Disproportionate Exposures in Environmental Justice and Other Populations: The Importance of Outliers

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We examined traditional environmental justice populations and other groups whose exposure to contaminants is often disproportionately high. Risk assessment methods may not identify these populations, particularly if they are spatially dispersed.

We suggest using a National Health and Nutrition Examination Survey approach to oversample minority communities and develop methods for assessing exposure at different distances from pollution sources; publishing arithmetic and geometric means and full distributions for minority populations; and paying particular attention to high-end exposures.

Means may sufficiently characterize populations as a whole but are inadequate in identifying vulnerable groups and subgroups. The number of individuals above the 95th percentile of any distribution may be small and unrepresentative, but these outliers are the ones who need to be protected. (*Am J Public Health*. 2011; 101:S53–S63. doi:10.2105/AJPH. 2011.300121)

ENVIRONMENTAL RISKS ARE not uniformly distributed across groups of people. Age, poverty, and minority status place some groups at a disproportionately high risk for environmental disease. Such groups are exposed to hazardous chemicals or conditions at levels well above those for the general populations.[1,2] These exposures may be high-end exposures (> 95th or 99th percentile) to common agents or exposures the general population does not encounter. In traditional risk assessment and management, outliers are excluded or log-transformed; however, special attention should be paid to them.

We discuss populations with high-end, unique exposure pathways (children, Native Americans, minorities, rural and urban poor), whose risk from combined exposures (chemical, physical, psychosocial) is likely to be underestimated by risk assessment practices, and examine their contribution to health disparities. Some of these populations are traditionally recognized environmental justice communities. We build on our conceptual model for unique exposure pathways, and we also make specific recommendations regarding how a National Health and Nutrition Examination Survey approach can focus attention on addressing information disparities.

We used Medline searches to identify the articles included in this review, using keywords for vulnerable populations, tables of contents searches for *environmental justice* in biomedical journals, US Environmental Protection Agency documents,[1] and our cumulative research experience. More search details are provided in our other article in this issue Our review is also based on our work with environmental health, exposure, and risk assessment.

BACKGROUND CONCEPTS

Risk assessment is evolving to improve toxicological basis, exposure assessment, and quantitative approaches,[3–5] with increasing attention paid to mixtures and cumulative exposures.[6] Here, we distinguish vulnerability (differential probability of exposure) from susceptibility (differential probability of experiencing adverse effects from exposure). Factors that contribute to differential exposure and response interact in complex ways involving state of health and nutrition, hazardous occupations, and hazardous behaviors such as smoking or lack of exercise.[7] For example, children with asthma from poor minority communities may be particularly sensitive to volatile organics.[8,9] We highlight other factors that interact to increase minority and low-income populations' potential for higher exposure (vulnerability) or high responsiveness (susceptibility) to environmental toxics that are under the purview of the Environmental Protection Agency (EPA).

Disparities in access to health information and health care are important aspects of the disproportionate burden faced by environmental justice communities. Poor access to health information and health care means less health promotion, less risk avoidance, a less healthy diet, and more adverse conditions that increase susceptibility to exposure. Delayed recognition of exposure, diagnosis, and treatment allows effects to accumulate.[10] For example, Pacific Northwest Tribes have experienced greater delays in access to medical care, in addition to lower quality care.[11] Data have suggested that their cancer incidence is higher than the national average, and their higher mortality may be the result of late-stage diagnosis and limited access to state-of-the-art care.[11] Limited access to medical care is well recognized[12] for Native Americans generally, for poor rural communities,[13] and for minority communities,[14] which adds to their already disproportionate risk of exposure to chemicals. In New York City, disparities in health outcomes from exposure to air pollution relate directly to less access to care as a result of socioeconomic status.[15]

Poor and minority groups experience unusually high exposures in home and neighborhood. They are also disproportionately affected by hazardous occupational exposures. Recent immigrants have low-paying, nonunion, and hazardous jobs, occupy crowded and deteriorating housing, experience economic and social stressors, and have less access to information and health care.[16] They are disproportionately exposed at work and are more likely to bring chemicals home on their clothing[17] than workers in factories with strong unions, who change out of work clothes and shower before leaving work.[18]

Smoking intersects with other risk factors, such as poverty and low educational level. Smoking is about 2 to 4 times more prevalent among those with less than a high school education than among college-educated people. Tobacco companies have targeted children and minorities to increase the number of new smokers.[19,20] Black men (27.1%) smoke more than non-Hispanic White men (24.0%) or Hispanic men (19.9%); for Black women, the rate was 18% higher; for non-Hispanic White women, 19.6%; and for Hispanic women, 10%.[19,21] Puerto Ricans had much higher smoking rates than Cubans or Dominicans. The highest smoking rate was among American Indians (32%).[21]

UNIQUELY EXPOSED POPULATIONS AND ROUTES OF EXPOSURE

People with unique exposure pathways include children,[22,23] farm and migrant workers,[24–26] urban poor populations,[27–29] rural or isolated populations,[30,31] Native Americans and Alaskan Natives, and minorities. These groups are often, but not always, immersed in a dominant culture. For example, Aleuts live in small communities separated from mainland Alaska by hundreds of miles,[32,33] and some poor, rural communities in Appalachia face disproportionately more environmental hazards.[34] Even in urban areas, low-income and minority communities may be found in otherwise affluent areas.[35]

The issues are as diverse as low group population,[32] inordinately high fish consumption rates (e.g., Native Americans),[36,37] high consumption rates of other subsistence foods,[33] high exposure to pesticides,[38,39] or cultural practices.[40–42] Environmental risk factors include hazardous waste, indoor toxins, indoor or outdoor air pollution, water quality, noise, crowding, housing quality, school quality, work exposure, and blighted neighborhoods.[43] We describe major groups of environmental justice populations facing unique exposures, beginning with children.

Children

Children should not be considered small adults in terms of exposure, dose, or response.[44,45] They may absorb more contaminants (e.g. lead) and metabolize differently; also, their developing nervous systems are more susceptible to chemicals. From conception through adolescence, children have critical developmental windows when the nervous system is more susceptible to damage. Children from low-income and minority families are more likely to be at risk of exposure because they (1) spend more time playing on contaminated soil than children from higher-income families, (2) spend more time in houses that have lead paint or high dust levels, (3) may be exposed to higher levels of contaminants in utero and in breast milk because their mothers are also disproportionately exposed, and (4) have inadequate diets that may increase the absorption of toxic chemicals from their digestive system.

Children in rural areas may live close to industrial sites,[46] mines,[47] smelters,[48] and waste sites and may be unduly exposed during exploration of their surroundings.[49,50] Infants and toddlers are differentially exposed when they spend time on the floor or ground putting their hands or objects in their mouths.[51,52] Crawling also provides an opportunity to ingest dust. In a Texas farming community, the rate of contact with dirt or grass and the rate of hand-to-mouth activities varied by age; children had higher rates of exposure indoors than outdoors[52] (Table 1). Freeman et al.[53] found similar rates of hand-to-mouth activities in children exposed to lead. Soil ingestion by young children is usually the driver in risk assessment scenarios. Kimbrough et al.[54] used values of 100 milligrams to 10 grams per day for daily deposition of soil containing 2,3,7,8-tetrachloro-dibenzodioxin on skin surfaces, and others have provided distributions for soil ingestion (mean = 14 mg/day).[49,55]

An example of how children may be differentially exposed to environmental toxins is children's exposure to lead. Lead poisoning in children is a classic example of failure and success in public health.[56] In the United States, the days of emergency admissions for lead encephalopathy with blood lead levels exceeding 100 micrograms per deciliter have largely passed, and the level that defines lead poisoning in children has been lowered to 10 micrograms per deciliter. Declines in blood lead levels in the United States tracked declines in leaded gasoline;[57] the number of children aged 1 to 5 years with blood lead levels exceeding 10 micrograms per deciliter has declined nationwide from more than 50% in the 1970s to 1.6% in 2002 but has remained higher than 5% in some cities.[58] Researchers have disagreed over whether a blood level of 10 micrograms of lead per deciliter is adequately protective.[59,60] Early childhood blood lead levels and reading achievement showed an evident negative association at 5 micrograms per deciliter,[61] and children with a lifetime average blood lead level of

TABLE 1—Contact Behavior of Infants and Children in a Texas Farming Community: 2000

Behavior	Infants, % or Mean (SD)	Aged 1 Year, % or Mean (SD)	Aged 2 Years, % or Mean (SD)	Preschool, % or Mean (SD)
Assessed via questionnaire (% of time having contact)[a]				
Dirt	15.7	54.5	66.7	100
Grass	8.3	36.4	44.4	100
Assessed via videotaping (hourly frequency)[a]				
Hand to mouth	19.8 (14.5)	15.8 (8.7)	11.9 (9.3)	22.1 (22.1)
Object to mouth	24.4 (11.6)	9.8 (6.3)	7.8 (5.8)	10.1 (12.4)
Food to mouth	10.8 (9.0)	17.2 (14.0)	14.7 (10.9)	15.7 (11.8)
Assessed via videotaping (% of time on floor)[a]		11 (10)	8 (5)	9 (4)

[a]Data from Black et al. 2005.[52]

Factors to Consider in Examining Pathways for High-End Exposure for Groups With a Subsistence Lifestyle, Recreationalists, and Native Americans With a Traditional Lifestyle

Components of the Activity	Special Exposure Considerations of the Activity
	Hunting
Preparation for hunting	Are products for food, drink, implements, cosmetics, ceremonies, or medicines?
Hiking to hunting site	What are the terrain types or aquatic conditions?
Canoeing or boating to site	Is game butchered on site or brought back to land or to home?
Conducting scouting trips	What are the exertion levels for and time spent in each activity?
Setting traplines	What are the total number of exposure pathways of each activity (inhalation, dermal, ingestion)
Building blinds	Do people live on a boat at sea or in other places?
Capturing or killing prey	How much is frozen, smoked, or freeze dried for later consumption?
Field dressing food	
Packing food	
Hauling food	
Cutting or storing food	
Drying or smoking food	
Preparing hides, skins, or antlers for decorations	
Returning remains to nature	
	Fishing
Preparations for fishing	What are the products involved?
Canoeing or boating to site	What types of terrain are crossed to get there, and what are the aquatic conditions for fishing?
Hiking to collecting site	Are fish butchered on site or brought back to home, camp, or a village?
Building weirs or traps	Contents of fish guts can influence exposure
Making or repairing nets	What are the exertion level and time spent in each activity?
Making or repairing poles	What are the total number of exposure pathways of each activity?
Constructing drying racks	Are fish given to neighbors or friends?
Fishing itself	
Cleaning or storing fish	
Drying fish	
Returning remains to nature	
	Gathering
Preparing materials	What are the products?
Canoeing or boating to site	Do they involve gardening, and if so what level?
Hiking to collecting site	What are the terrain types?
Searching for materials	What are the exertion levels and time spent in each activity?
Collecting materials	Is soil left on the products?
Carrying materials back to home	What are the total number of exposure pathways for each activity?
Preparing materials to store	
Preparing materials to dry or package	
Returning remains to nature	
	Food, herb, or medicine preparation
Basket making	What are the materials or structures constructed?
Building drying racks or smoking sites	Where are these built?
Separating parts of plants, fish, or game	What are the exertion levels and time spent in each activity?
Making storage buildings or smoke houses	What are the total number of exposure pathways for each activity?
Spreading materials around medicines or herbs (such as mercury)	Are there unique ceremonial activities (such as use of mercury)?
Creating amulets (e.g., of mercury)	

Continued

5 to 9.9 micrograms per deciliter showed a 4.9-point-lower performance on full-scale IQ.[62]

Black children have higher blood lead levels than White children.[63–65] Poor and minority families are more likely to live in older, deteriorated housing in which lead chips and dust as well as lead water pipes are the main culprits. National Health and Nutrition Examination Survey II data (1991–1994) for 2392 children aged 1 to 5 years showed higher blood lead levels for low-income children (8%; lead > 10 ug/dL), non-Hispanic Black children (11.2%), and children who lived in housing built before 1946 (8.6%) compared with about 2% for children in other categories.[65] In a Rochester, New York, study,[66] 2-year old Black children had a mean blood lead level of 9.6 micrograms per deciliter compared with 4.8 micrograms per deciliter for White children, but 47% exceeded 10 micrograms per deciliter compared with 6% of White children. Immigrant children may also be disproportionately exposed to lead. In New York City, children with blood lead levels higher than 10 micrograms per deciliter were 11 times more likely to have lived in the United States for less than 6 months.[67] Other risk factors were residence in pre-1950 buildings, living in buildings with only 1 or 2 units, putting fingers in the mouth, and eating nonfood items. Parent report of peeling paint was not a significant predictor.[67] In Chicago, lead levels higher than 10 micrograms per deciliter occurred in 30% of children and were inversely related to caretaker's educational level in Black children.[63] Moreover, Edwards et al.[68] found blood lead levels higher than 10 micrograms per deciliter in children aged 1.3 years and older

Continued

	Camping or hiking
Recreational	What are the time constraints?
For hunting or fishing	How many days and nights are involved?
Set up time	What are the ages of the participants?
Time in the field	Where does it take place?
Use of natural materials (food or fiber)	How many different habitats are used?
Involvement in multiple activities	What are the exposures for each activity on these trips?
	What is consumed on the trips versus brought home for immediate or future use?
	What is given away to others?

Note. Determining exposure pathways often involves dissecting major activity categories (for all ages and genders). For all of these activities, exposure pathway considerations involved each individual's age and stage (gender, life stage such as pregnancy), number of times per day (or other time period), duration of activities, duration of seasonal and lifetime exposure, and overnight or daily activities. Each pattern within an activity type is a potential exposure pathway (involving inhalation, ingestion, or dermal exposure).
Sources. Ridolfi[69]; Harper et al.[72]; Burger et al.[73]; Burger and Gochfeld[144]; and unpublished data.

living in neighborhoods in which lead levels in water were elevated, which was also true in the Rochester study.[66] Racial disparities in childhood lead exposure persist, and screening criteria need to target families with multiple risk factors for lead exposure and toxicity (older housing, nutrition, iron-deficiency anemia).

Native Americans

Native Americans are a unique exposure group because the more than 500 different tribes have different mores, economical and social structures, and environmental conditions. First Nation environmentalists have viewed health issues broadly and included cultural issues. Exposure scenarios developed for the Yakama[69] and the Confederated Tribes of the Umatilla Indian Reservation[37,70,71] of Washington State illustrate unusual exposures. Harper et al.[72] developed a landmark guidance manual for tribal exposure scenarios and risk assessments for Native Americans. It is a transferable resource for assessments conducted for other minority and ethnic groups. In developing exposure pathway scenarios for Native Americans, important aspects are recognizing their unique activities, the frequency and duration of these activities, and the holistic nature of their ecocultural dependency webs (see the box on the previous page). American Indian activities include fishing; hunting; gathering materials used for mats, baskets, and bags and for other uses; consumption and use of water; time spent outdoors; cultural activities; memorials; and ceremonies.[69] Sweat baths are a unique exposure pathway because of their intensity and duration.[72] Although several exposure pathways have been identified for Native Americans, few studies have examined human tissue levels in relationship to those pathways.

Other major exposure pathways for Native Americans and Alaskan Natives include consumption of plants, fish, and wildlife (see the box on the previous page). Native Americans' hunting and fishing rates can be very high compared with those of other groups (although such high rates are not limited to Native Americans).[74] Exposure occurs not only because of Native Americans' increased consumption rates but because of the higher diversity in the foods they eat (many kinds of fish, game, roots, berries, shoots, and leaves). Patterns differ among tribes, depending on where they live, food use, cooking and preparation traditions, parts consumed, and ratio of river-bottom to upland resources.[75] Native peoples see subsistence living as part of their culture, not as a reflection of necessity, poverty, or the minimum amount of food necessary to support life.[72]

Richardson and Currie[76] found gender-related differences in fish consumption in American Indians from Ontario (geometric means = 19 g/day for men and 14 g/day for women), with the highest rates of consumption in summer and the lowest rates in winter. Fish consumption increased with latitude, isolation, and age (older people ate more fish). For pregnant women, several months of high consumption can lead to significantly different risk. DeWeese et al.[77] found a mean monthly fish consumption of 121 grams per day for April, 113.5 grams per day for May, and 30 grams per day for January through March. Although the geometric mean for women was 14 grams per day, the arithmetic mean was 27.7 grams per day.[76] Moreover, the reported geometric mean hair mercury levels of 2.7 micrograms per gram (men) and 2.1 micrograms per gram (women) obscured the fact that mercury levels in some individuals of both genders exceeded 30 micrograms per gram,[76] a level consistent with severe methylmercury poisoning.

Higher consumption of fish, seal, and seal liver (which are linked to increased levels of mercury in hair) was associated with lower socioeconomic status in the Inuit, whereas consumption of whale was uniform across economic classes.[78] Women increased their consumption of fish and seal during pregnancy and averaged as many as 14.2 fish meals per month, 0.6 whale meals per month, and 0.8 seal meals per month. Traditional foods of the Dene and Metis in the Northwest Territories (Canada) were consumed on 65% of days (48 food types).[79] Studies of Native Americans' consumption rates can be used to understand both the breadth and the variation of exposure (Table 2). Traditional consumption rates for Native Americans were once much higher than they are now; current consumption rates are suppressed partly because of contamination in waterways,[75] which suggests that consumption may increase if this contamination declines. Thus, those assessing exposure need to consider the potential for future increased consumption rates when developing exposure risk scenarios, setting water quality standards, and developing fish consumption advisories.

Subsistence and Game or Sports Fishermen

Consumption of noncommercial food is a major route of exposure that can lead to adverse health outcomes for many Americans, as well as for environmental justice communities. These pathways need to be considered for other minority, low-income, and rural communities, as well as for children and Native Americans.

One of the main pathways for excessive exposure of minorities and low-income families is through consumption of wild-caught plants, fish, and game. For example, fishermen in Newark Bay, New Jersey, showed different patterns of exposure as a function of ethnicity and catch type.[84] Whites had higher consumption of crabs (highly contaminated with polychlorinated biphenyls), but lower consumption of fish (highly contaminated with mercury); Asian Americans had the highest consumption of fish, but the lowest consumption of crabs. Blacks who ate both fish and crabs had higher consumption rates than other groups. Consumption rates for all groups decreased with income.[84] Similarly, in South Carolina Blacks had higher consumption of wild-caught fish (high levels of mercury), whereas Whites had higher consumption of deer.[85] Data on consumption rates for minority, low-income, and recreational fish consumers support the need for site-specific data on high-end consumers and outliers, including at least the 95th percentile of distributions (Table 3). These data show that uniformity is needed in the approach to gathering information on consumption of both wild-caught and commercial foods.

Rural Populations

Disparities occur in rural areas,[98] characterized as having low traffic, high dust levels, low lead levels, high pesticide levels, and uncertain water quality.[99] Rural areas may be close to agriculture (farms, feedlots, swine facilities), where pesticide and animal waste exposures occur, and to mines, smelters, industries, and waste sites. Home-grown livestock and produce are a vector for pesticides, water pollutants, and soil contamination.[100] Unusual exposure pathways for rural residents include consumption of self-caught fish and game, exposure to pesticides, and exposure to higher levels of mining materials, such as arsenic,[100] and asbestos.[101]

People of low socioeconomic status may settle in rural areas in which housing is cheaper.[102] Some rural populations are predominantly Black or Latino; although Latinos have mainly immigrated to cities, they have also moved to rural areas in which housing costs are low. Rural populations with a high proportion of African Americans have high mortality rates from injuries, suicide, and chronic obstructive lung disease.[103]

In isolated communities that have low population levels, people may be less willing to provide exposure information or unwilling to share cultural information.[104,105] However, information gleaned from Aleut communities resulted in an understanding of the percentage of people who ate particular subsistence foods, although individual consumption rates were not obtained. Additionally, the low population level of many minority communities makes it difficult for residents (or researchers) to fathom a risk level of 1 in a million.

Farmers, Farm Workers, and Neighbors

Agriculture ranks among the most hazardous industries because of fatal and nonfatal injuries, work-related lung diseases, noise-induced hearing loss, skin diseases, and cancers associated with chemicals and prolonged sun exposure. Farming is one of the few industries in which the families are also at risk for injury, illness, and death and have measurable exposure to take-home pesticides.[106] Farmers may have pesticide exposures similar to those of their hired help. Children living on farms may engage in farm work or have incidental exposure to chemicals around the farm. Neighbors may also experience exposure to pesticides from wind drift or runoff.

Most studies of farm workers have focused on occupational

TABLE 2—Fish Consumption Reported for Native American Versus EPA Exposure Assumptions: 2005

Source	Average Daily Intake, g/d (kg/y)	Daily MeHg Intake, Fish With 0.3 ppm (μg/d)	Daily MeHg/kg Body Weight (Assumed to Be 70 kg)
EPA average[a] rate, US population	6.5 (2.4)	1.9	0.03
EPA default consumption rate[80]	17.5 (6.4)	5.2	0.08
EPA alternative recommended rate, two 6-oz meals/wk	48.5 (17.7)		0.21
EPA consumption rate[80]			
Subsistence fishers	142.4 (52.0)	42.7	0.61
Pregnant women	165.5 (60.4)	49.7	0.71
American Indians, Ontario[76]			
Men	19 (6.9)	5.7	0.08
Women	14 (5.1)	4.2	0.06
Native Americans, MI[81]	24.3 (8.9)	7.3	0.10
Tulalip and Squaxin Tribes, Puget Sound, WA[82]	60.72[b] (22.2)	18.2	0.26
Columbia River, WA, tribes[36]	63.2 (23.1)	19.0	0.27
Anishinaabe, Great Lakes[77]			
December	15.1 (5.5)	4.5	0.06
April[c]	121.1 (44.2)	36.3	0.52
Columbia River, median for 1950s[83]	350 (128)	105	1.5
Columbia River, 99th percentile[36]	389 (142)	117	1.7
CTUIR traditional rate[37]	454 (156)	136	1.9
Historic[d] Yakama[72,75]	620 (226)	186	2.7

Note. CTUIR = Confederated Tribes of the Umatilla Indian Reservation; EPA = Environmental Protection Agency; MeHg = methylmercury.
[a]EPA has established various assumption values for different fish types of fish consumers.
[b]Both fish and shellfish.
[c]Calculated from high rate for April for the tribe (× 227 g/meal).
[d]Refers to what tribal members ate historically before contamination and other factors both suppressed the fish population and rendered them high in contaminants, resulting in lowered fish consumption.

TABLE 3—Fish Intake Reported for Other High-End Consumption Groups: 2000

Source/Subgroup	Daily Intake g/d (kg/y)	Daily MeHg Intake, Fish With 0.3 ppm (ug/d)	Daily MeHg/kg Body Weight (Assumed to Be 70 kg)
EPA default consumption rate[80]	17.5 (6.4)	5.2	0.08
General population			
General population, freshwater fish, Maine[86]	3.7 (1.3)	1.1	0.02
Sport fishers, Lake Ontario[87]	4.9; 17.9 from all sources (1.8)	1.5	0.02
US population, 48 states (all fish)[88]	15.6 (5.7)	4.7	0.07
General population, Lake Ontario[87]	17.9 (6.5)	5.4	0.08
General population, Louisana[89]	23.5 (8.6)	7.1	0.10
Recreational anglers, Indiana[90]			
All, range	16.4-32.3 (6.0-11.8)	4.9-9.7	0.07-0.14
Minority	38.3 (14)	11.5	0.16
Angler population, Michigan,[91] range	40.9-61.3 (14.9-22.4)	12.3-18.4	0.18-0.26
General population, New Jersey,[92] mean ±SD	50.2 ±47 (18.3)	15.1	0.22
Recreational anglers, Washington[93]	52.8 (19.3)	15.9	0.23
Marine fish	53 (19.3)	15.9	0.23
Shellfish	25 (9.1)	7.5	0.11
Freshwater[94]	10 (3.7)	3.0	0.04
Minority			
Delaware[95]			
Black	15 (5.5)	4.5	0.06
Asian	6 (2.2)	1.8	0.03
Hispanic	3 (1.1)	0.9	0.01
Michigan[81]			
Native American	24.3 (8.9)	7.3	0.10
Black	20.3 (7.4)	6.1	0.09
White	17.9 (6.5)	5.4	0.08
San Francisco Bay, CA[95]			
Black	27 (9.9)	8.1	0.12
Chinese	28 (10.2)	8.4	0.12
Filipino	33 (12.0)	9.9	0.14
Pacific Islander	38 (13.9)	11.4	0.16
Asian	22 (8.0)	6.6	0.09
Hispanic	22 (8.0)	6.6	0.09
New Jersey[84]			
Asian	52 (19.0)	15.6	0.22
Hispanic	41 (15.0)	12.3	0.18
White	27 (9.9)	8.1	0.12
Black	23 (8.4)	6.9	0.10
South Carolina[96]			
Black men	70 (25.6)	21.0	0.30
Black women	48 (17.5)	14.4	0.21
White men	38 (13.9)	11.4	0.16
White women	26 (9.5)	7.8	0.11

Continued

exposures,[107] have not used biomarkers to assess exposure,[108] or have not studied household exposure. Pesticides may be airborne or tracked into houses on clothes and shoes. Pesticides may be measured in air, water, soil, dust, and urine. Associations between organophosphate residues in house dust and organophosphate metabolites in the urine of farm workers and children were significantly positive. Urinary pesticide levels and symptoms are not always related, although headaches and blurred vision have been consistently reported.[109]

Proximity to farms may result in exposures and adverse outcomes. The amount of cropland within 750 meters of a house predicted the amount of herbicide residue on carpets.[110] In California, pregnant mothers who lived within 500 meters of fields on which agricultural pesticides were applied (particularly dicofol and endosulfan) had a 6.1 odds ratio for having a child with autism spectrum disorder.[111] In Washington, 13% of farm workers said they had been directly sprayed or dusted,[112] as did Mexican farm workers in California.[113] Poor minority schools in North Carolina were closer to swine confinement factories and were more likely to experience animal waste odors than were White high schools.[114]

Migrant Workers

Migrant workers pose a risk assessment challenge because their exposures are seldom documented. They follow crops, encounter sequential exposures, and often have their families with them. Although 40% to 50% of all farm workers met the migrant definition, only 19% were follow-the-crop migrants.[115]

TABLE 3—*Continued*

San Diego Bay, CA[95]			
Asian	82 (29.9)	24.6	0.35
Filipino	50 (18.3)	15.0	0.21
Hispanic	24 (8.8)	7.2	0.10
White	11 (4.0)	3.3	0.05
Asians and Pacific Islanders, WA	117.2 (42.8)	35.2	0.50

Note. EPA = Environmental Protection Agency; MeHg = methylmercury. Some general population estimates from surveys with similar designs are included for comparison, but this list is not meant to be exhaustive.

Secondhand exposure occurs: In North Carolina, pesticides were found in 39 of 41 households (95%), on toys in 71%, and on children's hands in 55%.[116] In a study of 213 farm workers in Washington communities and labor camps, 20% identified mixing, loading, or spraying activities. However, take-home pesticide levels and children's urinary pesticide levels were higher for those who thinned crops than for those who sprayed them.[117]

Urban Poor

Many factors affect the health and well-being of people living in cities, particularly minority and low-income families, including housing age and quality; poverty, crime, and nutrition status; household pesticides;[35] lack of exercise resulting from unsafe neighborhoods and low walkability;[118] and a disconnect among planning, public health, biology, and social factors.[119] A college education is strongly associated with high self-assessment of health.[120] The stresses of drugs, crime, and unemployment create a toxic environment that compounds exposure to indoor and outdoor pollutants.

In the United States, approximately 6 million children are urban poor.[121] In 2 Chicago inner-city neighborhoods, living in dwellings built before 1919 was associated with child blood lead levels of more than 10 micrograms per deciliter.[63] Baxter et al.[122] implicated high-density, multiunit buildings as a risk factor for exposure to nitrogen dioxide and particles less than 2.5 micrometers in diameter. Air pollution studies comparing neighborhoods[123] or cities[124] have shown substantial intra- and intercity variability in space and time attributable partly to highways and industries.

The emphasis on asthma in children obscures the high rates of asthma in adults. A sample of central Harlem adults found that 14% reported asthma, with women being twice as likely to have activity restrictions and to report multiple emergency room visits.[125] Residents from households earning less than $9000 per year were more likely to report asthma than were those from households earning more than $20 000.

Pesticides are not confined to agricultural areas or suburban lawns. Kings County (Brooklyn) and Manhattan were the 2 New York counties with the highest rate of legal pesticide application,[35] mainly to control fleas and cockroaches. Pregnant women (68% Dominican, 31% Black) in northern Manhattan and South Bronx were surveyed for pesticide use and exposure; pesticide use in the home was reported by 61% of the women, and chlorpyrifos and diazinon were detected in virtually all household and personal air monitors.[126] Before the chlorpyrifos ban in 2001, birth weight and height decreased by 67 grams and 0.43 centimeters for every log unit increase in cord plasma level.[127] Urban gardening and locally grown food can be an important exposure pathway for metals and semivolatile organic chemicals from the atmosphere.[99]

Cultural Uses of Mercury

All forms of mercury are toxic, hence its widespread use in a variety of biocides. Elemental mercury (quicksilver) has been imbued with magical powers for centuries, and today many cultures covet mercury, including people in India, the Andes, and US cities. In the United States, cultural practices involving mercury are prominent in Latino Caribbean communities (Cuban, Dominican, Puerto Rican), in which mercury (called *azogue* or *vidajan*) is sold in specialty shops called *botanicas.* The cultural or spiritual practices in which mercury may be involved are Santeria (African Latino), Palo MayombÕ (Caribbean), CandomblÕ (African Brazilian), Voodoo (Haitan), Espiritismo (Puerto Rican), and Parad-Shivling (Hindu). Superstitious practices are more prominent than spiritual practices. Girls carry amulets containing liquid mercury to bring good luck or attract lovers; boys carry mercury to attract money.[128] Mercury droplets may be applied directly to the body, dispersed in cologne, or sprinkled around new cars or new apartments or over babies to ward off evil spirits. In rare cases, mercury may be injected, usually with severe consequences.[129] The popular press has attributed the superstitious uses to advice from Santeros, but practitioners have consistently denied that they recommend mixing mercury with perfume or bath water or sprinkling it over candles or babies.[40] Swallowing liquid mercury in capsules is still used as an alternative practice to relieve gastrointestinal symptoms,[130] mainly in Latino and Caribbean communities; this exposure pathway is less important exposure because elemental mercury is poorly absorbed from the gastrointestinal tract.[131] A cluster of children exposed to mercury brought home in amulets had elevated mercury levels, with a maximum of 1213 micrograms per liter compared with an upper limit of normal of 50 micrograms per liter.[132]

These cultural uses of mercury can be widespread,[133] and they provide a unique exposure pathway that has been resistant to intervention. Once a home is contaminated with mercury droplets, subsequent occupants may experience exposure. The EPA[134] has had more interest in cultural uses of mercury than have consumer product agencies,[135] which have been reluctant to regulate mercury for fear of driving it further underground.[131] Cultural uses raise controversy not only about freedom of religion, but also about blaming individuals for environmental contamination with mercury while much larger sources of contamination, such as coal-fired power plants, are weakly regulated.[136] Airborne mercury released by poorly regulated Midwestern power plants is deposited all over the northeastern United States, adding to the burden of otherwise environmentally stressed communities.

RECOMENDATIONS AND CONCLUSIONS

The presence of exposure outliers in a wide variety of populations and the intersection of risk factors are important aspects of risk assessment. The same individual may be an outlier for several risk factors at once, putting his or her combined exposure and risk far above that of any modeled estimate. On the one hand, critics of risk assessment decry reliance on unrealistic default values, and on the other hand, current methodology overlooks outlier individuals facing multiple environmental and social stressors. Although various EPA guidance manuals[137–138] have clearly described the general concepts of exposure assessment and provided guidance on conducting an exposure assessment for unique and highly exposed populations, we strongly encourage the systematic consideration of uniquely exposed populations in all risk assessments to support decision-making at the EPA and other agencies. We advance a framework to ensure that exposure assessments consistently examine unique exposure pathways. Combining this framework with information on types of uniquely exposed populations will enhance risk assessors' capacity to identify those who may experience high-end–exposures to environmental contaminants. The people who are often dismissed as outliers are those who are most at risk and most in need of protection. We provided scientific evidence that uniquely exposed populations with high-end-exposed individuals need to be specifically examined in risk assessments. These data should be translated into guidelines for risk assessors. The impact is greater in populations that experience multiple stressors, including multiple environmental exposures coupled with inadequate nutrition, poor access to health information and treatment, and socioeconomic stress.

We showed that data on uniquely exposed populations are often lacking or submerged in means and medians. We recommend investing in systematic data collection and reporting to fill these gaps, using complete distributional data that clearly identify high-end and high-risk individuals. These individuals are particularly likely to be found in environmental justice populations who face an excess of both environmental and socioeconomic stressors.

We suggest these approaches to research on highly exposed environmental justice communities:

- Expand the National Health and Nutrition Examination Survey model, and expand its use to local levels, modeled on the New York City Health and Nutrition Examination Survey.[139] Include questions regarding environmental justice communities, with more details on fish consumption, traditional medicines, and cosmetic use and more detailed links to demographic and geographic data on the built environment.
- Develop detailed site-specific consumption information to assess exposure at and beyond the 95th percentile, by publishing or making available raw data from which complete distributional details can be obtained.
- Develop a standardized methodology for assessing exposure at different distances from point-source pollution in minority, low-income, and Native American populations.
- For studies that rely on means, encourage publication of both arithmetic and geometric means (which down-weight the right tail of distributions).

Other approaches to research will take longer to develop and execute, including determining temporal effects of contaminants on fetal development in highly exposed populations, modeling the multiple exposures that environmental justice communities face, and developing a national exposure database for high-end exposures for known high-risk populations.[140,141] Risk assessment focuses on exposures averaged over time, whereas intermittent peak exposures may convey the greatest risk. An emphasis on tracking vulnerable groups is needed. Minority and low-income groups have higher residential mobility than Whites, partly because of lack of available jobs.[142] Studies that emphasize tracking and follow-up will gain considerable power in detecting risk-factor interactions on exposure.

The EPA should ensure that data collected on American Indians and other groups are not collapsed into an "other" category.[143] Data should be presented by tribe whenever possible. These data suggest a need to develop a holistic approach to exposure assessment for ethnic–racial, low-income, and other environmental justice communities, including broadening exposure to include religious, cultural, and other lifestyles that may not be mainstream. ■

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M. Gochfeld and J. Burger developed the emphasis on outliers, reviewed the literature, and wrote the article.

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Human Participant Protection

This article is a review of other articles; thus, no human participants were used and institutional review board approval was not needed.

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