Journal of Toxicology and Environmental Health, Part A, 75:272–287, 2012

ISSN: 1528-7394 print / 1087-2620 online
DOI: 10.1080/15287394.2012.652058

LEAD (Pb) IN BIOTA AND PERCEPTIONS OF Pb EXPOSURE AT A RECENTLY DESIGNATED SUPERFUND BEACH SITE IN NEW JERSEY

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The Raritan Bay Slag Site (New Jersey) was designated a Superfund site in 2009 because the seawall, jetties, and sediment contained lead (Pb). Our objective was to compare Pb and mercury (Hg) levels in biota and public perceptions of exposure at the Superfund and reference sites. Samples (algae, invertebrates, fish) were collected from the Raritan Bay Slag Site and reference sites and analyzed for Pb and Hg. Waterfront users were interviewed using a standard questionnaire. Levels of Pb in aquatic organisms were compared to ecological and human health safety standards. Lead levels were related to location, trophic level, and mobility. Lead levels in biota were highest at the western side of the West Jetty. Mean Pb levels were highest for algae (*Fucus* = 53,600 ± 6990 ng/g = ppb [wet weight], *Ulva* = 23,900 ± 2430 ppb), intermediate for grass shrimp (7270 ± 1300 ppb, 11,600 ± 3340 ppb), and lowest for fish (Atlantic silversides 218 ± 44 ppb). Within species, Pb levels varied significantly across the sampling sites. Lead levels in algae, sometimes ingested by individuals, were sufficiently high to exceed human safety levels. Mercury levels did not differ between the Superfund and reference sites. Despite the fence and warnings, people (1) used the Superfund and reference sites similarly, (2) had similar fish consumption rates, and (3) were not concerned about Pb, although most individuals knew the metal was present. The fish sampled posed no apparent risk for human consumers, but the algae did.

In the 1970s, scientists and the public began to recognize that communities living adjacent to hazardous waste sites were sometimes exposed to toxic contaminants. The potential harmful effects of exposure near waste sites led to regulations requiring remedial actions to prevent human exposure and environmental damage. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) requires that the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) develop a National Priorities List (NPL) of sites with known or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States (*Federal Register* 2009). The NPL, popularly referred to as “Superfund,” identifies sites for the U.S. Environmental

Received 9 August 2011; accepted 12 December 2011.
We thank P. Lioy, D. Wartenberg, and N. Fiedler for valuable comments during the research. This work was supported financially and logistically by the NJ-NIEHS Center for Environmental Exposures and Disease (P30ES005022), the Environmental and Occupational Health Sciences Institute, and the Consortium for Risk Evaluation (DE-FC01-06Ew07053). The views expressed in this article are those of the authors and do not represent those of the funding agencies.
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Protection Agency (EPA) to investigate and assess the extent of contamination and potential exposure associated with the site, and to determine what actions (if any) are appropriate to interdict exposure pathways. To date there have been more than 1600 sites listed on the NPL, and only 340 have been deleted. There are additional sites awaiting agency action for possible NPL listing (U.S. EPA 2010a).

CERCLA required the U.S. EPA and the Agency for Toxic Substances and Disease Registry (ATSDR) to prepare a list of priority substances that are most commonly found at NPL sites and that are determined to pose the most significant potential threat to human health due to their toxicity and exposure potential (ATSDR 2007). This list is a prioritization based on frequency at NPL sites, toxicity, and potential for human exposure at these sites. The top three ranked priority hazardous substances are arsenic (As), lead (Pb), and mercury (Hg) (ATSDR 2007). Recent attention focused on identifying emerging chemicals of concern near hazardous waste sites (Ela et al. 2011).

In the summer of 2007, the New Jersey Department of Environmental Protection (NJDEP) took samples along the Raritan Bay shoreline in the Morgan Beach and Laurence Harbor area of the Waterfront Park (Middlesex County, and Old Bridge and Sayreville townships), which showed high concentrations of Pb (U.S. EPA 2010b). NJDEP referred the information to U.S. EPA, which took additional samples in 2008 and 2009. The ATSDR Health Consultation report (ATSDR 2009) found potential exposure "at levels that could be harmful to health" and recommended closing the beach area to "prevent sitting on slag and eating and drinking, playing on sand and/or swimming." U.S. EPA sampled sediment about 50 m and 200 m from the shoreline, finding levels of Pb up to 198,000 ppm (= 20% level in sediment; U.S. EPA 2010b). A Toxicity Characteristic Leaching Procedure (TCLP) for Pb exceeded criteria (USACE 2010). U.S. EPA proposed the Raritan Bay Slag Site for NPL listing, and after a suitable comment period, the Raritan Bay Slag Site was added to the NPL in November 2009 (*Federal Register* 2009; U.S. EPA 2010b). The source of Pb was industrial slag from a Pb smelter used to construct the seawall to protect the beach. Following the NPL listing, U.S. EPA contracted a remedial investigation/feasibility study (USACE 2010) to (1) investigate levels of Pb, (2) conduct a risk assessment, (3) develop a work plan, and (4) develop a public participation plan. The initial public meeting was held in spring 2011 (USACE 2010).

Old Bridge Township temporarily fenced the area in 2007, and U.S. EPA subsequently erected security fencing to restrict access to the affected areas and placed warning signs along the fence. The fencing was broken periodically by people who had been using the sandy beach or fishing from the piers for many years (U.S. EPA 2010b). Unlike many Superfund Sites that are viewed by the public as contaminated industrial or hazardous waste sites, the Waterfront Park (designated the Raritan Bay Slag Site) was viewed by residents as a wonderful beach and fishing spot. The park contained a popular children's playground. Some public officials were also displeased with the closures. Further, although the Pb slag had been deposited years before, the beach had been used subsequently by the local population without apparent ill effect. This led to dissonance when the public saw the warning signs and fencing.

The objectives of this article are to (1) report Pb levels in biota collected from the site and at reference sites, (2) compare Pb levels among species, and (3) report public perceptions and concerns about the Site (and the fencing of the site). Hg levels were also examined as a control for pollution levels in general, since Hg was not listed as a contaminant of concern for the site. Data are provided on Pb concentrations and potential pathways to humans (Kamrin et al. 1994). Management and policy decisions also require information on human behavior and perceptions. This case study illustrates the dissonance between public perceptions of risks associated with the Raritan Bay Slag Site, and the high Pb levels in rocks, sediments, and biota (U.S. EPA 2010b, this study). Further, although not investigated directly, potential ingestion of both contaminated biota and contaminated sediment or soil on the beach could lead to adverse effects.

Our overall protocol had two objectives: to (1) compare the levels of Pb and Hg in biota collected from the Waterfront Park to those in biota from reference sites, and (2) interview people at the Waterfront Park in order to understand concerns and perceptions about the Site and compare their perceptions with those of subjects at a reference site.

METHODS

The Raritan Bay Slag Site spans about 2 km of waterfront between Margaret's Creek on the east to just west of the mouth of Cheesequake Creek inlet. This is known as Waterfront Park, including the Morgan Beach and Laurence Harbor area, in Old Bridge and Sayreville, NJ. Pb slag (blast furnace pot bottoms), in the form of rocks and boulders, was deposited along the beachfront in the late 1960s and early 1970s, and was partly used in seawall and jetty formation (Figure 1). The West Jetty at the mouth of Cheesequake Creek is referred to in reports as the West Slag Jetty. Large, boulder-sized "rocks" are strewn around the Site, and smaller fragments can be found in the sand (U.S. EPA 2010b).

The natural habitat in the region is sandy beach, bordered by upland shrubs, grasses and *Phragmites*, with shallow creeks flowing into the bay. The towns include a mix of residential and industrial or former industrial sites. Notably, Sayreville has 21 other NPL sites and Old Bridge has 9. The beach is wide, providing sufficient space for a range of recreational activities, and has been improved with a boardwalk, children's park, and adequate parking. U.S. EPA identified sensitive fishery areas in the region as part of its National Estuary Program, and the Site is on a state-designated water body for maintenance of aquatic life. Aquatic biota samples were collected at several places along the Site, as well as at reference sites along the bay at Keansburg, NJ (10.6 km east of the Site), and Leonardo State Marina (15.5 km east of the Raritan Bay Slag Site). Neither of the reference sites is known to have specific Pb or Hg contamination, but neither is pristine.

Samples were collected under appropriate state permits or fishing licenses. All protocols were approved by the Rutgers University Animal Review Committee (protocol 97-017), and by the University Human Subjects Institutional Review Board (protocols E96-108 and E03-231).

Collection of Biota and Analysis Methods

Several species of algae, invertebrates, and fish were collected in December 2009 and April 2010) from the Raritan Bay Slag Site and several other sites along Raritan Bay (Figure 1; scientific names found in Table 1) under appropriate collecting or fishing licenses. The mouth of Cheesequake Creek is flanked by a West Jetty and an East Jetty. Sampling was conducted on the west side of the West Jetty, an area identified by the U.S. EPA as heavily contaminated. Sampling was also conducted east of the East Jetty and at the eastern end of the seawall. The three reference sites were: (1) a near site about 1.1 km east of the eastern end of the sea wall, (2) Keansburg, NJ (10.6 km east), and (3) Leonardo State Marina (15.5 km east). Invertebrates and some fish were collected with seines. Algae were collected by hand. Fish samples were obtained from those caught by fishermen on hook and line.

Algae, invertebrate, and fish samples were kept in coolers and brought to the Environmental and Occupational Health Sciences Institute (EOHSI) of Rutgers University for elemental analysis. Organisms were rinsed to remove superficial traces of sand or sediment. All samples were run with standard calibration curves by the same laboratory chemist to avoid any variations. Individual specimens were analyzed for Pb and total Hg. Atlantic silversides, striped killifish, green crabs, sand shrimp, grass shrimp, sea lettuce, and rock weed were weighed fresh, analyzed whole, and dried prior to microwave digestion. For bluefish, blue crab, and ribbed mussels only muscle was analyzed. At EOHSI, a 2-g (wet weight) sample was digested in 4 ml

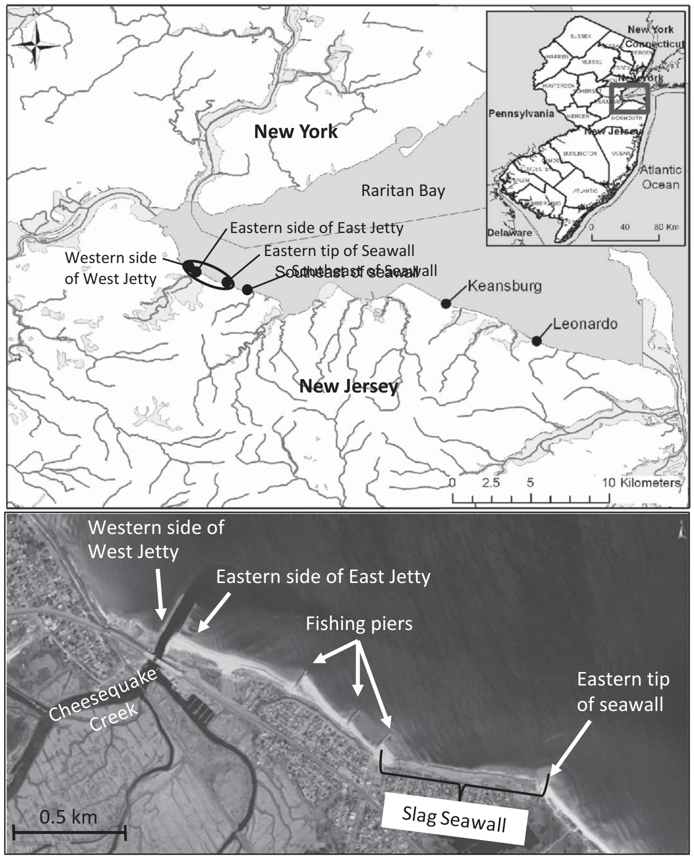

FIGURE 1. Upper map shows Raritan Bay Slag Site (circled) and reference sampling sites. Lower map provides detail on the Raritan Bay Slag Site. Pb slag was used in seawall and jetty formation. Inset shows location of Raritan Bay, New Jersey.

Fisher Scientific trace metal grade nitric acid and 2 ml deionized water in a microwave (MD 2000 CEM), using a digestion protocol of 3 stages of 10 min each under 50, 100, and 150 pounds per square inch (psi) (3.5, 7, and 10.6 kg/cm^2) at 80% of total power. Digested samples were subsequently diluted to 25 ml with deionized water. The same digestion methods were used for both Pb and Hg. All laboratory equipment and containers were washed in 10% HNO_3 solution and 18 MΩ deionized water rinse prior to each use (Burger et al. 2001).

Lead was analyzed by graphite furnace atomic absorption, with Zeeman correction. Mercury was analyzed by the cold vapor technique using the Perkin Elmer FIMS-100 Hg analyzer, with an instrument detection level of 0.2 ng/g, and a matrix level of quantification of 0.002 μg/g. All concentrations are expressed in parts per billion (ppb = ng/g) on a wet weight basis; all values in the text are given as wet weight unless so designated. A DORM-2 certified dogfish tissue was used as the calibration verification standard for Hg, and standard reference material (SRM) 1640, "Trace Elements in Natural Water," from the National Institute of Standards and Technology (NIST) was used for Zeeman graphite furnace atomic absorption spectroscopy quality control evaluation. Recoveries between 90 and 110% were accepted to validate the calibration for both Pb and Hg. All specimens were run in batches that included one spiked specimen and a blank. The accepted recoveries for spikes ranged from 85 to 115%; 10% of samples were digested twice and analyzed as blind replicates (with agreement within 15%).

Kruskal–Wallis nonparametric one-way analysis of variance (generating a χ^2 statistic)

TABLE 1. Fish Collected from Raritan Bay and Great Bay, New Jersey in 2008 through 2010. Given are Min, Max, Means and Standard Error in ppb Wet Weight (ng/g)

Fish species	Location	Distance to site (km)	n	Lead (ppb) mean	SE	max	Lead (ppb) Dry Weight Mean	Mercury (ppb) mean	SE	max
Bluefish	At site (Western side of West Jetty)		none[d]							
Pomatomus saltatrix	At site (Eastern fishing pier)	0	25	4.4	± 1.0	18.0	19	93.6	± 7.1	200
Moisture = 77%	Keansburg	10.6	25	2.0	± 0.5	9.8	9	129	± 15.7	440
	Leonardo State Marina	15.5	10	47.3	± 12.9	130	206	296	± 45.6	587
Kruskal Wallis X^2 (p)				25.4*				22.8*		
Atlantic Silverside	At site (Western side of West Jetty)	0	10	80	± 24.7	283	339	42.1	± 2.6	52.9
Menidia menidia	At site (Eastern tip of seawall) fall 2009[a]	0	10[a]	218	± 44.3	573	996	30.7	± 4.8	65.0
Moisture = 76%	At site (Eastern tip of seawall) spring 2010	0	10[b]	55.6	± 9.6	104	215	43.7	± 4.1	70.8
	Southeast of seawall fall 2009a	1.1	10[a]	56.8	± 12.9	144	260	27.6	± 4.4	59.2
	Southeast of seawall	1.1	10[b]	54.8	± 11.5	142	210	65.4	± 8.0	120.2
	Leonardo State Marina fall 2009a	15.5	10[a]	36.8	± 6.1	76.6	169	44.5	± 3.8	64.6
	Leonardo State Marina	15.5	10[b]	11.8	± 2.8	30.8	48	42.3	± 3.5	66.1
Kruskal Wallis X^2 (p)				38.3*				25.0*		
Striped Killifish	At site (Western side of West Jetty)	0	20	1050	± 315	5420	4270	18	± 4.3	87.6
Fundulus majalis	At site (Eastern tip of seawall)	0	12	414	± 87.6	931	1650	16.6	± 1.2	21.6
Moisture = 74%	Southeast of seawall	1.1	10	84.6	± 11.6	163	343	38.5	± 4.0	58.5
	Leonardo State Marina	15.5	9	34.5	± 12.8	110	128	20.7	± 2.7	33.4
Kruskal Wallis X^2 (p)				29.5*				20.7*		
Blue Crab (Body Muscle)	At site (Western side of West Jetty)	0	1	850	c		4250	88.0	c	
Callinectes sapidus	Keansburg	10.6	4	60.0	± 3.1	67.0	300	86.8	± 20.5	134
Moisture = 80%										
Blue Crab (Claw Muscle)	At site (Western side of West Jetty)	0	1	96.0	c		480	4.0	c	
Callinectes sapidus	Keansburg	10.6	4	57.5	± 2.9	65.0	288	66.8	± 18.6	115
Green Crab	At site (Western side of West Jetty)	0	4	22200	± 6040	34800	73000	18.7	± 4.4	28.3
Carcinus maenas	Keansburg	10.6	5	846	± 172	1250	1790	18.6	± 3.5	27.4
Moisture = 60%										
Kruskal Wallis X^2 (p)				6.0*				0.0		
Sand Shrimp	At site (Western side of West Jetty)	0	14	11600	± 3340	47700	44200	24.7	± 2.1	38.7
Crangon septemspinosa	At site (Eastern side of jetty and creek)	0	11	330	± 64.2	772	225	35.2	± 6.8	90.0
Moisture = 75%	At site (Eastern tip of seawall)	0	13	1320	± 703	9650	5560	13.7	± 2.3	26.2
	Southeast of seawall	1.1	9	644	± 389	3710	2620	19.1	± 4.4	36.0
	Keansburg	10.6	20	21.2	± 5.6	98.6	80	32.2	± 1.3	44.7
	Leonardo State Marina	15.5	18	97.5	± 19.5	277	399	24.0	± 2.4	45.1

(*Continued*)

TABLE 1. (Continued)

Fish Species	Location	Distance to site (km)	n	Lead (ppb) mean		SE	max	Lead (ppb) Dry Weight Mean	Mercury (ppb) mean		SE	max
Kruskal Wallis X^2 (p)				67.6*					29.1*			
Grass Shrimp	At site (Western side of West Jetty)	0	26	7270	±	1300	28900	2610	20.3	±	2.6	82.7
Palaemonetes pugio	At site (Eastern side of jetty and creek)	0	9	175	±	40.5	331	663	19.0	±	2.4	33.2
Moisture = 74%	At site (Eastern tip of seawall)	0	7	852	±	263	2160	3650	19.7	±	2.8	28.4
	Southeast of seawall	1.1	11	376	±	98.4	1020	1300	16.5	±	1.3	24.1
	Leonardo State Marina	15.5	2	32.7	±	32.7	65.5	135	12.4	±	0.3	12.7
Kruskal Wallis X^2 (p)				39.3*					4.9			
Ribbed Mussel	At site (Western side of West Jetty)	0	5	9240	±	3040	20000	53300	11.0	±	1.8	18.0
Geukensia demissa	Southeast of seawall	1.1	5	222	±	59.6	390	1230	16.1	±	0.8	19.0
Moisture = 82%												
Kruskal Wallis X^2 (p)				6.8*					3.2			
Sea Lettuce	At site (Western side of West Jetty)	0	5	23900	±	2430	32200	194000	16.7	±	4.3	32.1
Ulva lactuca	Southeast of seawall	1.1	5	1060	±	208	1860	13300	4.1	±	0.3	5.2
Moisture = 91%												
Kruskal Wallis X^2 (p)				6.8*					6.8*			
Rock Weed	At site (Western side of West Jetty)	0	5	53600	±	7000	74800	230000	9.8	±	1.6	14.9
Fucus gardneri	Leonardo State Marina	15.5	5	65.0	±	20.3	134	220	6.8	±	0.9	9.5
Mositure = 73%												
Kruskal Wallis X^2 (p)				6.8*					2.5			

a = Collected in Fall 2009 (seperated due to size differences in fish from the same location).
b = Collected in Spring 2010
c = no standard error or Wilcoxon chi-square because n = 1.
d = no Bluefish were encountered at West side of West Jetty

was used to examine differences among species and locations. The level for significance was designated as $p < .05$.

Interviews

The interviews followed a scripted questionnaire and were administered by trained personnel who had conducted these interviews at other sites along the New Jersey coast for more than 15 years about fishing, coastal activities, reasons for coming to beaches, and environmental perceptions and concerns (Burger 2002; 2004; 2008). The interviews required between 20 and 40 min, depending upon how many activities subjects engaged in and how many questions subjects asked about the survey or the designation of the site as a Superfund Site. Subjects were interviewed while they fished, watched children at the park, walked along the boardwalk, sunbathed, or played on the beach. Interviewers first introduced themselves as from Rutgers University and explained the overall purpose of the survey. Everyone present at the Site and at a reference beach close to the Keansburg sampling site was interviewed. Refusal rate was low, largely because fishers spend a great deal of time waiting, parents watching children at the park or beach were agreeable to talking to interviewers, and most individuals who came to the Site or other areas along the shore were relaxed and able to devote time to responding to the interview.

The questionnaire was divided into sections that included demographics, reasons for coming to the area, recreational activities, fishing behavior, consumption patterns, concerns or warnings they have heard, risks about eating fish, sources for health information, knowledge of Natural Resource Damage Assessment, restoration agencies, and specific activities of children at the site. Demographic information included age, gender, education, family income (asked at the end of the interview), and self-identified ethnicity. The questionnaire had been used for a number of studies of fishing and recreation along the New Jersey shore, but here only data relevant to potential exposure and perceptions about the safety of the Site are presented.

RESULTS

Pb and Hg Levels

Lead levels varied significantly among sites, with Pb levels being significantly higher at the Raritan Bay Slag Site than at the reference sites (Table 1). Across three species (sand shrimp, grass shrimp, striped killifish), Pb levels were several orders of magnitude higher at the west side of the West Jetty than elsewhere at the Raritan Bay Slag Site or the reference sites (Table 1 and Figure 2). There was no comparable variation in Hg levels among locations. Bluefish were unavailable from the West or East Jetty area, and showed higher Hg levels at the Leonardo reference site. Within the park, Pb levels were significantly higher at the west side of the West Jetty even compared to the East Jetty (Figure 2). In several species Pb levels were higher at the eastern tip of the seawall than at the reference site 1.1 km east, and were higher at the 1.1-km reference site than at the Leonardo sites (Table 2).

A wider range of organisms was samples at the west side of West Jetty (the location with the highest concentrations) and showed considerable variation in Pb levels (Figure 3), with significant differences among species. Contrary to expectation, fish had the lowest levels of Pb, invertebrates were intermediate, and algae had the highest levels (Figure 3). This was not true for Hg, which showed a more expected pattern (low in algae, higher in fish and crabs).

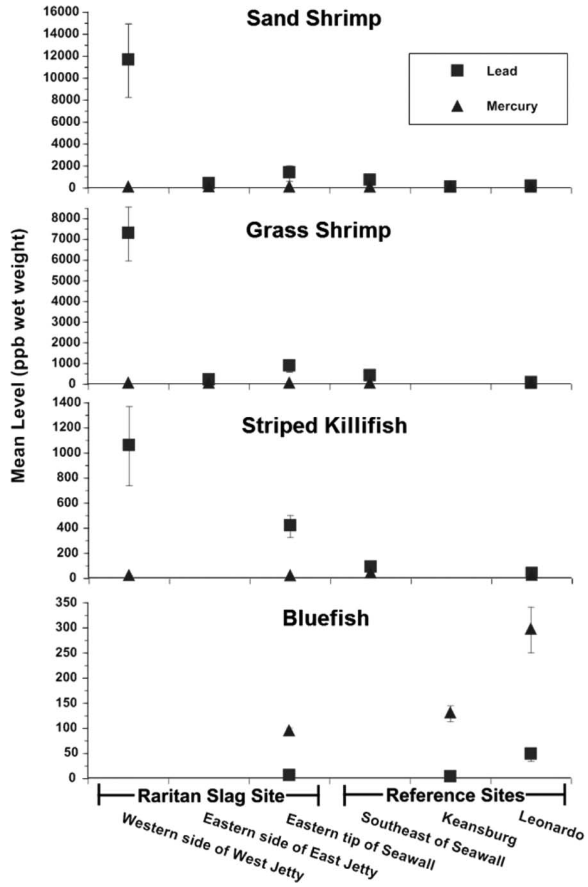

FIGURE 2. Comparison of Pb and Hg levels in marine biota at the Raritan Bay Slag Site and reference sites 1.1, 10.6, and 15.5 km east of the Raritan Bay Slag Site. Solid box (Pb) or triangle (Hg) designates mean ± SE.

For most species there were no seasonal differences in Pb levels. However, silversides had higher Pb levels in December (218 ± 44 ppb) than in April (55.6 ± 10 ppb), which was partly due to size differences, but also to their habit of feeding close to shore in the summer and going out to the ocean in winter (Hg levels did not vary during this period; Table 1).

Although Hg levels varied for some species, the variations among sites were small (less than an order of magnitude, Figure 3). This is illustrated for shrimp and killifish (Figure 2). Although the differences were significant for some species, they were not directional, and the West Jetty area (which consistently had the highest levels of Pb) did not have the highest levels of Hg.

TABLE 2. Comparison of Lead Levels in Organisms Within the Raritan Slag Site and Between it and Reference Sites. Shown are Kruskal-Wallis Chi Sq. * = $p < 0.05$

Comparison	All sites	East tip of seawall vs 1.1 km reference site	1.1 km reference site vs other reference sites
Atlantic Silversides	25.4 ($p < 0.0001$)	fall 11.6* spring 0.02*	fall 1.7* spring 12.6*
Striped Killifish	29.5 ($p < 0.0001$)	6.6*	6.2*
Sand Shrimp	67.6 ($p < 0.0001$)	5.9*	17.0*
Grass Shrimp	39.3 ($p < 0.0001$)	3.1*	2.5*

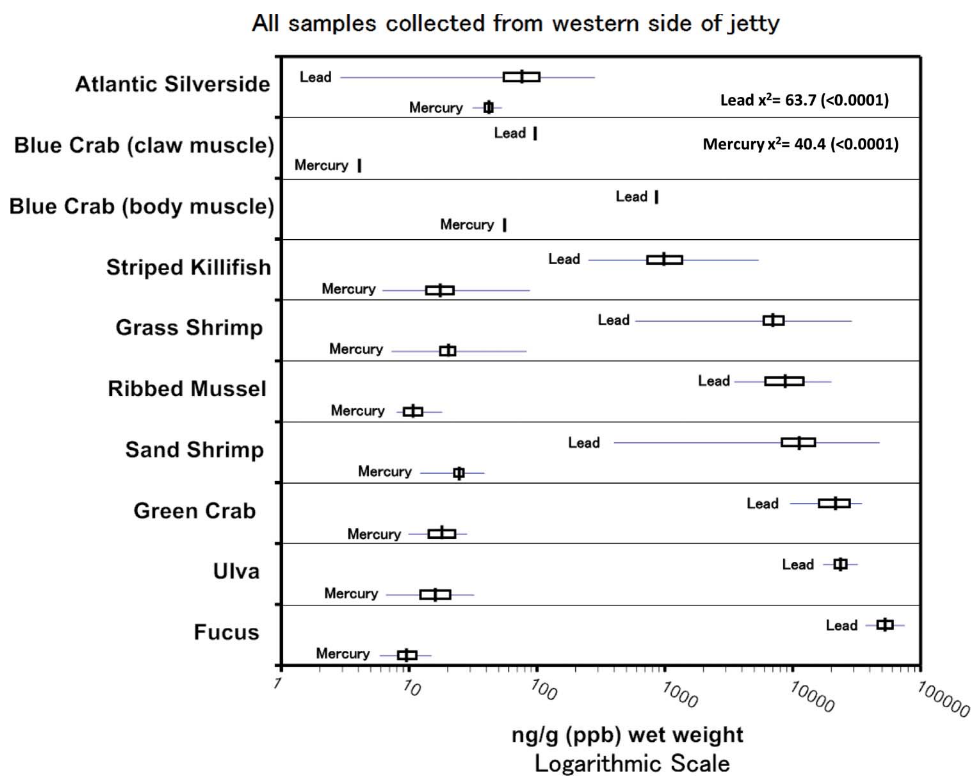

FIGURE 3. Hg and Pb concentration in biota collected at the west side of the West Jetty, the most contaminated part of the Raritan Bay Slag Site. Vertical line is mean; box is ±1 standard error. Horizontal line designates range (color figure available online).

Public Use and Perceptions

Most of the adults using the Site were male (73%), Caucasian (78%), and lived in New Jersey (92%). There were some differences between the Raritan Bay Slag Site and reference site in the percent of people engaging in fishing (higher at reference site) (Table 3). Fencing reduced the fishing area at the Raritan Bay Slag Site, while the accessible playground and boardwalk attracted nonfishing visitors. Significantly more people brought children to the Raritan Bay Slag Site than to the reference site, to use the playground at the Raritan Bay Slag Site and the wider sand beach areas.

When asked whether they knew of any concerns about either fish consumption or using the sites for nonconsumptive activities, between 70 and 86% of the subjects mentioned Pb, and there were no differences between the Raritan Bay Slag Site and the reference site. However, when asked if they had any concerns, only 9% of those interviewed at the Raritan Bay Slag Site said they were concerned about Pb (Table 3), and 46% said they had no concerns. Respondents at

TABLE 3. Public Participation in Activities, Risk Perception, and Risk at the Raritan Slag Site (Old Bridge, New Jersey) and a Reference Site (Cliffwood, New Jersey)

	Slag Site	Reference Site	X^2
Sample Size	92	50	
Overall Use			
% who come to fish	54%	90%	18.6*
% who come to crab	6%	8%	0.3
% who come to do non-consumptive activity	81%	56%	9.8*
% come to beach with family	22%	36%	3
Rate of Use			
Fishing (for those that fish)			
Mean times/month	7.9 ± 1.1	7.3 ± 1.1	0.2
Number months/year	6.8 ± 0.4	6.4 ± 0.5	0.3
Mean number of years	9.1 ± 1.4	12.6 ± 2.1	1.5
% that bring kids	33%	38%	0.2
Crabbing (for those that crab)			
Mean times/month	3.4 ± 1.3	6.7 ± 3.5	1
Number months/year	4.4 ± 0.9	3.5 ± 1.2	1
Mean number of years	18.2 ± 7.4	24.3 ± 14.0	0
% that bring kids	40%	0%	2.1
Non-consumptive (for those that come for non-consumptive activities)			
Mean times/month	10.0 ± 1.2	12.1 ± 3.6	0.1
Number months/year	6.6 ± 0.5	6.1 ± 0.8	0.6
% that bring kids	21%	6%	5.6*
Risk			
% heard any warnings for fishing	70%	75%	0.3
% say they believe the warnings about fish	86%	79%	0.9
% who ate fish (only of those who fish)	59%	73%	1.8
% who mentioned lead when asked do you know about any fish consumption concerns (open ended)	54%	40%	2.7*
% who mentioned lead when asked if they had any general concerns	9%	10%	0.07
% who said fence was there because of lead contamination	56%	18%	19.5*
% who ate crabs (only of those who crab)	40%	100%	2.1
% who feed fish to their children	53%	49%	0.1

the Raritan Bay Slag Site were interested in cleaning up the beach so they could use it without worrying about walking on garbage, and voiced concerns about garbage and pollution and cleaning up after dogs. Some people expressed dismay that "one side of the park was contaminated and the other was not," and others complained that "people are fishing without licenses" (perhaps because a new 2010 law requires that NJ saltwater fishermen register with the State). Others worried about the air, plants, sand, commercial fishing, and the wildlife. Subjects at the reference site were equally concerned about cleaning up the beaches, garbage, fish, and wildlife, but 60% said they had no concerns. Thus, subjects at both sites seemed aware of the warnings and concerns about fishing and recreation on the sites, but they personally were not concerned about Pb, and about half said they had no concerns themselves.

Despite the fact that the warning signs on the fence at the Raritan Bay Slag Site mentioned U.S. EPA, only one person said U.S. EPA should be responsible for restoring resources if they were damaged, while 47% said they should be restored by "government," and 20% said the responsible party should (Table 3).

DISCUSSION

Pb Levels

Data from this study indicated that: (1) Pb levels in the biota varied by location, with levels being significantly higher at the Slag Site than elsewhere along Raritan Bay; (2) Pb levels were highest for samples from the west side of the

West Jetty and were higher at the east tip of the sea wall than at reference sites (Table 2); (3) Pb levels varied significantly among species; (4) Pb levels reflect inverse trophic levels; and (5) fish migratory patterns affected Pb levels. In the latter case, fish that moved a short distance out into the ocean (silversides and killifish) had lower levels than other more sedentary organisms (shrimp, algae), and bluefish that were migratory along the Atlantic Coast had the lowest levels. Even among reference sites there was a west to east trend, with levels in fish and shrimp higher at the 1.1-km reference site than at the Leonardo site. Whether this reflects transport of Pb eastward along the shore by physical processes or movement of some species requires further study.

The high Pb levels found west of the West Jetty for algae (high of 74,800 ppb) occurred where the highest levels (198,000 ppm) were reported in sediment by U.S. EPA (2010b). U.S. EPA found that Pb levels decreased with sediment depth, which may relate to fine particles of the Pb slag still remaining in the sediment.

Fucus both attaches to the sediment and drifts in the water, allowing absorption everywhere. Further, algae grow in shallow water and remain stationary near the source, while shrimp, crabs, and fish are mobile. For comparison with published data on dry weight (dw) bases, average moisture contents for each species (Table 1) were determined and used as an adjustment factor to convert from wet weight (ww) to (dw). West Jetty *Fucus* averaged 230 ± 27 ppm dw. *Fucus* levels have been reported for several places, including the St. Lawrence River (0.44 ppm, dw, Phaneuf et al. 1999), Italy (2 ppm, dw, Caliceti et al. 2002), Greenland (0.1 to 0.6 ppm, dw, Riget et al. 1995), France (0.2-2.0 ppm, dw, Miramand and Bentley 1992), and England (3 ppm, dw, Martin et al. 1997), as well as for species of *Ulva*, including Hong Kong (9 ppm, dw, Ho 1990) and Canada (14.6 ppm, dw, Sharp et al. 1988), to name a few. In comparison, the values at the Raritan Bay Slag Site are very high.

A number of exposure factors affect the quantity of Pb absorbed by the body, including proximity to source, contact with contaminated water, duration of exposure, and internal factors. For example, algae grow in shallow water, near the shore where slag was located. Shrimp move within the area, particularly under tidal influence. The small fish move in and out of the creeks, along the shore, as well as out into the bay (where dilution would diminish exposure). Bluefish are migratory, and although the young fish hatch in the estuary they spend little time along the beach front. Other factors can also affect uptake of Pb in organisms, such as dissolved organic matter (Sanchez-Marin et al. 2007), but one of the primary causes of high Pb levels at the Raritan Bay Slag Site resulted from wave-driven erosion of the slag.

The Pb levels found in this study reflect inverse trophic level considerations: Algae (sedentary) had the highest levels, invertebrates have intermediate levels, and fish had the lowest levels. Thus, bioaccumulation was highest for lowest trophic levels, and biomagnifications did not occur. The high levels of Pb in the sediments (USACE 2010; U.S. EPA 2010b) and high levels in algae were mainly restricted to the west side of the jetty near Cheesequake Creek. Thus, by moving only a short distance invertebrates would encounter a different Pb environment, and moving out into the bay in the winter (killifish), and migrating south along the Atlantic Coast in the winter (bluefish) removed organisms from contaminated water and prey.

The remedial investigation/feasibility study (RI/FS) (USACE 2010) focused on sediment and pore water levels, reported Pb levels for biota only from the eastern part of the Site along the seawall, and analyzed three to five composite samples per species and report ranges on a dry weight basis. The maximum results for three species for the present study and the USACE study at the site were: (1) killifish: USACE up to 0.92 ppm; EOHSI up to 22 ppm; (2) ribbed mussel: USACE up to 8.6 ppm; EOHSI up to 109 ppm; and (3) *Ulva:* USACE up to 80 ppm; EOSHI up to 240 ppm. The RI/FS study did not sample the more highly contaminated West Jetty area, and the process of compositing reduced the impact of high levels.

In both studies, algae accumulated the highest levels of Pb, known as reliable bioaccumulators (Burger et al. 2007). This makes algae useful as bioindicators, as well as for biosorption and bioremediation (Mata et al. 2008; Mehta and Gaur 2005), and potentially harmful to consumers (including humans) because of their highest levels of Pb and are known as at contaminated sites. *Ulva* (sea lettuce) is eaten in some cultures. However, the ability to bioaccumulate Pb, or other contaminants, varies among species. *Fucus* accumulated higher levels than *Ulva*, and would thus be more reliable as a bioindicator for future studies; *Fucus* has been widely used throughout the world to monitor metal pollution (Martin 1997; Miramand and Bentley 1992; Riget et al. 1995; Wallenstein et al. 2009).

Pb Effects in Biota

Lead can affect the organisms themselves, as well as the consumers that eat them, including humans. Lead in fish and invertebrates produces abnormalities in locomotion, foraging ability, and predator avoidance (Weis and Weis 1998). Ecosystem effects derive from individual effects, in that changes in population levels can secondarily affect their competitors, their prey, and their predators, including humans. Levels in the diet of 50 ppm may produce adverse reproductive effects in some predators, and dietary levels as low as 0.1 to 0.5 ppm are associated with learning deficits in vertebrates (Eisler 1988). This suggests that sensitive vertebrates consuming killifish, green crabs, sand shrimp, grass shrimp, mussels, and algae from the west side of the West Jetty might experience behavioral deficits.

An additional exposure route, particularly for birds, may be the ingestion of Pb particles (small Pb slag stones or pellets) available at the site. Particles could be ingested either intentionally as grit, or inadvertently while foraging on vegetation growing in the sediment. Ducks, geese, and other waterfowl that forage in this habitat may inadvertently pick up these Pb pellets, similar to the exposure from Pb shot (with known adverse effects) (Eisler 1988; Kirby et al. 1983). Further, while such metal exposure may not produce direct adverse effects, indirect effects might occur, especially under starvation conditions (Kirby et al. 1983). Sediment exposure deserves additional risk assessment by U.S. EPA and relevant agencies for the Raritan Bay Slag Site, especially given the importance of Raritan Bay as a migratory and overwintering site for waterfowl (Frank 2010; U.S. Fish & Wildlife Service 1997).

Pb Effects in Humans

Potential human exposure was examined in terms of use of the beach area (not the fenced area, but next to the fences); Pb levels were not measured in people. However, data indicate that local residents use the beach extensively (see later discussion); children play in the sand and swim in the bay, and residents eat the fish they catch. The general human population is exposed to Pb through ingestion of food and water, rather than occupationally (WHO 1995).

Lead produces adverse human health effects, such as anemia, psychological disorders, peripheral neuropathy, nephropathy, abdominal colic, and cognitive disruptions (Chen et al. 2005; Counter et al. 2009; Needleman et al. 1990; WHO 1995), as well as endocrine disruption (Iavicoli et al. 2009) and disruptive behavior and juvenile delinquency (Dietrich et al. 2001). Cognitive abnormalities can occur at blood Pb levels of 5–10 μg/dl (Surkan et al. 2007; Counter et al. 2009), although others have provided a rationale for lower action levels (Gilbert and Weiss 2006). Developing fetuses and young children are most vulnerable because of higher gastrointestinal absorption and greater vulnerability of developing systems (Castellino et al. 1995). WHO (1995) guidelines are 0.3 ppm (ww) and a maximum daily dietary intake of 450 μg for Pb.

The algae collected from the West Jetty had Pb levels as high as 74,800 ppb (= 74.8 ppm for *Fucus*), which is considerably higher than the WHO (1995) guideline for Pb. The *Codex Alimentarius* Commission (2002) specifies a human diet level for Pb of 0.2 ppm for fish and 0.5 ppm for mollusks. Both species of algae examined in this study had levels higher than this (up to 74 ppm). Marine algae and kelp are used in human diets in many places (Chan et al. 1995; van Netten et al. 2000), and some use may well occur in Raritan Bay, especially among Asian immigrants. Although *Fucus* is rarely eaten, other algae, such as *Ulva*, may be ingested.

Small fish such as killifish and silversides can be caught and eaten whole. While the extent of this practice is not known for the Raritan Bay Slag Site (or nearby), the levels found in small fish are sufficiently high to suggest cause for concern if people eat them. During sampling, fishermen who were fishing on the eastern tip of the seawall, where levels of Pb were 0.4 ppm in striped killifish, explained that they were not worried. Sixty to 70% of the fishermen who were interviewed said they ate their fish, so if people fish for them, they would likely ingest them.

Bluefish collected from the Slag Site averaged Pb levels of 4.4 ppb (= 0.004 ppm), which is well below any adverse health level. Although adult bluefish are migratory, the bluefish caught at the site were generally less than 20 cm in total length. Fishermen said that it was difficult to catch big bluefish from the jetty or pier, which may reduce any exposure from older fish that had longer time to accumulate Pb or other contaminants (Burger and Gochfeld 2011).

The Hg levels reported in this study were low. Of the species collected, bluefish are the species most likely to pose a risk because people fish for them off the pier. The mean level of Hg in bluefish at the Raritan Bay Slag Site was 93.6 ppb (or 0.09 ppm), which is well below any human health advisory levels. However, at the Leonardo reference site the bluefish averaged 0.3 ppm. The bluefish collected in this study were relatively small (16–20 cm), and the Hg levels were similar to those found in the same size bluefish from other regions of New Jersey (Burger 2009).

Lack of Worry About the Raritan Slag Site

Recreational activities and subsistence fishing are important for many people, particularly those living near the shore in New Jersey. Individuals go fishing for a variety of reasons and many salt water fishers eat the fish they catch. Out of 12 possible reasons for visiting New Jersey coastal areas, subjects ranked communing with nature highest, followed by solitude and getting away from demands, fishing, sunbathing, and then crabbing (Burger 2002; 2003). While there were differences among bays and coastal areas, commune with nature was rated the highest everywhere. Thus, resource extraction is not the only or main reason many people visit coastal areas.

The Raritan Bay Slag Site was a place individuals had used for years or generations, without noticeable adverse health effects, and they suddenly found part of the beachfront fenced off with signs designating it a contaminated site. Interviews with people after the site was fenced indicated that subjects used the site for multiple activities (fishing, crabbing, nonconsumptive activities), for an average of 7 months per year, for an average of 3 (crabbing) to 10 (nonconsumptive) times a month, for an average of 9 years for fishers. Yet although people were aware of the Pb warnings, only about 10% even mentioned Pb as a concern.

To some extent, people are balancing competing risks and benefits. The benefits of the site are the recreational opportunities that it provides. The risk is the potential exposure to Pb through consumption. For individuals to make informed decisions about whether the potential risk from Pb should influence activities, they need to know the Pb levels in media they are exposed to, their exposure rate, and the levels of Pb that pose a risk (as well as their own potential vulnerabilities). This information is not available to people along the beach; only warning signs are present. Further, it may take individuals longer to adjust to the new idea that the beach they believed was safe and wholesome was not benign. Thus, Rogers's (2003) theory of diffusion of innovation or new ideas may apply.

The dissonance between the fencing and signs, and the familiar appearance of the site (the portion still available to them), indicated that people were not worried about the Pb. This is an unusual case because usually scientists rate the risk lower than does the general public (Kraus et al. 1992; Slovic et al. 1995). However, in this case the public rated the risks lower. Subjects who used the site did so at the same frequency as did people at a reference site, even though the "EPA scientists" put up fences and warning signs. Individuals who may have chosen to stay away from the beach for various reasons were not interviewed. Among beach-goers the lack of worry can be attributed to (1) indirect personal gain (some people had businesses near the site), (2) familiarity (people had used the site for years), (3) voluntarily continuing to use the site (Ost 1995), and (4) lack of effects. It is a matter of control; people accept risks they themselves have chosen (Slovic 1987). Familiarity with the site, coupled with a lack of clear effects, leads to deamplification (Kasperson et al. 1998; Rogers 1997).

CONCLUSIONS

Risk as the Slag Site is a function of Pb levels in the sand, water, and biota, exposure to these media, mainly through deliberate or inadvertent ingestion, and the duration and pattern of exposure (e.g., months, years). Individuals who came to the site engaged in multiple activities, over different time periods. Subjects came to the beach to fish or crab, or engage in nonconsumptive activities, an average of 7 months per year, and had been coming to this beach for an average of 6–7 years. Further, individuals brought their children 20–40% of the time. Thus, the potential for exposure is high for this population, and if the Pb levels are sufficient, individuals could be at risk.

The levels in algae and small fish were all sufficiently high to pose a potential human health risk if they were regularly eaten. There was little evidence that this was the case, although some people used a net to catch small baitfish, and the potential exists that some people might eat them. Pb levels in bluefish were not sufficient to pose a risk.

Despite the presence of a fence around the beach, and the signs proclaiming the site contaminated with Pb, people continued to use the site, fish and crab, engage in nonconsumptive activities, and bring their children to use playground facilities. Beach users had heard warnings, and 60% of the people using the Raritan Bay Slag Site said that they knew about Pb. However, when asked if they were concerned about anything, the majority (90 %) did not volunteer Pb as a concern. Many expressed the feeling that they and their families had been using the site for years without risk, and would continue to do so.

Interviews were drawn from waterfront users. It is entirely possible that some people avoided the beach because they were concerned about contamination and Pb exposure. Partly the lack of concern may relate to the fact that both Old Bridge (with 9 other superfund sites) and Sayreville (with 21 other superfund sites) have a long industrial history and familiarity with environmental contaminations issues.

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