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ENVIRONMENT AND CONTAMINANTS IN TRADITIONAL FOOD SYSTEMS OF NORTHERN INDIGENOUS PEOPLES

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■ **Abstract** Traditional food resources of indigenous peoples are now recognized as containing a variety of environmental contaminants which reach food species through local or long-range transport avenues. In this chapter we review the published reports of contaminants contained in traditional food in northern North America and Europe as organochlorines, heavy metals, and radionuclides. Usually, multiple contaminants are contained in the same food species. Measurement of dietary exposure to these environmental contaminants is reviewed, as are major issues of risk assessment, evaluation, and management. The dilemma faced by indigenous peoples in weighing the multiple nutritional and socioeconomic benefits of traditional food use against risk of contaminants in culturally important food resources is described.

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INTRODUCTION AND DEFINITIONS

In this chapter, we discuss the impact of environmental contaminants on the traditional food resources of indigenous peoples. We limit our focus to food resources that are locally available to indigenous cultures in northern North America and northern Europe and to a limited list of approximately 21 organochlorine, heavy-metal, and radionuclide contaminants. The review covers the impact of contemporary dietary change on contaminant exposure, how exposure is measured, and general principles of contaminant risk as it applies to the traditional food resources of northern indigenous peoples. Our review includes the multidisciplinary literature, taking into consideration the primary methods of nutrition and toxicology and incorporating the multiple benefits of traditional food use that must be weighed against the possible risk of contaminants in culturally important food resources.

Traditional Food Systems

The term “traditional food system” includes all of the food species that are available to a particular culture from local natural resources and the accepted patterns for their use within that culture. This term also embraces an understanding of the sociocultural meanings given to these foods, their acquisition, and their processing; the chemical composition of these foods; the way each food is used by age and gender groups within a selected culture; and the nutrition and health consequences of all of these factors for those who consume these foods.

Indigenous Peoples

Generally speaking, the term “indigenous people” refers to a cultural group in a particular ecologic area that has developed a successful subsistence base by using available natural resources. The various terms used for indigenous peoples and a summary of perspectives on their place in society have been recently reviewed (72).

In this review, we describe the reported contaminant exposures of indigenous peoples in ecological settings of Alaska, other areas of the United States, Canada, Greenland, and northern Europe. We refer to First Nations peoples (formerly called Indians) from several different locations in the United States and Canada; Inuit (also called Eskimos) from Alaska, arctic Canada, and northern Europe; Metis (those of mixed European and aboriginal ancestry in Canada); the Saami of northern Scandinavia; and the indigenous minorities of Russia. All of these cultures have in common a deep spiritual relationship with the land and the life forms it supports. Traditional food species include wild animals and plants and agricultural species. It is the lower latitudes where traditional agricultural food systems predominate, with more intense use of wild animals, fish, and sea mammals in more northern latitudes.

The focus on the presence of contaminants in traditional food systems of indigenous peoples and the impact of these contaminants on the lives of those using the food systems is important because these systems and cultures are sentinels of global food and nutritional health. Because foods from the natural environment have been used as subsistence for thousands of years by indigenous peoples living close to the land, traditional food systems hold fascinating insights into many issues of human food use and nutrition, such as the evolution of human diets, preindustrial dietary patterns and nutritional requirements, and food species that may be revisited for their potential as global food resources. Although many non-indigenous peoples may consume the same wildlife (fish, game, or plants) as food, it is the indigenous peoples who retain the most knowledge about these foods, including how total diets of traditional food are constituted. That naturally grown and harvested food species produced by the world's original cultural groups may be contaminated beyond what is generally considered fitness for human consumption or that these foods may contribute to morbidity or mortality because of contamination are serious matters, and understanding them should bolster efforts toward global control of environmental pollution.

Contaminants

The chemical contaminants considered here are primarily those that are transported to the northern environments by long-range atmospheric currents and have bioaccumulated in the food chains of northern indigenous peoples (8, 60). Besides long-range transport, some contaminants are problematical because of additional local sources of contamination, which results from local geology and/or industrial activities such as mining and pesticide use. We have not included review of other contaminants that are found in food species, such as microbiological or viral contaminants, those associated with insects or other vermin, or those associated with disposal of human and community waste.

Heavy metals covered in this review include arsenic, cadmium, lead, and mercury. The following organochlorines are included: aldrin, chlordane, chlorinated benzenes, dichlorodiphenyl-trichloroethane (DDT), dieldrin, dioxin, hexachlorocyclohexanes (or lindane), polychlorinated biphenyls (PCBs), and toxaphene. The radionuclides covered include cesium-137, cesium-134, strontium-90, iodine-131, polonium-210, radium-226, and lead-210.

ISSUES SURROUNDING ENVIRONMENT AND CONTAMINANTS FOR INDIGENOUS PEOPLES

The contexts in which foods are produced and consumed must be considered when evaluating contaminants in the food systems of indigenous peoples. In particular, it is germane to understand the extent of use of these foods and their places in total contemporary diets. Also, an understanding of the sources of contaminants in remote arctic areas is needed. These data lead to better appreciation of contaminant exposure through diet or body burden and how these assessments can lead to risk evaluation and risk management for communities of indigenous people.

Current Patterns of Traditional Food System and Species Use

Like all developing societies, indigenous peoples are undergoing dietary change, and the major manifestation is their use of fewer species and lower total quantities of local traditional food resources and more commercially produced, imported market food. People choose their food items based on a variety of environmental, societal, and personal factors. These include broad considerations of food availability and quality (e.g. as influenced by climate, environmental pollution, species survival, and harvesting/processing technology), cultural preferences and practices (e.g. for taste and texture of food, meal structure, and beliefs about food and food distribution), affordability in the broad definition (e.g. costs involved in purchase or harvest), education and media influences, and biological needs [e.g. age and gender constraints, exercise, and illness (70, 72)].

Several studies of northern indigenous peoples have documented the dichotomization of their contemporary diets into traditional food and market food, with attention to the fact that market food usually provides a greater proportion of daily energy. After a dietary-patterns study conducted bimonthly over a full year in a Baffin Inuit community, it was reported that men's average market food intake provided 62% of total dietary energy expended, with the maximum average intake of market food equaling 70.5% of energy during the early winter and the minimum average intake equaling 53% during the late summer harvest season (67). Communities in other Canadian arctic areas have a similar dichotomy of food use between traditional and market foods; however, the degree of transportation remoteness from southern food supplies can affect these data. For example, among women in the sister Sahtú Dene/Métis communities of Kásho Goti̱ne and the more remote Káhbamitúé, those of Kásho Goti̱ne consumed seasonal amounts of 69%, 74%, and 71% of dietary energy as market food during spring, summer, and winter, respectively, but women of Káhbamitúé consumed only 50%, 42%, and 52% of dietary energy as market food during the same seasons, respectively (73). Receveur et al (98) showed that Dene/Métis communities that were evaluated in the two seasons of highest and lowest traditional-food intake had average total dietary energy from traditional food ranging from 12% to 33%. The levels were roughly parallel to latitude, with those who consumed more market food located further south and thus closer to food distribution networks.

Traditional food systems of northern indigenous peoples contain a broad range of species of both animals and plants that have filled important cultural and dietary needs. More recent studies of quantitative food use have shown that, although these people retain knowledge of the use of many plant species, the amount of animal food ingested far outweighs that of plant food (76, 83, 98–100, 126, 127).

The actual species and quantities of traditional food ingested are profoundly affected by season, with the result that both nutrient and contaminant profiles contributed by traditional food vary considerably during the year. For example, in the Inuit community noted above, where six bimonthly dietary evaluations were done, it was shown that certain species (seals in particular) were constants in the diet, whereas other species (e.g. caribou) that were available for a short season were consumed in abundance and favored over seals during that season. The total intake of traditional food by the community of ∼400 people averaged 138 kg/day, which varied from 100 kg/day in early winter to 180 kg/day in the late summer harvest season (67). Generally speaking, traditional food consumption is greater for men than for women and for older individuals than younger ones (73, 76).

As can be expected, traditional food contributes significantly to nutrient intake for arctic adults and children. Although usually providing smaller proportions of daily energy and total dry weight in diets than market food, traditional food contributes significantly more protein, iron, zinc, copper, and magnesium to the diets of Sahtú men, women, and children and, in addition, more vitamin A to the diets of Inuit men, women, and children (13, 67, 73, 76; see below).

Economic Development, Environmental Change, and Sources of Contaminants

With changes in the world economy, northern indigenous peoples have developed their communities to take advantage of resources beyond those available in the local environment. However, the extent of development has not been consistent for all. Families in many communities, reservations (in the United States), and reserves (in Canada) still rely on traditional food resources, by necessity or by choice, although, as noted above, the extent of market food use is considerable. The processes of delocalization of the food supply have intensified in recent years, with increasing socioeconomic and political interdependence. Although industrial societies have an increasing diversity of food species and processing techniques available to them through delocalization, many communities of indigenous people in rural areas experience the opposite effect, with a decreasing diversity of food items consumed as people use less of their traditional resources and rely more on limited kinds of market food (72, 95). The continuing importance of traditional local food in the diets of indigenous peoples makes the issues of contamination of these foods especially worrisome.

Increasing global industrialization, especially in the last 50 years, has caused pollution of all of the world's ecosystems. The formerly pristine northern homelands of indigenous peoples have also been affected, even though the industries at fault are often quite distant. Persistent contaminants are detected throughout northern ecosystems—in air, fresh water, seawater, snow, sediments, birds, fish, plants, and terrestrial and sea mammals (9, 47, 60, 85, 105). Pathways for delivery of contaminants into northern environments include atmospheric, marine, and freshwater/terrestrial routes. Although most sources are distant from the North, there are some local/regional sources, especially those related to mineral extraction (particularly heavy metals such as mercury and arsenic), local geology (such as mercury and cadmium), abandoned military sites (PCBs), and pesticide use (e.g. DDT and toxaphene) (86, 88, 111). Most radionuclide contaminants are the result of nuclear testing or contaminant release from nuclear power stations or nuclear satellites (9).

Contaminants in the environment can be accumulated in food species. Bioavailability of contaminants found in soils, sediments, plants, or water depends on factors such as their concentration and physical and chemical forms and physicochemical factors such as pH and organic-carbon content. Once an organism in the food chain assimilates a contaminant, it can be subject to bioaccumulation or can facilitate transfer of the contaminant to other organisms. Factors such as inertness of the chemical, solubility in lipid or water, and speciation for metals all influence bioaccumulation. In addition, the length of the food chain or the number of species it passes through before consumption by humans affects concentration of a contaminant in food through biomagnification—the successive increase in chemical concentration. For example, the highest biomagnification occurs between fish (prey) and marine mammals or sea birds (predators; 53, 85).

Contaminants present in marine, freshwater, or terrestrial wild food species that are consumed by northern indigenous peoples vary with the species, owing to factors of environmental and biological variability. Mercury and toxaphene are considered important contaminants in freshwater fish, marine fish, and mammals. Cadmium is a significant contaminant in the liver and kidney of important food land mammals such as caribou and moose. DDT, PCBs, and chlordane are important in piscivorus marine mammals as well as waterfowl and their eggs, and radionuclides are important contaminants in caribou. As noted earlier, regional differences in contaminant levels of food species depend on local mineralogy and mining, military radar sites, and proximity to heavy industrialization (e.g. the Great Lakes and St. Lawrence estuary). Differences within regions and species depend on the ages and genders of the animals. For example, older, larger animals contain greater concentrations of contaminants, and male animals generally accumulate more organochlorines than do young-bearing female animals (15, 85, 89).

Measurement of Contaminant Exposure Through Food Among Northern Indigenous Peoples

Similar to dietary assessments for nutrient intake, human contaminant exposure through food is measured by determining the contaminant level in each food consumed and assessing the extent of usual consumption. This is accomplished by constructing databases of contaminants in food and by dietary-intake interviews.

Interviews for these purposes have included 24-h recall (62) and food frequency interviews that are restricted to traditional food of the region and season (14).

The quality and variability of the food composition data must be understood for these assessments. Although data on harvested raw wildlife are often more plentiful and give direction to understanding the magnitude of contaminant presence, data on the composition of food consumed by individuals are preferred for assessing dietary-contaminant exposure. Certain processes of food preparation are known to reduce organochlorine contaminant levels in food, such as trimming of fat, boiling, or other cooking techniques that remove fat (21, 132).

Dietary assessments present the option of better understanding the relative risk of consuming certain food items by including the extent of consumption. For example, consuming a great deal of a particular food that has low contaminant levels may present the same exposure as consuming a small amount of a food with high contaminant levels (74). Assessing the entire diet, as is done with 24-h recalls of a population, gives perspectives on these issues that are not found by considering a few individual intakes or by compiling frequency questionnaires for only a limited number of species.

Dietary standards for contaminant exposure (Table 1) are compared with dietary intake assessments for an evaluation of population exposure. In much the same way that short-term individual dietary-intake data (e.g. one or two 24-h recalls) cannot be used to assess an individual's usual nutrient intake, assessing an individual's usual contaminant exposure with these limited data is also not possible. Therefore, the best use of intake data is for population assessments. Two caveats in comparing dietary-intake standards with contaminant-intake standards are (*a*) that tolerable intakes are expressed as intakes that are assumed to occur every day for life and (*b*) that there are several safety factors based on orders of magnitude which are built into contaminant standards. Therefore, although precision in dietary data is desirable, the expression of extent of risk derived from dietary data must be carefully considered and expressed, especially when the same foods that contribute the risk also contribute substantial health and societal benefits (62, 74, 108).

Measurement of Human Contaminant Exposure Through Body Burden

In addition to dietary-exposure measurements, exposure can be assessed by biomarkers in various human samples. Examples of these are concentrations of contaminants in blood, umbilical cord blood, breast milk, urine, deciduous teeth, fat or organ biopsies, and cadaver samples. Guideline levels of contaminants in these fluids or tissues have been established by the World Health Organization (WHO), where data on pharmacokinetics and dose-response relationships are available for human populations (112, 116, 117, 119, 120). Further discussion of guideline levels is given in later sections.

At this point, there are no conclusive reports of deleterious effects among indigenous peoples as a result of consumption of traditional food. However, there

TABLE 1 Dietary intake guidelines now in effect[a]

	Organization (reference) and guideline (μg/kg bw/d)			
Contaminant	**Health Canada (51): ADI/TDI/PTDI**	**ATSDR (6): Minimum risk levels**	**JECFA/WHO (121): ADI/PTDI**	**EPA (32): Reference dose**
Arsenic	2.0 (121)	0.3 (Chronic)	2.0 (inorganic)	0.3
Cadmium	1.0 (121)	0.2 (Chronic)	1.0	1.0
Lead	3.57(121)	na[b]	3.57	na
Mercury	0.471 (M Hg) 0.714 (Hg)	0.3 (M Hg, chronic)	0.471 (M Hg) 0.714 (Hg)	0.003
Aldrin	0.1 (121)	2 (Acute) 0.03 (Chronic)	0.1	0.03
Chlordane	0.05[c]	1 (Acute) 0.6 (Chronic)	0.5	0.5
Chlorinated benzenes	na	100 (Dichloro-benzene)	na	0.8
DDT	20	0.5 (Acute)	20	0.5
Dieldrin	0.1 (121)	0.07 (Acute) 0.05 (Chronic)	0.1	0.05
Dioxin	0.00001 (TCDD equivalents)	0.000001	0.000001–0.000004	na
HCH	0.3[c]	na	na	0.3
PCB	1.0	na	na	0.7
Toxaphene	0.2	5 (Acute) 1 (Intermediate)	na	na

[a]Abbreviations: ADI/TDI/PTDI, Acceptable Daily Intake/Provisional Tolerable Daily Intake; ATSDR, Agency for Toxic Substances and Disease Registry; JECFA/WHO, Joint Food and Agricultural Organization/World Health Organization Expert Committee on Food Additives; ADI/PTDI, Acceptable Daily Intake/Provisional Tolerable Daily Intake; EPA, U.S. Environmental Protection Agency; DDT, dichlorodiphenyl-trichloroethane; HCH, hexachlorocyclohexanes; PCB, Polychlorinated biphenyls, TCDD, 2,3,7,8-tetrachloridibenzo-p-dioxin.
[b]Not available
[c]Health Canada, personal communication.

is some epidemiological evidence that human exposure to contaminants at levels possibly found in traditional food may result in adverse health effects, particularly during early development. Neurobehavioral effects of prenatal exposure to PCBs from consumption of contaminated fish have been investigated most extensively in two prospective longitudinal studies, one in North Carolina and the other in Michigan (59). The North Carolina study found poorer gross motor function during infancy in relation to prenatal PCB exposure; the Michigan study found poorer infant visual-recognition memory. However, cognitive deficits found at 4 years of age in Michigan were not seen in North Carolina, possibly owing to a different pattern of exposure or a different congener mix. Two other controlled, longitudinal studies investigated effects of prenatal Hg exposure from seafood consumption on child neurodevelopment (23, 45, 46). The first study, conducted in the Republic of Seychelles, showed that no adverse outcomes at 66 months were associated with either prenatal or postnatal methyl mercury exposure. The second study, conducted in the Faroe Islands, showed that children whose mothers had a hair Hg concentration of 10–20 ppm showed mild decrements in the domains of motor function, language, and memory.

Effects of chronic low-dose exposure among human populations remain controversial because of the inconsistent findings among different studies and populations. Moreover, the potential exists that multiple factors, such as smoking, substance abuse, and general malnutrition, can confound the consideration of health effects from a particular contaminant. The fact that most northern food resources containing heavy metal or organochlorine contaminants also contain other multiple contaminants (14, 74) is another confounding consideration. There have been few studies on the body burden or the biological effects of multiple simultaneous contaminants in the food supply.

Risk characterization of multiple chemical exposure poses a major challenge for toxicologists because most risk assessments address only single chemicals. Information on toxicologic interactions of environmental contaminants is very limited. However, there is ample evidence of supra-additive and intra-additive interactions among environmental contaminants (65). Because many of these contaminants affect the same target organ, any observed symptoms may be a result of possible interactive effects of a mixture of contaminants. Further complicating the risk characterization process are potential compounding factors such as nutrients in the diet and disease status of subjects. For example, it has been hypothesized that high levels of zinc and antioxidants such as selenium and vitamin E in the traditional diet (62) may play a protective role against contaminant toxicity (101). On the other hand, diseases such as diabetes and alcoholism are serious problems among many indigenous peoples (80, 131); these factors may potentiate the toxicity of contaminants, but are usually not considered in risk assessment for contaminant exposure.

Contaminant Risk Assessment, Risk Evaluation, and Risk Management

A study of the risks of consuming traditional food resources by northern indigenous peoples requires careful evaluation not only of the risks of using the food, but also of the benefits of using the food and of the potential health risks of not using the food. An overview of how to weigh the benefits and risks is given below.

Generally speaking, the determination of dietary contaminant risk to health involves several steps. First is identification of the hazard [the contaminant(s) in food that may cause an adverse health outcome], followed by estimation of the risk (the extent of consumption from all dietary sources). Risk assessment then proceeds to evaluation of the various options for dealing with the risk. When a decision is made on the best course of action, management of the risk includes implementation of this best course of action, followed by monitoring, evaluation, and regular review of the process. Risk determination is a process that is constantly evolving, because new data on contaminants, their health effects, and the consequences of use of traditional food all have an impact on management decisions (51, 90, 91, 115).

The issuing of advisories on species consumption has been the primary risk management effort for contaminants found in the natural food resources of northern indigenous peoples. Advisories are usually based on maximum residue limits or tolerable intakes (see Table 1) and anticipated consumption levels. One example is the special fish advisory (based on PCB levels) issued by the Department of Health of New York State for the Mohawk population in 1990. The advisory stated that an individual should eat no more than one meal per month of flesh or roe from St. Lawrence River lake sturgeon and that women of childbearing age and children under the age of 15 should not eat any flesh or roe from these fish (36). Another example is from the consumption of burbot liver, a favorite food in the Northwest Territories, Canada. With toxaphene concentrations in burbot liver ranging from 137 to 1887 ng/g in the Fort Smith area on the Slave River, the recommendation was to limit consumption to $<$13.4 g/day or 93.8 g/week, and an advisory was thus issued in that region (Slave River) not to eat more than one burbot liver per person per week. This would translate to 52 livers per year, although burbot are only seasonally available (107), which illustrates one problem with advisories of contaminated traditional food species that are consumed only seasonally. Guideline maximum residue limits and tolerable intakes assume regular daily consumption throughout the year and throughout life. The effects of consuming more than the annual daily allotment during seasons of food availability and subsequently not consuming the food in off-seasons have not been studied and are not known.

OVERVIEW OF THE MAJOR FOOD CONTAMINANTS IN TRADITIONAL FOOD SYSTEMS OF NORTHERN INDIGENOUS PEOPLES

The contaminants described below are those affecting northern indigenous peoples that are persistent or resistant to degradation and therefore accumulate in the world's environments. We discuss contaminant intake guidelines (summarized in Table 1) and also review current knowledge of regional exposure levels for indigenous peoples, which are summarized in Table 2. The health implications of chronic exposure through food to low doses (environmental levels) of these contaminants are usually not known. Factors influencing risks at low levels of exposure include age, gender, and genetics; within these categories, another factor is individual variability. The major concern is for the general health of those in the sensitive early life stages—the fetus and newborn. Interaction of a particular contaminant with other contaminants or food chemicals can also influence toxicity. For example, zinc, calcium, iron, and selenium all interact with heavy metals and modulate toxicity.

TABLE 2 Radionuclide guidelines now in effect[a]

	Organization (reference) and guideline (Bq)	
Radionuclide	**CACAR (60) annual limit of intake**	**WHO (113) oral annual limits of intake**
Cesium-137	5×10^4	4×10^6
Cesium-134	5×10^4	3×10^6
Strontium-90	3×10^4	1×10^6
Iodine-131	4×10^4	1×10^6
Polonium-210	8×10^2	
Radium-226	4.5×10^3	
Lead-210	1×10^3	

[a]Abbreviations: CACAR, Canadian Arctic Contaminants Assessment Report; WHO, World Health Organization.

Mercury and Other Heavy Metals

Mercury, cadmium, arsenic, and lead are the toxic metals recognized as pollutants of major concern in North American environments. They are subject to long-range transport, as well as local point sources, and they have been identified in food species and human tissues of northern indigenous peoples.

Bioavailability of metals is a significant factor in toxicity. Organic forms of mercury (methyl mercury) are much more toxic than the elemental form, whereas inorganic arsenic is much more toxic than the organic form (112). Cadmium and lead are bioavailable in the inorganic forms, and the extent of absorption depends on life stage (i.e. children absorb lead much more readily than do adults) as well as factors in diet and nutritional status that are related to calcium, zinc, copper, iron, and possibly other unknown substances (42, 43).

In traditional food systems of northern indigenous peoples, the primary food species recognized as sources of mercury are fish and marine mammals (14, 20). Arsenic has been identified as a contaminant in fish and in various berries collected near gold mine tailings (14, 20). Lead has been implicated in human toxicity from several environmental sources (e.g. paint, vehicle exhaust, soil, and water from lead pipes) as well as food. Traditional food systems in North America (10, 14, 17, 20, 55, 69) and northern Europe (44) have shown high levels of lead in plant ash, fish, sea mammals, and birds. The sources of lead vary from natural soil and water levels to lead shot used for hunting. Cadmium sources in traditional food systems are highest in the organs of large mammals (e.g. caribou and moose) and fish (14, 61), but are much less significant than cadmium exposure from tobacco smoking (7).

Heavy metals are present in a wide variety of human tissues; understanding the body distribution of metals allows the identification of target organs (e.g. cadmium in kidneys) and the use of particular tissues for dosimetric studies (e.g. mercury in hair). Metals have been measured in blood and umbilical cord blood [mercury, lead, cadmium, and arsenic (108)], deciduous teeth [lead (69, 92)], hair [mercury (96)], and urine [arsenic and cadmium (16, 63)]. The kinetics of distribution of all heavy metals among various human tissues are complex, depending on which tissues store the metals (e.g. bone for lead and hair for mercury), thereby leading to the establishment of guideline levels, primarily for blood.

Oral exposure to high levels of these metals can injure several body tissues or target organs. Long-term exposure to mercury can permanently damage the brain, kidney, and developing fetus (4). Chronic exposure to arsenic can be carcinogenic and may also lead to neurotoxicity, vascular disease, and liver injury (1). Lead toxicity is especially well known for children, with effects detected in the nervous system, in blood cells as anemia, and in damage to the kidneys (42). The kidney is the target organ for cadmium toxicity, with bone disorders as a possible consequence of kidney malfunction (22); however, cadmium is also a lung carcinogen (58). Although oral exposure can lead to these toxic effects, there are no reports of environmental levels of these contaminants in traditional-food-system species that have resulted in mortality or morbidity (108); however, long-term chronic effects of low-dose exposure to heavy metals on human populations are still not clear.

Polychlorinated Biphenyls and Other Organochlorines

PCBs and other organochlorines are lipid soluble and accumulate in human fatty tissues. They are primarily present in northern environments as a result of long-range transport; however, some local point sources have been identified, such as radar stations. The presence of PCBs in humans has been measured in breast milk, blood, umbilical cord blood at birth, and fat tissue biopsies. Given that several organochlorines, for example, PCBs and toxaphene, may contain hundreds of individual compounds, known as congeners, measurement in human samples is not easily done. For the same reason, the specific effects of independent congeners in human physiological systems and on ultimate health are not easily understood. Epidemiological comparisons among populations with different exposures are also complicated by the environmental routes of transport, which may affect the interconversion of congeners (85).

Considerable literature related to industrial accidents with PCBs in Japan and Taiwan points to potential effects of organochlorines on children's growth and their role in developmental delays, endocrine disruption, and neurobehavioral deficits. Toxic effects of DDT and metabolites, as well as toxaphene and metabolites, are known in the nervous system and liver, and a possible carcinogenic effect is known from high doses given in animal experiments (2, 3). Dioxins and furans are similar structurally, and each contains multiple congeners. Some congeners have been shown to have carcinogenic or teratogenic effects or result in reproductive impairment in laboratory animal experiments; however, human exposure to large amounts results in skin disorders, variation in serum lipids, and gastrointestinal alteration (103). Mirex and hexachlorocyclohexanes have not been extensively studied in humans, although animal studies show effects in organ systems, reproduction, and the immune system (57, 118). Little is known of the effects of chlordane in humans, although animal experiments show long-term-exposure effects on neurological and immune systems (114). Similarly, hexachlorobenzene has little documentation of human health effects (41).

Because of lipid solubility and food chain accumulation in freshwater and marine environments, the most significant contributors of PCBs and other organochlorines to the traditional food systems of northern indigenous peoples are fish, marine mammals, and, to a lesser extent, fish-eating birds (Table 2). Indigenous peoples who consume a great deal of these food resources have been shown to have higher levels of organochlorines in blood and breast milk than do non-native people living in more urban environments (27–29, 108). However, effects on physiology and health have not been determined (108).

Radionuclides

Radionuclides are present in traditional food resources of northern indigenous peoples as a result of natural or anthropogenic sources. Natural sources in soil, air, and water are generally the same in the north as in temperate zones, and anthropogenic sources may be local or distantly spread. Generally speaking, the recognized risk is for carcinogenic effects from radiation; other possible effects, particularly of low-level exposure, have not been documented.

Food chain accumulation and consumption of large amounts of wildlife foods may put some indigenous peoples at risk. As noted in Table 2, the risk among northern indigenous peoples is primarily associated with the consumption of caribou, which feed on lichens that accumulate several radionuclides (105). Generally, in arctic Canada, the major natural radionuclides are lead-210 and polonium-210, whereas the major anthropogenic radionuclide is cesium-137 (108). Although exposure to some radioactivity occurs from consumption of caribou, it has been concluded that these exposures are not sufficiently large to recommend cessation of the harvest and consumption of caribou (12). In New Mexico, where extensive nuclear testing takes place, strontium-90 and other radionuclide contaminants have been found in fish, deer, elk, and plant crops such as pinto beans, sweet corn, and zucchini (38–40; Table 3).

The Chernobyl accident and nuclear weapons testing released high levels of cesium-137 and strontium-90 into the atmosphere, which affected food systems in the circumpolar North. Indigenous peoples such as the Saami, Dene, and Inuit, who consume large quantities of reindeer or caribou, have been affected (104), but health endpoints in these groups from radioactivity have not been proven.

Examples of Multiple Contaminants Found in Traditional Food Species

It is important that, within any traditional food resource from the natural environment, multiple contaminants are present. Understanding the impact of the presence

TABLE 3 Exposure of northern peoples of contaminants in traditional food

Contaminant	Cultural group/location	Major food sources[a]	Reference(s)
Heavy metal(s)			
As, Cd, Pb, Hg	Wemindji (Cree territory), Quebec, Canada	Canada goose (*Branta canadensis*)	10
As, Cd, Pb, Hg	Coastal inland reservoirs of the James Bay Cree, Quebec, Canada	Brook trout (*Slavelinus fontinalis*) Cisco (*Coregonus artedii*) Lake trout (*Slavelinus namaycush*) Pike (*Exos lucius*) White fish (*Coregonus clupeaformis*)	11
As, Cd, Pb, Hg	Adult men and women from 16 Dene/Métis communities in NWT, Canada	Cisco (*C. artedii*) Caribou (*Rangifer tarandus*) Moose (*Alces alces*) Loche (*Lota lota*) Whitefish (*C. clupeaformis*) Beluga (*Delphinapterus leucas*)	14
Pb	Hopi and Papago Indian, communities, Arizona, USA	Corn (*Zea mays amylacea*, *Zea mays saccharata*) with plant ash (*Atriplex canescens*)	17
Cd, Pb, Hg	Inuit adults and children from Qikiqtarjuaq, eastern Baffin Island, Canada	Arctic char (*Slavelinus naresi*) Caribou (*R. tarandus* spp. *groenlandicus*) Kelp (*Rhodymenia* sp. and *Laminaria* sp.) Narwhal (*Monodon monoceros*) Ringed seal (*Phoca hispida*)	20
Hg	Ojibwa from Lake Superior area, Wisconsin, USA	Walleye (*Stizostedion vitreum*)	24
Hg	Six Ojibwa reservations in the Upper Great Lakes region (Lakes Superior, Michigan, and Huron), USA	Lake trout (*S. namaycush*) Lake whitefish (*C. clupeaformis*) Walleye (*S. vitreum*)	25
Cd, Pb, Hg	Coast of Newfoundland, Canada	Thick milled murre (*Uria lomvia*)	30
Cd, Pb, Hg	Southampton Island, Lake Harbor, Cape Dorset; Arviat and Bathurst (herds), Canadian arctic	Caribou (*R. tarandus*)	31

TABLE 3 (*Continued*)

Contaminant	Cultural group/location	Major food sources[a]	Reference(s)
Cd, Pb, Hg, others	Bering Sea coasts, western Alaska, USA	Emperor goose (*Chen canagica*)	37
Cd, Pb, Hg	Greenland Inuit (five districts)	Polar bear, walrus, and several species of seals, whales, and fish	49, 50
Cd	Indigenous adults from Fort Resolution, Canada	Moose (*A. alces*) Caribou (*R. tarandus*) Jackfish (*Esox lucius*) Loche (*L. lota*) Sucker (*Catostomus catostomus*) Trout (*Salvelinus namaycush*)	61
Pb, Hg	Upper Fraser River, British Columbia, Canada	White sturgeon (*Acipenser transmontanus*)	79
Pb, Hg	Lake St. François, Lake St. Louis, upper St. Lawrence River System, Canada	Several local fish species	81
Hg, Pb	Great Lakes region, USA	Several local fish and wild-game species	102
Me-Hg	Lake Ontario, USA	Several local fish species	109
Cd, Pb, Hg, others	Eastern and western Arctic, Canada	Beluga (*D. leucas*) Narwhal (*M. monoceros*) Ringed seal (*P. hispida*)	123
Hg, Me-Hg, Se	Sachs Harbor, Holman, Paulatuk, East White Fish, Shingle Point, Hendrickson Island, Repulse Bay, Sanikiluaq, Iqaluit, Resolute Bay, Coral Harbor, Pond Inlet, Broughton Island, Grise Fiord, Clyde River, Aviat, Umiujaq, Canada	Beluga (*D. leucas*) Narwhal (*M. monoceros*) Ringed seal (*P. hispida*)	124
Pb, Hg	Faroe Islands	Pilot whale (*Globicephala melaena*)	125
Me-Hg, Hg	514 Native communities across Canada	Arctic char, bearded seal, beluga, cod, lake trout, land locked char, murre, mussels, walrus, other fish	128, 129

(*Continued*)

TABLE 3 (*Continued*)

Contaminant	Cultural group/location	Major food sources[a]	Reference(s)
Organochlorines			
Chlordane, chlorobenzene, DDT, dieldrin, HCH, PCB, toxaphene	Adult men and women from 16 Dene/Métis communities in NWT, Canada	Arctic char, loche liver, trout flesh, cisco flesh, beluga blubber and mattak	14
Chlordane, PCB, toxaphene	Inuit women from Qikiqtarjuaq, eastern Baffin Island, NWT, Canada	Narwhal blubber and mattak (*M. monoceros*) Ringed seal blubber (*P. hispida*) Walrus blubber (*Odobenus rosmarus*)	18
Chlordane, chlorobenzene, DDT, dieldrin, HCH, mirex, PCB	Indigenous people from Nass River, Kitimaat, Nuxalk Nation at Bella Coola, Knights Inlet, Kingcome Inlet (coastal areas) of British Columbia, Canada	Ooligan grease (*Thaleichthys pacificus*)	19
Nonspecified organochlorines and PCB	Six Ojibwa reservations in the Upper Great Lakes region (Lakes Superior, Michigan, and Huron), USA	Lake trout (*S. namaycush*) Lake whitefish (*C. clupeaformis*) Walleye (*S. vitreum*)	25
PCB	Inuit men and women, Quebec, Canada	11 species of fish, 3 of marine mammals, 8 of edible waterfowl	26
Dieldrin, HCB, PCB, others	Coast of Newfoundland, Canada	Thick milled murre (*U. lomvia*)	30
Chlordane, DDT, dieldrin, HCB, HCH, PCB	Southampton Island, Lake Harbor, Cape Dorset, Arviat and Bathurst, herd areas, Canadian arctic	Caribou (*R. tarandus*)	31
DDE, PCB	Mohawk men, women, and infants from Akwesasne (New York, Ontario, Quebec)	Several species of local fish and wild game (mostly ducks)	33
PCB	Mohawk women from Akwesasne (New York, Ontario, Quebec)	Local fish (22 species from 12 locations)	34
PCB	Mohawk women from Akwesasne (New York, Ontario, Quebec) vs Caucasian women	Several species of local fish and breast milk	35

TABLE 3 (*Continued*)

Contaminant	Cultural group/location	Major food sources[a]	Reference(s)
DDE (dichloro diphenyl dichloro ethylene), PCB	Lake Blåsjön, northern Sweden	Arctic char (*S. alpinus* sp. complex)	48
Dioxins, furans, PCB, others	Finlayson, Tay, and Bonnet Plume herd areas, NWT, Canada	Caribou (*R. tarandus*)	54
HCH, others	Baltic Sea, North Sea, Iceland	Gray seal (*Halichoerus grypus*) Harbor seal (*Phoca vitulina*) Harp seal (*Phoca groenlandica*) White-beaked dolphin (*Lagenorhynchus albirostris*)	56
PCB, PCC (poly-chlorinated camphenes)	Inuit from Baffin Island, Canada	Arctic char (*S. naresi*) Bear (*Ursus maritimus*) Beluga (*D. leucas*) Caribou (*R. tarandus*) Narwhal (*M. monoceros*) Seal (*P. hispida*) Walrus (*O. rosmarus*)	62
Chlordane, DDT, PCB	Norton Sound (Alaska, Bering Sea), Prince William Sound (Gulf of Alaska), St. Paul Island (southern Bering Sea), Washington, Oregon, USA	Bearded seal (*Erignathus barbatus*) Harbor seal (*P. vitulina*) Northern fur seal (*Callorhimus ursimus*) Ringed seal (*P. hispida*)	64
Chlordane, chlorobenzene, DDT, dieldrin, HCH, PCB, toxaphene	Inuit women (20 –>60 y) from Baffin Island, Canada	Bearded seal (*E. barbatus*) Narwhal (*M. monoceros*) Ringed seal (*P. hispida*) Walrus (*O. rosmarus*)	74
Chlordane, chlorobenzene, DDT, dieldrin, HCH, PCB, toxaphene	Sahtú Dene/Métis women (20 –>60 y), NWT, Canada	Caribou (*R. tarandus* ssp. *groenlandicus*) Whitefish (*C. clupeaformis*) Black scoter (*Melanitta perspicillata, Melanitta fusca*)	74

(*Continued*)

TABLE 3 (*Continued*)

Contaminant	Cultural group/location	Major food sources[a]	Reference(s)
		Inconnu (*Stenodus leucichthys*) Trout (*S. namaycush*) Cisco (*C. autumnalis*)	
Dioxins, furans, PCB, others	Upper Fraser River, British Columbia, Canada	White sturgeon (*A. transmontanus*)	79
Chlordane, chlorobenzene, DDT, dieldrin, HCH, PCB, toxaphene	Hendrickson Island (Canadian Arctic), St. Lawrence River estuary, Canada	Beluga (*D. leucas*)	82
DDT, HCH, PCB	North Atlantic, North Pacific, Bering Sea/ Arctic Ocean	Beluga (*D. leucas*) Bowhead (*Balaena mysticetus*) Dolphin (*D. delphis*) Harbor seal (*P. vitulina*) Northern fur seal (*Callorhimus ursimus*) Pilot whale (*G. melanena*)	84
Chlordane, chlorobenzene, DDT, dieldrin, HCH, PCB, others	Pond Inlet, northern Baffin Island, Canada	Narwhal (*M. monoceros*)	86
Dioxins, furans, PCB, others	St. Lawrence River estuary, Canada	Beluga (*D. leucas*)	87
Chlordane, DDE, dieldrin, PCB	Eastern Russia; North America; Greenland; Svalbard, Norway	Polar bear (*U. maritimus*)	93
Chlordane, DDT, HCH, PCB, others	Alaska, Baltic Sea, Canada; Greenland; Svalbard, Norway	Beluga (*D. leucas*) Narwhal (*M. monoceros*) Ringed seal (*P. hispida*) Polar bear (*U. maritimus*)	94
DDE, DDT, PCB, others	Great Lakes region, USA	Several species of local fish and wild game	102
DDE, HCB, PCB, others	Lake Ontario, USA, fish eaters	Several species of local fish	109
Chlordane, DDT, HCB, PCB, toxaphene, others	Baltic Sea, North Sea, and Iceland	Harbor porpoises (*Phocoena phocoena*) Harbor seals (*P. vitulina*)	110

TABLE 3 (*Continued*)

Contaminant	Cultural group/location	Major food sources[a]	Reference(s)
Chlordane, DDT, PCB, toxaphene	Point Lay, northern coast of Alaska, USA	Beluga (*D. leucas*)	122
PCB	Faroe Islands	Pilot whale (*G. melaena*)	125
Chlordane, dieldrin, HCB, HCH, PCB, others	Schrader Lake, Alaska, USA	Arctic grayling (*Thymallus arcticus*) Lake trout (*S. namaycush*)	130
Cesium-137, lead-210, polonium-210	Dene/Métis people from Gwich'in, Sahtú, Dogrib, Deh Cho, South Slave, NWT, Canada	Caribou (*R. tarandus*)	12
Cesium-134, cesium-137, radium-226, others	Southampton Island, Lake Harbor, Cape Dorset; Arviat and Bathurst herds, Canadian Arctic	Caribou (*R. tarandus*)	31
Cesium-137, strontium-90, others	Alluvial floodplain area within Los Alamos canyon, New Mexico, USA	Pinto beans (*Phaselous vulgaris*) Sweet corn (*Z. mays*) Zucchini squash (*Cucurbita pepo*)	38
Cesium-137, strontium-90, others	Lands from Los Alamos National Laboratory, New Mexico, USA	Mule deer (*Odocoileus hemionus*) Rocky Mountain elk (*Cervus elaphus*)	39
Cesium-134, cesium-137, radium-226, others	Canyons that cross Los Alamos National Laboratory in New Mexico and Rio Grande, USA	Carp (*Cyprimus carpio*) Channel catfish (*Ictalurus punctatus*) White sucker (*Catostomus commersoni*)	40
Cesium-137, lead-210, polonium-210	Pond Inlet and Lake Harbor (Baffin Island), Yukon, Banks Island, Canada	Caribou herds (*R. tarandus*)	78
Cesium-137	Saami reindeer herders, Finland	Reindeer meat	104
Cesium-137, lead-210, polonium-210, radium-226, others	Wollaston Post, northern Saskatchewan, Canada	Caribou (*R. tarandus groenlandicus*)	106

[a]Genus and species reported when known by authors.

of multiple contaminants in the species or in those consuming it is not possible at this time, and more research is needed. For example, in Table 3 it can be seen that a single food item, ooligan grease, which is consumed by many cultures of indigenous peoples in British Columbia, contains multiple organochlorines—chlorobenzene, hexachlorohexanes, chlordane, DDT, mirex, dieldrin, and PCBs (19). Similarly, multiple radionuclides, organochlorines, and metals are found in caribou (12, 31).

Another significant principle to consider in traditional food systems of indigenous peoples is that usually >50 species of animals and plants are contained in a traditional food system for one culture. Thus, when multiple contaminants are present in many, if not all, species consumed, the complexities of understanding dietary exposure are formidable [e.g. in research with Baffin Inuit communities, where several organochlorines and heavy metals are found in several food items (18, 20, 74)]. Using dietary data and contaminant composition data for frequently consumed items permits calculation of intake and comparison of mean intakes by age and gender groups to the accepted standards (74, 108). Understanding intake at this level of detail makes possible an understanding of the best way (e.g. which species and how much) to moderate diet to reduce intake of particular or all contaminants, while maintaining maximum possible use of traditional food because of the multiple benefits it provides.

Table 3 demonstrates the great diversity of food systems that have been identified to date as affected by multiple environmental contaminants. Birds, mammals (land and sea), and fish food sources predominate in the identified species from food systems of indigenous peoples throughout North America and northern Europe. Plants used by indigenous peoples from the southwestern United States have also been identified to contain heavy metals, as well as radionuclides. It must be noted that research to identify these contaminants in species known by indigenous peoples is relatively new and that additional research will undoubtedly extend this list.

Modifying Diet to Reduce Toxicity

There are several options for reducing contaminant levels in the diets of indigenous peoples. The first, of course, is to carefully consider whether there is the need to reduce intake, if the level of contaminant is not considered harmful and therefore within established guidelines.

As noted earlier, attention must be given to the level of contaminant(s) in the food as well as to how much and how often the particular food is consumed. It is likely that food items consumed seasonally and in small quantities do not have to be reduced to ensure that individual diet is within guideline levels. If advisories are issued that take into account seasonal use and portion size, these should be carefully considered. For example, an advisory was given for the trout in a particular lake neer Inuvik, Northwest Territories, Canada, in which maximum weekly consumption of fish muscle was 180 g (3/4 cup) or 55 g/week of liver (1/4 cup). In the Yukon, an advisory was issued for the consumption of caribou liver and kidney from the Finlayson and Tay herds—the maximum adult consumption being seven to eight kidneys and four to five livers per year (60). In each case, these levels of consumption are not practiced, and the levels are not exceeded.

Studies have been done on the capacity for removing fat from food portions to reduce the total quantity of organochlorines of various kinds (18). Although fat is often a desirable food component (for example, in muktuk, a food containing layers of whale skin and fat), reducing the amount of fat can considerably reduce the contaminant contents of the portion.

Harvesting younger animals and those that do not migrate or live near point source contaminant areas is another strategy to reduce intake of organochlorine or heavy-metal contaminants. For this strategy to be effective, communications must ensure that hunters and fishers have knowledge of these sites.

Finally, if emissions of contaminants are slowed or stopped, it is a matter of monitoring to find the time when contaminants are sufficiently reduced in traditional food resources. For example, radionuclides from nuclear testing in reindeer and total dietary intakes in northern Europe were reduced substantially from the 1950s until the mid-1980s, when the Chernobyl accident increased levels (104). Hopefully, industrial controls and international conventions will gradually increase confidence in low contaminant levels in traditional food resources.

THE CONTAMINANT DILEMMA FOR INDIGENOUS PEOPLES

There are multiple benefits and contaminant risks from the consumption of traditional food by indigenous peoples, and weighing these considerations against each other is complex. Table 4 gives a summary of these considerations as faced by those harvesting and using traditional food species.

The risks or unknown probability of effects from using traditional food are summarized either for the contaminants under discussion as single entities or for mixtures of contaminants presented simultaneously in a food or the diet. The health effects may result from a single contaminant, mixtures of contaminants, or contaminants in synergism with other physiological insults, and they may affect the neurobehavioral system, development, immune system, or kidneys, and they may be carcinogenic. For completeness, the risk of accidents that occur during hunting and fishing must also be considered.

In contrast, some benefits of traditional foods used by northern indigenous peoples are known with certainty, including better nutrient density (particularly in animal wildlife food), the availability of key essential nutrients, physical activity during harvesting, lower food costs, the prevention of chronic disease by consumption of more nutritious food, and multiple sociocultural values that contribute to mental health and cultural morale.

It is the consumers of these foods who face the dilemmas and ultimate decisions about whether to continue their use in family and personal meal patterns. Although

TABLE 4 Identified risks and benefits of traditional food use by northern indigenous peoples[a]

Risks (unknown probability)	Benefits (known with certainty)
Effects of low level chronic exposure from:	High nutrient density
Heavy metals (Hg, Pb, d, As)	Protein, iron, zinc
Organochlorines (aldrin, chlordane	Vitamins A, D, E
Cl-benzenes, DDT, dieldrin, dioxin	Fatty acids
HCH, PAH, PCB, toxaphene)	Other nutrients
Radionuclides (^{137}Cs, ^{134}Cs, ^{90}Sr, ^{131}Io, ^{210}Po, ^{226}Ra, ^{210}Pb)	
Possible effects from simultaneous multiple contaminants:	Prevention of chronic disease
Neurobehavioral	Obesity
Developmental	Diabetes
Immune system	Cardiovascular
Kidney	Other
Cancer	
Synergistic effects with drugs, alcohol, other products	Lower food costs
Accidents during hunting/fishing	Physical activity in harvest
	Known sociocultural values
	Cultural identity
	Preferred taste, flavors, etc
	Favors community sharing
	Contributes to children's education
	Contributes the healthiest food
	Shows responsibility for others
	Participation in nature conservation
	Other

[a]References: 1–7, 10–12, 14, 18, 20, 42, 43, 50, 57, 58, 60–62, 66–68, 70, 72, 74, 75, 78, 97, 98, 104, 107, 108, 112–115, 117–120, 128, 129.

not described in detail here, the quality of alternative food from imported market sources is also part of the equation and decision process. Unlike traditional wildlife foods, market food sources are monitored for contaminants through domestic policies and international trade laws; to this extent there is some assurance that food species and ingredients are safe for consumption. However, the nutrient density and overall wholesomeness of the market food available to families of indigenous peoples in the circumpolar North is also to be considered, along with the impact of this food on patterns of dietary change and frequency of chronic disease, such as diabetes and cardiovascular disease (97, 98). Thus, in reviewing Table 4, one should also consider the chronic-disease, nutritional, sociocultural, and economic effects of not using traditional food. The alternatives of emphasizing use of poor-quality market food weighed against the potential, but largely unproven, health effects of low levels of contaminants in traditional food consumed seasonally present a difficult choice, indeed.

In the last section, we mentioned some of the political issues raised by the effects of pollution in traditional food systems and its impact on indigenous peoples.

Considering the Benefits of Traditional Food System Use

Although multiple contaminant risks of traditional food have been discussed, indigenous people also derive many benefits from using traditional food. These can be grouped by nutrient content, health benefits of traditional lifestyle/hunting, food preferences, and sociocultural values.

Nutrient profiles of wild-animal and -plant foods are similar to profiles of domesticated-animal and -plant foods before processing. Meats and fish are rich sources of energy, protein, minerals such as iron and zinc, and multiple vitamins such as niacin and pyridoxine. Fats and unsaturated fatty acids are notable exceptions in this comparison of wild and domestic meat and fish, because their quantities are less in most wildlife meats than in domestic meats. Traditional food components of diets of contemporary indigenous peoples have been shown to be lower in fat and to contain less saturated fat than the market food used to complement their diets (6, 70, 98). Further complementing dietary nutrients are patterns of food use that include nutrient-rich organ meats and other carcass portions (e.g. brain, stomach, and intestines) not usually consumed from domestic market meat sources (68, 75). The same ingenuity in traditional food use by indigenous peoples extends to plants, with many different species and parts of species being used, some with exceptional nutrient contents (77). Unfortunately, the market foods derived from plants that are available and used by families of indigenous peoples do not contain high nutrient density, but provide carbohydrates, energy, and nutrients through fortification (68, 83, 98). It is the general consensus that the traditional food of indigenous peoples is the best food that is available to them.

An important health benefit of traditional lifestyle is conferred in harvesting of traditional food species. Hunting, fishing, berry picking, and plant harvests are activities requiring physical activity and experiences in nature. When they are part of regular activity patterns, these pursuits contribute to fitness and general health, which has been documented in surveys of traditional food use in northern Canada (66, 99, 100).

Food preferences by indigenous people invariably include traditional food species that are prepared as they prefer and appreciated for taste, texture, and other perceptions of the values of these foods, including their place in routine dietary structure. Other cultural benefits of the use of traditional food in contrast to market food include beliefs about food healthfulness and spiritual provisioning, use of food for its educational value, economic benefits, and place in the social fabric of community life (72, 107).

Weighing Benefits and Risks of Traditional Food System Use

Weighing the various benefits of traditional food systems against contaminant risks is not easily done and cuts across the disciplines of nutrition, toxicology, environmental policy, and public health practice; each discipline has its unique perspective. When life-threatening risk is not present in a food source, particularly food that is wildlife based and therefore not under food industry regulations, decisions are usually left with the harvester and consumer. Consumption advisories based on contaminant residue limits and projected intakes may be issued, but, unless these are widely circulated and respected, consumption of the food continues.

There is currently a research gap concerning the perspectives of indigenous peoples on the benefits and risks of traditional food use and how personal food choices are made in the total context of family and community life. The social and cultural factors that influence the choice to continue using a food when advisories are issued are not well described.

It appears that there is still more good news than bad news about traditional-food consumption. This is not to say that vigilance is not still required to monitor levels of persistent contaminants in the environment for their potential effect through the food chain on human health and to continue monitoring traditional food use. An excellent example of the good sense needed in decisions to use or not to use traditional food relates to continued advice to promote breast-feeding. As a traditional food with multiple known benefits for the infant, the presence of contaminants recorded to date in milk of lactating northern indigenous women who consume traditional food of many kinds has not deterred public health advice to continue breast milk as the best food for infants (108).

Political Issues

The political implications of contaminants found in the traditional food systems of indigenous peoples are several and are briefly summarized below. A full discussion of these issues is beyond the scope of this review.

First, it is obvious that there is a need for intense efforts on the international stage for negotiations to stop emissions of persistent pollutants into the world's environment. Knowledge that organochlorines, heavy metals, and radionuclide contaminants surround vast areas of the planet after transport on air and ocean currents is now at hand. The presence of these contaminants in food resources of indigenous peoples is alarming and worthy of the utmost consideration. The health of the wildlife environments is a matter of concern that is sufficient in itself to justify pollution controls. Negotiations on the levels of these contaminants are not easily accomplished and require many considerations, including the use of these chemicals, particularly pesticides, in rich vs poor countries and the complexities of monitoring their use.

An important consideration for many indigenous leaders is that of rights of land use and harvest of traditional wildlife resources, which are often in competition with the rights of nonindigenous sports enthusiasts. Competition for indigenous agricultural lands is well known in international economics. When contamination of these environments is known, especially from distant sources that bring no direct benefit to the people affected, it confounds the issue and negotiations, often introducing the need for compensation to indigenous peoples for their loss of resources.

It is clearly a political goal to have sufficient research funding and priority to better understand the chemical and physiological actions of the contaminants noted in this review. A better knowledge of the contaminants now in environments and traditional food systems is needed, with particular attention to the effects of mixtures of these contaminants found in the same food items. It would be beneficial for industries that contribute these contaminants to the environment to contribute to the resolution of these problems.

Finally, better controls must be in place for all industries to stop the release of all contaminants and especially environmentally persistent contaminants. The effects of these contaminants on all life on the planet are not understood, but what we do know is not encouraging. The political will and capacity to accomplish this control can be generated through numerous agencies and ministries within world governments.

CONCLUSIONS

It is clear that the traditional food systems of northern indigenous peoples contain multiple organochlorine, heavy-metal, and radionuclide contaminants, the effects of which are of concern for human health. The same food items containing these contaminants benefit indigenous peoples in many ways, including nutritionally, economically, and socially. The nutritional quality of these foods is high, and they are often the best food alternatives for family use. In addition, the harvest and preparation of these foods are often an important part of community life.

Risk assessment, evaluation, and management strategies must take into account both benefits and risks of using this food, the complexities of seasonal use, and the total dietary intake and health. The knowledge of these contaminants in traditional food systems of northern indigenous peoples and the associated risks should spur international economic and political endeavors to reduce industrial pollution and promote environmental protection.

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LITERATURE CITED

1. Agency for Toxic Substances and Disease Registry. 1992. *Toxicological Profile for Arsenic.* US Dep. Health Hum. Serv., Public Health Serv., Atlanta, GA
2. Agency for Toxic Substances and Disease Registry. 1994. *Toxicological Profile for 4,4′-DDT, 4,4′-DDE, 4,4′-DDD.* US Dep. Health Hum. Serv., Public Health Serv., Atlanta, GA
3. Agency for Toxic Substances and Disease Registry. 1994. *Toxicological Profile for Toxaphene. Draft-Update.* US Dep. Health Hum. Serv. Public Health Serv., Atlanta, GA
4. Agency for Toxic Substances and Disease Registry. 1999. *Toxicological Profile for Mercury.* US Dep. Health Hum. Serv. Public Health Serv., Atlanta, GA
5. Agency for Toxic Substances and Disease Registry 1999. *Minimum Risk Levels for Hazardous Substances.* http://www.atsdr.cdc.gov/mrls.html
6. Appavoo DM, Kubow S, Kuhnlein HV. 1991. Lipid composition of indigenous foods eaten by the Sahtú (Hareskin) Dene-Métis of the Northwest Territories. *J. Food Comp. Anal.* 4:108–20
7. Archibald CP, Kosatsky T. 1991. Public health response to an identified environmental toxin: managing risks to the James Bay Cree related to cadmium in caribou and moose. *Can. J. Public Health* 82:22–26
8. Arctic Monitoring and Assessment Programme. 1998. *AMAP Assessment Report: Arctic Pollution Issues.* Arct. Monit. Assess. Programme, Oslo, Norway. 859 pp.
9. Barrie LA, Gregor D, Hargrave B, Lake R, Muir D, et al. 1992. Arctic contaminants: sources, occurrence and pathways. *Sci. Total Environ.* 122:1–74
10. Belinsky D, Kuhnlein HV. 2000. Macronutrient, mineral and fatty acid composition of Canada Goose (Branta canadensis): an important traditional food resource of the eastern James Bay Cree of Quebec. *J. Food Comp. Anal.* In press
11. Belinsky DL, Kuhnlein HV, Yeboah F, Penn AF, Chan HM. 1996. Composition of fish consumed by the James Bay Cree. *J. Food Comp. Anal.* 9:148–62
12. Berti PR, Chan HM, Receveur O, Macdonald CR, Kuhnlein HV. 1998. Population exposure to radioactivity from consumption of caribou among the Dene/Metis of Denendeh (western Northwest Territories, Canada). *J. Expo. Anal. Environ. Epidemiol.* 8(2):145–58
13. Berti PR, Hamilton SE, Receveur O, Kuhnlein HV. 1999. Food use and nutrient adequacy in Baffin Inuit children and adolescents. *J. Can. Diet. Pract. Res.* 60:63–70
14. Berti PR, Receveur O, Chan HM, Kuhnlein HV. 1998. Dietary exposure to chemical contaminants from traditional food among adult Dene/Metis in the western Northwest Territories, Canada. *Environ. Res.* 76(2):131–42
15. Braune B, Muir D, DeMarch B, Gamberg M, Poole K, et al. 1999. Spatial and temporal trends of contaminants in Canadian Arctic freshwater and terrestrial ecosystems: a review. *Sci. Total Environ.* 230:145–207
16. Buchet JP, Lauwerys R, Roels H. 1981. Urinary excretion of inorganic arsenic and its metabolites after repeated ingestion of sodium meta arsenite by volunteers. *Int. Arch. Occup. Environ. Health* 48:111–18
17. Calloway DH, Giauque RD, Costa FM. 1974. The superior mineral content of some American Indian foods in comparison to federally donated counterpart commodities. *Ecol. Food Nutr.* 3:203–11
18. Chan HM, Berti PR, Receveur O, Kuhnlein HV. 1997. Evaluation of the

population distribution of dietary contaminant exposure in an Arctic population using Monte Carlo statistics. *Environ. Health Perspect.* 105(3):316–21

19. Chan HM, El, Khoury M, Sedgemore M, Sedgemore S, Kuhnlein HV. 1996. Organochlorine pesticides and polychlorinated bipheny congeners in ooligan grease: a traditional food fat of British Columbia First Nations. *J. Food Comp. Anal.* 9(1):32–33
20. Chan HM, Kim C, Khoday K, Receveur O, Kuhnlein HV. 1995. Assessment of dietary exposure to trace metals in Baffin Inuit food. *Environ. Health Perspect.* 103(7–8):740–46
21. Chan HM, Receveur O, Kuhnlein HV. 1996. Assessment of effects of preparation on levels of organic contaminants in Inuit traditional food. In *Synopsis of Research Conducted under the 1994/95 Northern Contaminants Program. Environmental Studies No. 73*, ed. JL Murray, RG Shearer, SL Han, pp. 323–31. Ottawa, Can: Indian North Aff. Can.
22. Cherian MG, Goyer RA. 1989. Cadmium toxicity. *Comments Toxicol.* 3:191–206
23. Davidson PW, Myers GJ, Cox C, Axtell C, Shamlaye C, et al. 1998. Effects of prenatal and postnatal methylmercury exposure from fish consumption on neurodevelopment: outcomes at 66 months of age in the Seychelles Child Development Study. *J. Am. Med. Assoc.* 280:701–7
24. Dellinger J, Kmiecik N, Gerstenberger S, Ngu H. 1995. Mercury contamination of fish in the Ojibwa diet. I. Walleye fillets and skin-on versus skin-off sampling. *Water Air Soil Pollut.* 80:69–76
25. Dellinger JA, Meyers RM, Gebhardt KJ, Hansen LK. 1996. The Ojibwa Health Study: fish residue comparisons for Lakes Superior, Michigan, and Huron. *Toxicol. Ind. Health* 12(3–4):393–402
26. Dewailly E, Ayotte P, Blanchet C, Grondin J, Bruneau S, et al. 1996. Weighing contaminant risks and nutrient benefits of country food in Nunavik. *Arct. Med. Res.* 55 (Suppl. 1):13–19
27. Dewailly E, Ayotte P, Bruneau S, Laliberté C, Muir DCG, Norstrom RJ. 1993. Inuit exposure to organochlorines through the aquatic food chain in Arctic Quebec. *Environ. Health Perspect.* 101:618–20
28. Dewailly E, Ayotte P, Laliberte C, Weber JP, Gingras S, Nantel AJ. 1996. Polychlorinated biphenyls (PCBs) and dichlorodiphenyl dichloroethylene (DDE) in breast milk of women living in the province of Quebec, Canada. *Am. J. Public Health* 86:1241–46
29. Dewailly E, Nantel AJ, Weber JP, Meyer F. 1989. High levels of PCBs in breast milk of Inuit women from Arctic Quebec. *Bull. Environ. Contam. Toxicol.* 43:641–46
30. Donaldson GM, Braune BM, Gaston AJ, Noble DG. 1997. Organochlorine and heavy metal residues in breast muscle of known-age thick milled murres (Uria lomvia) from the Canadian Arctic. *Arch. Environ. Contam. Toxicol.* 33(4):430–35
31. Elkin BT, Bethke RW. 1995. Environmental contaminants in caribou in the Northwest Territories, Canada. *Sci. Total Environ.* 160–161:307–21
32. Environmental Protection Agency. 1998. *Reference Doses.* http://www.epa.gov/ttnuatw1/hlthef/
33. Fitzgerald EF, Brix KA, Deres DA, Hwang S, Bush B, et al. 1996. Polychlorinated biphenyl (PCB) and dichlorodiphenyl dichloroethylene (DDE) exposure among Native American men from contaminated Great Lakes fish and wildlife. *Toxicol. Ind. Health* 12(3/4):361–68
34. Fitzgerald EF, Hwang S, Brix KA, Bush B, Cook K, Worswick P. 1995. Fish PCB concentrations and consumption patterns among Mohawk women at Akwesasne. *J. Expo. Anal. Environ. Epidemiol.* 5(1):1–19
35. Fitzgerald EF, Hwang S, Brix KA, Bush B, Cook K, Worswick P. 1998. Fish consumption and breast milk PCB

concentrations among Mohawk women at Akwesasne. *Am. J. Epidemiol.* 148(2): 164–72

36. Forti A, Bogdan KG, Horn E. 1995. *Health Risk Assessment for the Akwesasne Mohawk Population from Exposure to Chemical Contaminants in Fish and Wildlife.* New York State Dep. Health, Centre Environ. Health, Bureau Toxic Subst. Assess. Albany, New York. 112 pp.
37. Franson JC, Schmutz JA, Creekmore LH, Fowler AC. 1999. Concentrations of selenium, mercury, and lead in blood of Emperor geese in western Alaska. *Environ. Toxicol. Chem.* 18(5):965–69
38. Fresquez PR, Armstrong DR, Mullen MA, Naranjo L. 1999. The uptake of radionuclides by beans, squash, and corn growing in contaminated alluvial soils at Los Alamos National Laboratory. *J. Environ. Sci. Health B.* 33(1):99–121
39. Fresquez PR, Biggs JR, Bennett KD, Kraig DH, Mullen MA, Ferenbaugh JK. 1999. Radionuclides in deer and elk from Los Alamos National Laboratory and the doses to humans from the ingestion of muscle and bone. *J. Environ. Sci. Health B.* 34(5):901–15
40. Fresquez PR, Kraig DH, Mullen MA, Naranjo L. 1999. Radionuclides and trace elements in fish collected upstream and downstream of Los Alamos National Laboratory and the doses to humans from the consumption of muscle and bone. *J. Environ. Sci. Health B.* 34(5):885–99
41. Government of Canada. 1993. *Priority Substances List Assessment Rep. Hexachlorobenzene.* Supply Serv. Can. Ottawa, Can.
42. Goyer RA. 1996. Toxic effects of metals. In *Casarett and Doull's Toxicology*, ed. CD Klaassen, pp. 691–736. New York: McGraw-Hill. 5th ed.
43. Goyer RA. 1997. Toxic and essential metal interactions. *Annu. Rev. Nutr.* 17:37–50
44. Grandjean P, Weihe P, Jorgense PJ, Clarkson T, Cernichiari E, Videro T. 1992. Impact of maternal seafood diet on foetal exposure to mercury, selenium and lead. *Arch. Environ. Health* 47:185–95
45. Grandjean P, Weihe P, White RF, Debes F. 1998. Cognitive performance of children prenatally exposed to "safe" levels of methylmercury. *Environ. Res.* 77:165–72
46. Grandjean P, Weihe P, White RF, Debes F, Araki S, et al. 1997. Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. *Neurotox. Teratol.* 19:417–28
47. Gregor DJ, Peters AJ, Teixeira C, Jones N, Spencer C. 1995. The historical residue trend of PCBs in the Agassiz Ice Cap, Ellesmere Island, Canada. *Sci. Total Env.* 160/161:117–26
48. Hammar J, Larson P, Klavins M. 1993. Accumulation of persistent pollutants in normal and dwarfed Arctic char (Salvelinus alpinus sp. complex). *Can. J. Fish. Aquat. Sci.* 50:2574–80
49. Hansen JC. 1981. A survey of human exposure to mercury, cadmium and lead in Greenland. *Meddelelser Om Grønland, Man Soc. 3*. 36 pp.
50. Hansen JC. 1998. Pollution and Human Health. In *AMAP Assessment Report: Arctic Pollution Issues,* pp. 775–844. Arct. Monit. Assess. Program, Oslo, Norway
51. Health Canada. 1993. *Health risk determination: the challenges of health protection. Cat. No. H49-40. Minist.* Supply Serv. Can., Ottawa, Can.
52. Health Canada. 1997. *The Health and Environment Handbook for Health Professionals. (Contaminant Profiles)* Health Can. Ont. Minist. Health, Ottawa, Can. 153 pp.
53. Heath AG. 1987. *Water Pollution and Fish Physiology.* Boca Raton, FL: CRC Press. 245 pp.
54. Hebert CE, Gamberg M, Elkin BT, Simon M, Norstrom RJ. 1996. Polychlorinated dibenzodioxins, dibenzofurans and non-ortho substitued polychlorinated biphenyls in caribou (*Rangifer tarandus*)

from the Canadian Arctic. *Sci. Total Environ.* 185:195–204
55. Hovinga ME, Sowers M, Humphrey HEB. 1993. Environmental exposure and lifestyle predictors of lead, cadmium, PCB and DDT levels in great lakes fish eaters. *Arch. Environ. Health* 48:98–104
56. Hummert K, Vetter W, Luckas B. 1995. Levels of alpha-HCH, lindane and enantiomeric ratios of alpha-HCH in marine mammals from the northern hemisphere. *Chemosphere* 31(6):3480–500
57. International Agency for Research on Cancer. 1987. *IARC Monographs on the evaluation of carcinogenic risk of chemicals to humans.* Suppl. 7:72
58. International Agency for Research on Cancer. 1994. *Monograph on the Eation of Risks to Humans. Cadmium, Mercury, Beryllium and the Glass Industry,* Vol. 58. Lyon, France: Int. Agency Res. Cancer. 444 pp.
59. Jacobson JL, Jacobson SW. 1997. Evidence for PCBs as neurodevelopmental toxicants in humans. *Neurotoxicology* 18(2):415–24
60. Jensen J, Adare K, Shearer R. 1997. *Canadian Arctic Contaminants Assessment Rep.* Dep. Indian Aff. North. Dev. Ottawa, Can. 459 pp.
61. Kim C, Chan HM, Receveur O. 1998. Risk assessment of cadmium exposure in Fort Resolution, Northwest Territories, Canada. *Food Addit. Contam.* 15(3):307–17
62. Kinloch D, Kuhnlein H, Muir DCG. 1992. Inuit foods and diet: a preliminary assessment of benefits and risks. *Sci. Total Environ.* 122:247–78
63. Kjellstrom T, Nordberg GF. 1978. A kinetic model of cadmium metabolism in the human being. *Environ. Res.* 16:248–69
64. Krahn MM, Becker PR, Tilbury KL, Stein JE. 1997. Organochlorine contaminants in blubber of four seal species—integrating biomonitoring and specimen banking. *Chemosphere* 34(9–10):2109–21
65. Krishnan K, Brodeur J. 1994. Toxic interactions among environmental pollutants: corroborating laboratory observations with human experience. *Environ. Health Perspect.* 102 (Suppl. 9):11–17
66. Kuhnlein HV. 1992. Change in the use of traditional food by the Nuxalk native people of British Columbia. *Ecol. Food Nutr.* 27:259–82
67. Kuhnlein HV. 1995. Benefits and risks of traditional food for Indigenous Peoples: focus on dietary intakes of Arctic men. *Can. J. Physiol. Pharmacol.* 73:765–71
68. Kuhnlein HV, Appavoo DM, Morrison N, Soueida R, Pierrot P. 1994. Use and nutrient composition of traditional Sahtú (Hareskin) Dene/Métis food. *J. Food Compos. Anal.* 7:144–57
69. Kuhnlein HV, Calloway DH. 1977. Minerals in human teeth: differences between pre-industrial and contemporary Hopi Indians. *Am. J. Clin. Nutr.* 30:883–86
70. Kuhnlein HV, Kubow S, Soueida R. 1991. Lipid components of traditional Inuit foods and diets of Baffin Island. *J. Food Comp. Anal.* 4:227–36
71. Kuhnlein HV, Pelto GH. 2000. Ethnographic aspects of human nutrition. In *Encyclopedia of Life Support Systems.* UNESCO. Paris: EOLSS Publishers. In press
72. Kuhnlein HV, Receveur O. 1996. Dietary change and traditional food systems of Indigenous Peoples. *Annu. Rev. Nutr.* 16:417–42
73. Kuhnlein HV, Receveur O, Morrison NE, Appavoo DM, Soueida R, Pierrot P. 1995. Dietary nutrients of Sahtú Dene/Métis vary by food source, season and age. *Ecol. Food Nutr.* 34:183–95
74. Kuhnlein HV, Receveur O, Muir DC, Chan HM, Soueida R. 1995. Arctic indigenous women consume greater than acceptable levels of organochlorines. *J. Nutr.* 125(10):2501–10
75. Kuhnlein HV, Soueida R. 1992. Use and nutrient composition of traditional Baffin

Inuit foods. *J. Food Compos. Anal.* 5:112–26

76. Kuhnlein HV, Soueida R, Receveur O. 1995. Baffin Inuit food use by age, gender and season. *J. Can. Diet. Assoc.* 56:175–83
77. Kuhnlein HV, Turner NJ. 1991. *Traditional Plant Foods of Canadian Indigenous Peoples: Nutrition, Botany and Use.* New York: Gordon & Breach Publishers. 620 pp.
78. Macdonald CR, Ewing LL, Elkin BT, Wiewel AM. 1996. Regional variation in radionuclide concentrations and radiation dose in caribou (Rangifer tarandus) in the Canadian Arctic; 1992–1994. *Sci. Total Environ.* 182:53–73
79. MacDonald DD, Ikonomou MG, Rantalaine AL. 1997. Contaminants in white strugeon (Acipenser transmontanus) from the upper Fraser River, British Columbia, Canada. *Environ. Toxicol. Chem.* 16(3):479–90
80. MacMillan HL, MacMillan AB, Offord DR, Dingle JL. 1996. Aboriginal health. *Can. Med. Assoc. J.* 155(11):1569–78
81. Mergler D, Bélanger S, Larribe F, Panisset M, Bowler R, et al. 1998. Preliminary evidence of neurotoxicity associated with eating fish from the upper St. Lawrence River lakes. *Neurotoxicology* 19(4–5):691–702
82. Metclafe C, Metcalfe T, Ray S, Paterson G, Koeing B. 1999. Polychlorinated biphenyls and organochlorine compounds in brain, liver and muscle of beluga whales (Delphinapterus leucas) from the arctic and St. Lawrence estuary. *Mar. Environ. Res.* 47(1):1–15
83. Morrison NE, Receveur O, Kuhnlein HV, Appavoo DM, Soueida R, Pierrot P. 1995. Contemporary Sahtu Dene/Metis use of traditional and market food. *Ecol. Food Nutr.* 34:197–210
84. Mossner S, Ballschmiter K. 1997. Marine mammals as global pollution indicators for organochlorines. *Chemosphere* 34(5–7):1285–96
85. Muir D, Braune B, DeMarch B, Norstrom R, Wagemann R, et al. 1999. Spatial and temporal trends and effects of contaminants in the Canadian Arctic marine ecosystem: a review. *Sci. Total Environ.* 230:83–144
86. Muir DCG, Ford CA, Grift NP, Stewart REA. 1992. Organochlorine contaminants in narwhal (Monodon monoceros) from the Canadian Arctic. *Environ. Pollut.* 75(3):307–16
87. Muir DCG, Ford CA, Rosenberg B, Norstrom RJ, Simon M, Beland P. 1996. Persistent organochlorines in beluga whales (Delphinapterus leucas) from the St. Lawrence River estuary. I Concentrations and patterns of specific PCBs, chlorinated pesticides and poluchlorinated dibenzo-p-dioxins and dibenzofurans. *Environ. Pollut.* 93(2):219–34
88. Muir DCG, Wagemann R, Hargrave BT, Thomas DJ, Peakall DB, Norstrom RJ. 1992. Arctic marine ecosystem contamination. *Sci. Total Env.* 122:5–134
89. Muir D, Braune B, DeMarch B, Norstrom R, Wagemann R, et al. 1997. Ecosystem uptake and effects. In *Canadian Arctic Contaminants Assessment Report*, ed. J Jensen, K Adare, R Shearer. pp. 183–294, Indian North. Aff. Can., Ottawa, Can.
90. National Research Council. 1983. Risk Assessment in the Federal Government: Managing the Process. Committee on the Institutional Means for Assessment of Risks to Public Health. Natl. Acad. Press, Washington, DC. 191 pp.
91. National Research Council. 1994. *Science and Judgement in Risk Assessment. Committee on Risk Assessmentof Hazardous Air Pollutants*. Natl. Acad. Press, Washington, DC. 651 pp.
92. Needleman HL, Shapiro IM. 1974. Dentine lead levels in asymptomatic Philadelphia schoolchildren: subclinical exposure in high and low risk groups. *Environ. Health Perspect.* 7:27–31

93. Norstrom RJ, Belikov SE, Born EW, Garner GW, Malone B, et al. 1998. Chlorinated hydrocarbon contaminants in polar bears from eastern Russia, North America, Greenland, and Svalbard: biomonitoring of arctic pollution. *Arch. Environ. Contam. Toxicol.* 35(2):354–67
94. Norstrom RJ, Muir DCG. 1994. Chlorinated hydrocarbon contaminants in arctic marine mammals. *Sci. Total Environ.* 154:107–28
95. Pelto GH, Pelto PJ. 1983. Diet and delocalization: dietary changes since 1750. *J. Interdiscip. Hist.* 14(2):507–28
96. Phelps RW, Clarkson TW, Kershaw TG, et al. 1980. Interrelationships of blood and hair mercury concentrations in a North American population exposed to methlymercury. *Arch. Environ. Health* 35:161–68
97. Popkin BM. 1994. The nutrition transition in low income countries: an emerging crisis. *Nutr. Rev.* 52(9):285–98
98. Receveur O, Boulay M, Kuhnlein HV. 1997. Decreasing traditional food use affects diet quality for adult Dene/Metis in 16 communities of the Canadian Northwest Territories. *J. Nutr.* 127:2179–86
99. Receveur O, Boulay M, Mills C, Carpenter W, Kuhnlein HV. 1996. *Variance in Food Use Dene/Métis Communities. Final Rep.* Cent. Indig. Peoples, Nutr. Environ. 198 pp.
100. Receveur O, Kassi N, Chan HM, Berti PR, Kuhnlein HV. 1998. *Yukon First Nations, Assessment of Dietary Benefit/Risk. Final Rep.* Cent. Indig. Peoples, Nutr. Environ. 154 pp.
101. Sarafian TA, Bredesen DE, Verity MA. 1996. Cellular resistance to methylmercury. *Neurotoxicology* 17(1):27–36
102. Schantz SL, Sweeney AM, Gardiner JC, Humphrey HEB, McCaffrey RJ, et al. 1996. Neuropsychological assessment of an aging population of Great Lakes fisheaters. *Toxicol. Ind. Health* 12(3/4): 403–17
103. Schulz CO, Brown DR, Munroe IC. 1990. Characterization of human health risks. *Environ. Toxin Ser.* 3:93–139
104. Strand P. 1998. Radioactivity. In *AMAP Assessment Report: Arctic Pollution Issues,* pp. 525–620. Oslo, Norway: Arct. Monit. Assess. Program
105. Thomas DJ, Tracey B, Marshall H, Norstrom RJ. 1992. Arctic terrestrial ecosystem contamination. *Sci. Total Environ.* 122:135–64
106. Thomas PA, Gates TE. 1999. Radionuclides in the lichen-caribou-human food chain near uranium mining operations in northern Saskatchewan, Canada. *Environ. Health Perspect.* 107(7):527–37
107. Usher P, Baikie M, Demmer M, Nakashima D, Stevenson MG, Stiles M. 1995. *Communicating About Contaminants in Country Food: The Experience in Aboriginal Communities.* Res. Dep., Inuit Tapirisat of Can., Ottawa, Can.
108. Van Oostdam J, Gilman A, Dewailly E, Usher P, Wheatley B, et al. 1999. Human health implications of environmental contaminants in Arctic Canada: a review. *Sci. Total Environ.* 230:1–82
109. Vena JE, Buck GM, Kostyniak P, Mendola P, Fitzgerald E, et al. 1996. The New York Angler Cohort Study: exposure characterization and reproductive and developmental health. *Toxicol. Ind. Health* 12(3/4):327–34
110. Vetter W, Luckas B, Heidermann G, Skirnisson K. 1996. Organochlorine residues in marine mammals from the northern hemisphere: a consideration of the composition of organochlorine residues in the blubber of marine mammals. *Sci. Total Environ.* 186(1–2):29–39
111. Voldner EC, Li Y-F. 1995. Global usage of selected persistent organochlorines. *Sci. Total Environ.* 160/161:201–10
112. World Health Organization. 1981. *Arsenic. Int. Programme Chem. Saf. Environ. Health Criteria* 18, WHO, Geneva, Switzerland

113. World Health Organization. 1983. *Selected Radionuclides. Int. Programme Chem. Saf. Environ. Health Criteria 25,* WHO, Geneva, Switzerland
114. World Health Organization. 1984. *Chlordane. Int. Programme Chem. Saf. Environ. Health Criteria* 34, WHO, Geneva, Switzerland
115. World Health Organization. 1987. *Principles for the Safety Assessment of Food Additives and Contaminants in Food. Int. Programme Chem. Saf. Environ. Health Criteria 70,* WHO, Geneva, Switzerland
116. World Health Organization. 1989. *Lead-Environmental Aspects. Int. Programme Chem. Saf. Environ. Health Criteria 85,* WHO, Geneva, Switzerland
117. World Health Organization. 1990. Methylmercury. *Int. Programme Chem. Saf. Environ. Health Criteria 101,* WHO, Geneva, Switzerland
118. World Health Organization. 1991. *Alpha- and Beta-hexachlorocyclohexanes. Int. Programme Chem. Saf. Environ. Health Criteria 123,* WHO, Geneva, Switzerland
119. World Health Organization. 1992. *Cadmium. Int. Programme Chem. Saf. Environ. Health Criteria 134,* WHO, Geneva, Switzerland
120. World Health Organization. 1993. *Polychlorinated Biphenyls and Terphenyls. Int. Programme Chem. Saf. Environ. Health Criteria 140,* WHO, Geneva, Switzerland
121. World Health Organization. 1998. *Summary and Conclusions: Joint FAO/WHO Expert Committee on Food Additives,* Presented at 51st Meet., WHO, Geneva, Switzerland. http://www.who.int/pcs/jecfa/summary_51
122. Wade TL, Chambers L, Gardinall PR, Sericano JL, Jackson TJ. 1997. Toxaphene, PCB, DDT, and chlordane analyses of Beluga whale blubber. *Chemosphere* 34(5–7):1351–57
123. Wageman R, Innes S, Richard PR. 1996. Overview and regional and temporal differences of heavy metals in Arctic whales and ringed seal in the Canadian Arctic. *Sci. Total Environ.* 186(1–2):41–66
124. Wageman R, Trebacz E, Boila G, Lockhart WL. 1998. Methylmercury and total mercury in tissues of arctic marine mammals. *Sci. Total Environ.* 218(1):19–31
125. Weihe P, Grandjean P, Debes F, White R. 1996. Health implications for Faroe islanders of heavy metals and PCBs from pilot whales. *Sci. Total Environ.* 186(1–2):141–48
126. Wein EE, Freeman MR. 1995. Frequency of traditional food use by three Yukon First Nations living in four communities. *Arctic* 48:161–71
127. Wein EE, Sabry JH, Evers FT. 1991. Food consumption patterns and use of country foods by native Canadians near Wood Buffalo National Park, Canada. *Arctic* 44:196–205
128. Wheatley B, Paradis S. 1996. Balancing human exposure, risk and reality: questions raised by the Canadian Aboriginal Methylmercury Program. *Neurotoxicology* 17(1):241–50
129. Wheatley MA, Wheatley B. 1981. The effect of eating habits on mercury levels among Inuit residents of Sugluk, Province of Quebec. *Étud. Inuit Stud.* 5(1):27–43
130. Wilson R, Allen-Gil S, Griffin D, Landers D. 1995. Organochlorine contaminants in fish from an Arctic lake Alaska, USA. *Sci. Total Environ.* 160/161:511–19
131. Young TK. 1994. *The Health of Native Americans. Towards a Biocultural Epidemiology.* New York: Oxford Univ. Press. 275 pp.
132. Zabik ME, Hoojjat P, Weaver CM. 1979. Polychlorinated biphenyls, dieldrin and DDT in lake trout: cook by broiling, roasting or microwave. *Bull. Environ. Contam. Toxicol.* 21:136–43