are more important than the risks from contaminants. An Institute of Medicine (IOM, 2006) study concluded that for "most people", the health benefits of eating finfish and shellfish outweigh any risks from contamination by toxic chemicals. The operative word, however, is "most" people, and we maintain that public health officials should still consider and provide information to high-end consumers, since clearly even non-subsistence people can obtain enough mercury from fish to provide clinical symptoms of mercury positioning (Hightower and Moore, 2003). Further, Aleuts and other subsistence peoples are not most people, and pregnant Aleuts who live on remote islands with no access to supermarkets can rely heavily on subsistence foods.

The data from this study show a wide range in mercury level in Aleut subsistence foods, from 0.001 ppm in kelp to 0.69 ppm in sea lion liver. Most algae were below 0.005 ppm, and most invertebrates were below 0.05 ppm, an order of magnitude below the level generally considered safe by some states and countries. Birds showed a range of mean values from eider muscle to pigeon guillemot muscle, which was nearly 0.5 ppm, clearly a level of concern. Fish also showed a range from species that averaged very low (salmon, ocean perch) to species that averaged 0.3 ppm. The wide variation in mercury levels in Aleut subsistence foods suggests that women (pregnant or in the child-bearing age) could choose foods to reduce their mercury intake while still eating a largely subsistence diet.

While most consumption advisories suggest limits on the amount of specific fish (or all fish, in the case of some waters, Burger and Gochfeld, 2006), we suggest that a prudent approach for subsistence cultures is to provide people with the information on mercury levels in different wild-caught foods, and with information on safe levels for different risk groups. Some fish with high levels may not be preferred (such as irish lords and sculpin, according to some Aleuts); informing them of the levels might encourage them to avoid these species. Providing information on mercury levels is especially prudent for subsistence cultures where consumption patterns vary daily and seasonally. For example, in the Aleutians, Aleuts consume bird eggs (with mean mercury levels of 0.19 ppm and 0.36 ppm, and maximums of 0.81 ppm) mainly in June, and they are not frozen for later consumption. Some species, such as salmon are dried, smoked, or frozen for use throughout the winter, while others are only frozen (halibut). Marine organisms also show seasonality of metal content (Vasconcelos and Leal, 2001). Dried fish obviously contain higher mercury levels per oz because of the moisture loss during drying, and this loss would have to be accounted for. During the spawning season, salmon are sometimes consumed three meals a day (which may be over 8 oz each), and the mercury levels suggest that this is not a problem (and women could be so informed).

The risks from consumption of fish are not limited to mercury, but include PCBs and other contaminants (Huang et al., 2006). Although there is no apparent risk from radionuclides in these same species (Burger et al., 2006b, 2007b), information on PCBs is not yet available. However, Egeland and Middaugh (1997) have called attention to the countervailing nutritional value of fish consumption, which increases the importance of identifying suitable local fish with low contaminant levels, especially during pregnancy. It is a matter of risk balancing (Burger and Gochfeld, 2006; Gochfeld and Burger, 2005; Willett, 2005). Such considerations of risk–risk tradeoffs are beginning to make the popular press (Cohen, 2006). Public health losses due to decreased fish consumption could derive from two sources: 1) fish consumption is associated with decreased heart disease (Konig et al., 2005), and 2) fish consumption by pregnant women is associated with improved fetal cognitive function (Cohen et al., 2005a). Public health losses could occur if women, particularly of child-bearing age, decrease fish consumption, although switching from high to low-contaminant fish confers health benefits (Cohen et al., 2005b). One way of providing appropriate information, especially to women of child-bearing age, is to produce information that lists contaminant levels in fish (especially mercury and PCBs), as well as levels of omega-3 fatty acids. Such information should aim to be site specific as well as species specific, should include information on size and contaminant levels, and should be updated frequently. Finally, eating too many fish of species whose populations are threatened can damage food chains and ecosystem health, which in the long run, will impair human health (MEA, 2005; McMichael and Butler, 2005). Selection of fish low in mercury could put an added burden on some species of fish.

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