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Project Summary

Biological Monitoring of Toxic Trace Elements

Dale W. Jenkins

The contamination of plants, animals, and humans by toxic trace elements poses a continuing and increasing threat to our environment. Of 20 trace elements that are known to be toxic, this report identifies 14 as particularly noxious because of their widespread production and use, and subsequent discharge and persistence in the environment. These 14 elements of particular concern are antimony, arsenic, beryllium, boron, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, tin, and vanadium.

Trace elements are known to accumulate in plants and animals. An analysis of data about their accumulation, together with a review of the organisms used for monitoring environmental gradients of trace elements, resulted in an extensive list of potential biological monitoring organisms.

Volume 1 of the two volumes in this report treats the problems, needs, selection, and use of living organisms for monitoring. The author also reviews global and national integrated exposure assessment programs and environmental and food surveillance programs. Volume 2 contains comprehensive data about bioaccumulation and bioconcentration of these 14 trace elements.

This Project Summary was developed by EPA's Environmental Monitoring Systems Laboratory, Las Vegas, Nevada, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Trace Element Selection

Before selecting the toxic elements for study, data were compiled about the toxic effects on humans, and major exposure routes and pathways; relative abundance and concentrations, production, and use; emissions into the environment for each trace element; and, the major sources and pathways of each trace element into plants and animals. After the data compilation, the following selection criteria were used to identify toxic trace elements:

1. The elements are toxic to humans and/or their food organisms;
2. The elements are fairly common and widespread;
3. The exposure to the elements is sufficient to cause a hazard, or potential hazard;
4. The elements are persistent in the environment; and
5. The elements are becoming more important because of increased production and/or use.

On the basis of the criteria, the following 14 trace elements or metalloids were selected: antimony, arsenic, beryllium, boron, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, tin, and vanadium.

Trace Element Toxicity

Certain chemical forms of each of the 14 trace elements that were selected for evaluation are dangerous to humans and other biological organisms. A summary of the toxicity of the element, its most toxic compounds, food hazards, and air pollution hazards, and primary route of entry into humans is presented in Table 1. When ingested, antimony, arsenic, beryllium, cadmium, chromium, lead, mercury, selenium, and tin are toxic; when injected, most of the 14 elements are toxic. Some of the trace elements—arsenic, cadmium, lead, and mercury—function as cumulative poisons; others, including beryllium, chromium, nickel, and arsenic, are carcinogenic. Cadmium and lead shorten life and cause neurological disruptions in experimental animals; at low concentrations, copper, mercury, boron, tin, cobalt, and nickel are toxic to certain species and have been used as biocides for certain plants and animals.

Of the 14 elements with known degrees of toxicity to humans, only five presently constitute an important threat to humans. These are, in order of their importance, lead, cadmium, mercury, arsenic, and nickel.

Toxic Trace Elements in the Environment

Data on abundance, production, uses, environmental emissions and dispersion, sources and pathways to humans are important to establish the extent of environmental pollution and the priorities for each trace element. This information is essential in order to select appropriate biological monitoring organisms, the type of monitoring required, and the number and geographic distribution of monitoring sites.

Elements in Earth's Crust

The abundance of the selected trace elements in the earth's crust, in dry soil, in the ocean, and in freshwater is summarized in Table 2. This information is related to base lines and background concentrations per element in non-polluted areas. Toxic

Table 1. *Toxicity of selected trace elements*

	Toxicity to humans	*Most toxic compounds*	*Food hazard*	*Air pollution hazard*	*Primary route of entry into humans*
Antimony	*toxic*	*halides and stibnine*	*L*	*low potential hazard*	*occupational exposure; therapeutic use; food*
Arsenic	*S*	As_2O_3, *arsine*	*hazard*	*hazard*	*occupational exposure; poisoning*
Beryllium	*toxic*	*all*	*low*	*potential hazard*	*occupational inhalation*
Boron	*low*	*borane*	*none*	*unknown*	—
Cadmium	*toxic*	*all*	*hazard, L*	*hazard*	*occupational inhalation; food*
Chromium	*S*	*hexavalent Cr*	*low*	*none*	*occupational inhalation*
Cobalt	*low*	—	*hazard*	*none*	—
Copper	*low*	—	—	*none*	*occupational exposure*
Lead	*toxic*	*all, especially tetraethyl Pb*	*hazard, L*	*hazard*	*occupational exposure*
Mercury	*toxic*	*methyl Hg and alkyl Hg*	*hazard*	*hazard*	*occupational exposure; food*
Nickel	*S*	*nickel carbonyl*	*low*	*hazard*	*occupational exposure*
Selenium	*toxic*	—	*hazard*	*none*	*occupational exposure*
Tin	*S*	*triethyltin tetraethyltin*	*L*	*none*	*occupational exposure; food*
Vanadium	*low*	—	*none*	*none*	*occupational exposure*

S—Specific compounds toxic or highly toxic, but element moderate to low toxicity.
L—Leaching from container contaminates food.

Table 2. *Abundance of trace elements in the environment*

	Igneous rocks, earth's crust (ppm)	*Soil (dry) (ppm)*	*Ocean (ppm)*	*Freshwater (ppm)*
Antimony	*0.2*	*2.0–10.0*	*0.00033*	*—*
Arsenic	*1.8*	*6.0*	*0.003*	*0.0004*
Beryllium	*2.8*	*6.0*	*0.0000006*	*0.001*
Boron	*10.0*	*10.0*	*4.6*	*0.013*
Cadmium	*0.2*	*0.06*	*0.00011*	*0.08*
Chromium	*100.0*	*100.0*	*0.00005*	*0.00018*
Cobalt	*25.0*	*8.0*	*0.00027*	*0.0009*
Copper	*55.0*	*20.0*	*0.003*	*0.01*
Lead	*12.5*	*10.0*	*0.00003*	*0.005*
Mercury	*0.08*	*0.03*	*0.0001*	*0.00008*
Nickel	*75.0*	*40.0*	*0.0054*	*0.01*
Selenium	*0.05*	*0.2*	*0.00009*	*0.02*
Tin	*2.0*	*10.0*	*0.003*	*0.00004*
Vanadium	*135.0*	*100.0*	*0.002*	*0.001*

trace abundance in the earth's crust for the 14 selected elements ranges from 0.08 to 135.0 ppm and 0.03 to 100.0 ppm in dry soil. Toxic trace abundance in the ocean ranges from 0.0000006 to 4.6 ppm, and in freshwater from 0.00004 to 0.02 ppm. These estimates show the relative abundance of toxic trace elements when compared with iron (56,300 ppm) in the earth's crust, and calcium (41,500 ppm) or sodium (10,500 ppm) in seawater.

Toxic Element Production and Use

To provide an indication of pollution or potential pollution for each trace element, Table 3 presents annual world productions, annual U.S. consumption, and estimates of the annual air pollution emissions in the United States. More than one million metric tons of boron, chromium, copper, and lead are mined annually, and more than one million metric tons of copper and lead are used annually in the United States. Less than one million metric tons of the other trace elements are mined or used in the United States annually.

Table 3. *Toxic element production and use (1,000 metric tons)*

	World production 1976	*U.S. consumption 1976*	*Human-caused air pollution in U.S. 1 year*
Antimony	*75.065*	*34.581*	*0.25*
Arsenic	*39.28*	*4.196*	*9.76*
Beryllium	*10.0*	*0.519*	*0.45*
Boron	*2,263.68*	*110.23*	*10.5*
Cadmium	*18.594*	*5.886*	*0.4*
Chromium	*4,203.9*	*284.44*	*16.46*
Cobalt	*28.228*	*8.287*	*0.75*
Copper	*8,083.09*	*2,206.60*	*200.0*
Lead	*4,625.79*	*1,466.47*	*234.5*
Mercury	*8.429*	*2.241*	*20.0*
Nickel	*872.342*	*160.35*	*4.885*
Selenium	*1.364*	*0.486*	*0.50*
Tin	*225.24*	*61.934*	*30.0*
Vanadium	*25.537*	*4.65*	*20.0*

Contamination of Biological Organisms

Plants and animals acquire trace elements from naturally occurring environmental sources, such as soil or water (Table 4), through uptake in plants and ingestion in animals, as well as from exposure to environmental contamination.

Normally, plants take up minute amounts of trace elements through the roots. The concentrations of a particular trace element in soil may be augmented through (1) the deposition of industrial air pollutants (fallout), (2) the addition of sewage sludge as a soil amendment, (3) the application of biocide to control unwanted weeds or pests, and (4) the direct application of industrial wastes. All these influences may cause elevated element concentrations in plants. The concentration of trace elements on plant surfaces also increases because air pollution fallout accumulates on leaves and stems (Table 4).

Terrestrial animals normally ingest trace elements through food and water. Additionally, they may be acquired through breathing contaminated air,

Table 4. *Sources and pathways of toxic trace elements to plants*

	*Sb**	*As*	*Be*	*B*	*Cd*	*Cr*	*Co*	*Cu*	*Pb*	*Hg*	*Ni*	*Se*	*Sn*	*V*
Uptake by roots														
A. Soil or groundwater	x	x	x	x	x	x	x	x	x	x	x	x	x	x
B. Fallout to soil from air pollution	x	x	x	x	x	x	x	x	x	x	x	x		x
C. Sewage sludge soil amendments		x			x	x		x	x	x	x	x		
D. Biocides applied to soil and/or seed		x		x	x			x	x	x			x	
E. Surface water contamination		x				x			x					x
F. Fertilizers		x			x	x		x		x	x		x	
G. Industrial pollution		x			x	x		x		x	x		x	
Uptake by leaves and stems														
A. Pollutant fallout from industrial sources	x	x	x		x	x	x	x	x	x	x	x		
B. Pollutant fallout from auto emissions									x					
C. Biocide applications to plants		x		x	x			x	x	x			x	
D. Pollution fallout from incineration of fossil fuels and refuse	x	x	x	x	x	x	x	x	x	x	x	x	x	x

**Key: Sb = Antimony; As = Arsenic; Be = Beryllium; B = Boron; Cd = Cadmium; Cr = Chromium; Co = Cobalt; Cu = Copper; Pb = Lead; Hg = Mercury; Ni = Nickel; Se = Selenium; Sn = Tin; V = Vanadium.*

eating contaminated food, licking fur or feathers that are contaminated, receiving therapeutic drugs, or eating biocides or poison baits. Aquatic animals are subjected to similar sources of toxic trace elements when sewage and industrial effluents are discharged into aquatic environments (Table 5).

All of the toxic elements under consideration are also found in, and distributed as, air pollutants.

Biological Monitoring

Biological organisms of many types have been used to measure the concentrations of trace elements at the pollutant site; these measurements are compared with different distances and with a control. Gradients of trace elements may be downwind, downstream, or in a circumferential zone around a pollution source. The results of biological monitoring of environmental gradients were compiled from the published literature for each of the selected trace elements. Detailed documentation concerning the organism selected for gradient analysis, the pollution source, the tissue analyzed, the concentration gradient in the organism, and the authority are presented in this report.

The priorities for biological monitoring of toxic trace elements on a global, regional or national, and local scale are based on the toxicity of the element and of its most toxic compounds, its world production and use, its emissions into the environment, its degree of hazard to humans and domestic animals, and its hazards when ingested as trace elements in food (Table 6, page 6).

Value of Biological Monitoring

If biological organisms are used for monitoring, they provide important data about, and actual responses to, pollutant exposure, instead of predicting biological responses and effects from physical and chemical measurements of the environment. Using living organisms as monitors is advantageous because they:

1. Provide early warning and help researchers to discover and identify toxic trace element pollutants in the early stages of environmental contamination;
2. Identify impact areas and sites of accumulation, and help researchers to measure the environmental levels of trace elements from sources;
3. Define critical pathways of pollutants to humans from water, air, and food;

Table 5. *Sources and pathways of toxic trace elements to animals*

	*Sb**	*As*	*Be*	*B*	*Cd*	*Cr*	*Co*	*Cu*	*Pb*	*Hg*	*Ni*	*Se*	*Sn*	*V*
Terrestrial														
A. Breathing contaminated air	x		x	x	x	x	x	x	x	x	x	x	x	x
B. Eating contaminated plant or animal tissue	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C. Drinking contaminated water	x	x	x	x	x	x	x	x	x	x	x	x	x	x
D. Licking or preening fur or feathers									x					
E. Receiving therapeutic drugs (domestic animals)		x												
F. Eating biocides or poison baits		x											x	
Aquatic														
A. Metal in water	x	x	x	x		x	x	x	x	x	x	x	x	x
B. Runoff and fallout		x			x	x		x	x	x	x	x	x	x
C. Sewage and industrial waste outfalls	x	x		x	x	x	x	x	x	x	x		x	
D. Mine tailings or smelter waste leachate		x			x	x		x	x	x			x	
E. Contaminated plants, animals, or sediment	x	x	x	x	x	x	x	x	x	x	x	x	x	x
F. Biocides or runoff		x		x				x					x	
G. Lead shot									x					

**Key: Sb = Antimony; As = Arsenic; Be = Beryllium; B = Boron; Cd = Cadmium; Cr = Chromium; Co = Cobalt; Cu = Copper; Pb = Lead; Hg = Mercury; Ni = Nickel; Se = Selenium; Sn = Tin; V = Vanadium.*

4. Establish base lines and integrated levels of trace elements over geographic areas;
5. Help show trends and rates of changes in levels of toxicity over time;
6. Integrate biological exposure of toxic trace elements with physical and chemical measurements in the environment;
7. Provide continuous monitoring systems over time, correlated with many other factors in the environment; and
8. Help researchers to evaluate the effectiveness of control measures.

Both plants and animals can serve as biological monitors for showing changes in levels of pollution and environmental contamination, and as reference points for determining direct or indirect effects on humans.

Types of Biological Monitoring

Biological monitoring can be conducted using two fundamentally different but complementary methods. The first method is to measure the accumulation or concentration of toxic trace elements in selected biomonitoring organisms. The second method is to measure impacts or effects of toxic trace elements on organisms, or on populations and communities of organisms. Only the first method, that is, biological monitoring using accumulator and concentrator organisms, is considered here.

Bioaccumulator organisms take up, accumulate, and store specific pollutants so that the organism's intake is greater than its output. Bioconcentrator organisms selectively accumulate and concentrate specific pollutants by sequestering them into certain organs or tissues, such as hair, bone, feathers, and so forth. A summary of the bioaccumulation and bioconcentration of toxic trace elements for plants and animals is presented in Table 7. All elements, except antimony and beryllium, are concentrated by some biological organisms present in the environment.

Recommendations for Biological Monitoring

Recommendations for biological monitoring of the selected trace toxic elements are presented in Table 6. Of those evaluated, there is an urgent, high-priority, and well-defined need to monitor lead, primarily because of air pollution that comes from the combustion of lead-containing gasoline. The author also recommends global environmental monitoring for arsenic and cadmium at a lower priority than for lead. No global monitoring is recommended for the remaining 11 elements.

On a regional or national, and a local basis, biological monitoring for arsenic, cadmium, lead, mercury, and nickel is recommended, especially around mining sites, near smelters, or near industries using these elements. Nationally, no monitoring is necessary for antimony, beryllium, boron, chromium, cobalt, copper, or tin. All elements, except boron, require at least surveillance monitoring at the local level.

Table 6. *Priorities for Biological Monitoring*

		Environmental monitoring		
	Global	*Regional, national*	*Local*	*Food surveillance*
Antimony	*o*	*o*	*x*	*o*
Arsenic	*x*	*xx*	*xx*	*xx*
Beryllium	*o*	*o*	*x*	*o*
Boron	*o*	*o*	*o*	*o*
Cadmium	*x*	*xx*	*xxx*	*xxx*
Chromium	*o*	*o*	*x*	*o*
Cobalt	*o*	*o*	*x*	*x*
Copper	*o*	*o*	*x*	*x*
Lead	*xxx*	*xxx*	*xxx*	*xx*
Mercury	*o*	*xx*	*xx*	*xx*
Nickel	*o*	*x*	*xx*	*x*
Selenium	*o*	*x*	*x*	*x*
Tin	*o*	*o*	*x*	*x*
Vanadium	*o*	*x*	*x*	*o*

o—no biological monitoring (except minimum global base line surveillance)
x—limited surveillance monitoring only of selected sites or foods
xx—surveillance and exposure assessment monitoring of suspected sites and foods
xxx—surveillance and exposure assessment monitoring of all needed sites and foods in a coordinated program

Biomagnification and Biominification

Biomagnification is the increase in concentration of trace elements in organisms with increasing or higher trophic levels in food chains. This trophic level magnification indicates that concentrations of trace elements are higher in predators than they are in prey. For biomagnification to occur, the prey (or food organism) must contain a trace element in its edible or digested parts so that the element can be absorbed and retained by the predator. Biomagnification has been documented for all the toxic trace elements that were selected for this study.

In terrestrial habitats, biomagnification results in increasing levels of trace elements from soil to plants for

Table 7. *Bioaccumulation and bioconcentration of toxic trace elements*

	Mammals, birds, and fish	*Mollusks, crustacea, and lower animals*	*Higher plants*	*Mosses, lichens, and algae*
Antimony	*x*	*x*	*x*	*x*
Arsenic	*xx*	*xxx*	*xxx*	*xx*
Beryllium	*x*	*x*	*x*	*x*
Boron	*x*	*xx*	*xxx*	*x*
Cadmium	*xxx*	*xxx*	*xxx*	*xxx*
Chromium	*xx*	*xxx*	*xxx*	*xxx*
Cobalt	*x*	*x*	*xxx*	*x*
Copper	*xxx*	*xxx*	*xxx*	*xxx*
Lead	*xxx*	*xxx*	*xxx*	*xxx*
Mercury	*xxx*	*xxx*	*x*	*x*
Nickel	*xx*	*xxx*	*xxx*	*xxx*
Selenium	*xx*	*x*	*xxx*	*x*
Tin	*xx*	*x*	*xxx*	*x*
Vanadium	*x*	*xxx*	*xx*	*xx*

x—Low or limited. *xx—Moderate.* *xxx—High to very high.*

beryllium, boron, cadmium, lead, mercury, nickel, selenium, tin, and vanadium. In herbivores, increases take place for antimony, arsenic, cadmium, chromium, copper, lead, mercury, and selenium; only mercury and cadmium biomagnify in terrestrial carnivores. In aquatic habitats, levels of trace elements increase from seawater to algae for all except beryllium and boron. In herbivores, increases occur for antimony, arsenic, cadmium, and mercury; from prey to carnivores, an increase occurs for cadmium and mercury.

Biominification is the decrease in concentration of trace elements in organisms with increasing or higher trophic levels in food chains. This phenomenon will occur if:

1. The trace element concentration is low in the edible or digested parts of prey or food organism,
2. The element has been sequestered or stored in inedible tissues, such as bones,
3. The absorption of the trace element in the digestive system of the predator is low,
4. The element has been transformed from a highly absorbed to a poorly absorbed chemical form, and
5. The retention time of the trace element is short.

For terrestrial organisms, frequently all 14 trace elements are biominified in trace level between soil and plants. Herbivore biominification is documented for all trace elements except beryllium; no change is documented for cobalt and mercury. Biominification from prey to carnivore occurs for antimony, arsenic, cadmium, lead, and mercury; no change occurs for chromium. In aquatic habitats, biominification from sediment or soil occurs only in freshwater rooted plants for cadmium, copper, and lead; no change occurs for mercury. In herbivores, decreases occur for arsenic, cobalt, copper, lead, and nickel; in carnivores, decreases occur for antimony, arsenic, cadmium, copper, lead, nickel, and selenium. No change occurs for mercury in herbivores or carnivores.

Selecting Suitable Organisms

The procedure for selecting biological monitoring organisms was accomplished in the following steps. First, data about concentrations of trace elements in various species were compiled, in comparable terms. Second, the data were evaluated, with regard to (1) the species that are suitable for monitoring, that bioaccumulate and bioconcentrate the elements, and that retain or store them in organs or tissues, (2) the usefulness of various species for monitoring the environmental gradients of trace elements, (3) the species' biomagnification and biominification in food chains, and (4) the species' biotransformation of trace elements to other forms or compounds.

This information allowed a tentative selection of potential monitoring organisms. Finally, a selection was made based on several criteria; the organism must:

- accumulate various elements
- be common
- be geographically widespread
- be easily collected
- be of adequate size to permit resampling of tissue
- occur in the impact and unpolluted area
- show correlation with environmental levels of trace elements.

Also, background data for that species must be available. Major groups of organisms were considered with regard to the choice of potential monitoring organisms for each trace metal selected. The tentative selections of organisms for biological monitoring are presented in Table 8; these selections take into account the need for monitoring in the vicinity of humans; in urban, industrial, and rural areas, and in freshwater, estuarine, and marine environments.

The use of biological organisms for monitoring environmental gradients of the select toxic elements is summarized next.

Antimony—The experience of using biological monitors for measuring environmental gradients of antimony is limited and more studies are needed.

Arsenic—Comparatively few species of plants and animals have been used to measure environmental gradients of arsenic pollution. Horse and cow hair, and plants appear to be fairly effective as monitors.

Beryllium—In the only known research where environmental gradients of beryllium were measured, Spanish moss was used. Only three sites contained over 2 ppm ash weight out of 123 samples.

Boron—Three species of higher plants have been used successfully to measure environmental gradients of boron. No animals, mosses, lichens, or algae have been tested.

Cadmium—Forty-five species of plants and animals have been used to measure environmental gradients of cadmium pollution. The results show that several species of plants and animals appear to be excellent candidates for biological monitoring.

Chromium—Twenty-one species have been used to measure environmental gradients of chromium. Plants appear to be the most effective biomonitors, although some animals also show gradients.

Cobalt—Environmental gradients of cobalt have been measured using two species of animals and eight species of higher plants. Gradients found in higher plants were most definitive.

Copper—Environmental gradients of copper have been monitored using 48 species of animals and plants. Certain mollusks, and both higher and lower plants, appear to be suitable for monitoring environmental gradients of copper.

Lead—Over 95 species of animals and plants have been used successfully to monitor environmental gradients of lead.

Mercury—Animals, mammals, birds, amphibians, fish, mollusks, crustaceans, insects, and annelid worms accumulate mercury and have been used in monitoring environmental gradients. Few species of higher plants accumulate mercury.

Table 8. *Selected organisms for biological monitoring*

	Human and animal hair	*Mammal organs*	*Bird feathers*	*Bird organs*	*Fish*	Mytilus edulis *or other*	*Higher plants*	*Mosses and lichens*	*Algae*
Antimony	*E*	*liver, G*	—	—	*P*	*P* *Arbacia, G*	*Rose, E*	—	—
Arsenic	*E*	*kidney, G*	*G*	*liver, P*	*G*	*E*	*E*	—	*E*
Beryllium	—	*P*	*P*	*P*	—	*G*	*G*	—	—
Boron	—	*bone, P*	—	—	—	*coral, crustacea, G*	*E*	—	—
Cadmium	*E*	*kidney, G*	*P*	*kidney, liver, E*	*G*	*E*	*E*	*E*	*E*
Chromium	*E*	*spleen, E*	—	—	*P*	*G*	*E*	*E*	*G*
Cobalt	—	—	—	—	*P*	*E*	*E*	—	*G*
Copper	*G*	*liver, G*	*G*	*liver, G*	*P*	*oyster, E*	*E*	*E*	*E*
Lead	*E*	*kidney, bone, E*	*E*	*femur, E*	*P*	*E*	*E*	*E*	*E*
Mercury	*E*	*liver, E*	*E*	*liver, E* *kidney, liver, G*	*E*	*E*	*G*	*G*	*P*
Nickel	*G*	*liver, P*	—	*kidney, G*	*G*	*G*	*E*	*E*	*G*
Selenium	*G*	*kidney, G*	*G*	*liver, G*	*P*	—	*E*	—	—
Tin	*G*	*kidney, P*	—	*kidney, G*	*freshwater, G*	—	*E*	—	*G*
Vanadium	*G*	*liver, G*	—	—	*P*	*tunicates, E*	*E*	*E*	*G*

P = Poor.
G = Good.
E = Excellent.
— = Insufficient data.

Nickel—For measuring environmental gradients of nickel, mollusks and crustaceans have shown limited potential. Higher plants, mosses, and lichens appear to be excellent biomonitors.

Selenium—Plants appear to be the best organisms for measuring environmental gradients of selenium.

Tin—Research reveals that no species of animal has been used to measure environmental gradients of tin. Higher plants have been effective, and certain species appear to have promise for biological monitoring.

Vanadium—Fish, mollusks, and some plants have been used as biomonitoring organisms for vanadium.

Biological Monitoring Programs in the United States

Under the Federal Environmental Pesticide Control Act of the United States, pesticide residues and heavy metals must be monitored in fish, shellfish, birds, small mammals, humans, and food destined for human consumption. The vehicles for monitoring are a series of networks, including the National Freshwater Fish Monitoring Network, National Ocean Monitoring Network, National Estuarine Monitoring Network, National Pesticide Network for Monitoring Birds, National Small Mammals Monitoring Network, National Human Tissue Monitoring Network, and the National Food and Feed Monitoring Network.

The author recommends that the National Environmental Pesticide Monitoring Networks (NEPMN) program establish and implement monitoring that will assess the exposure to metals having a "high priority." The program proposed for biological monitoring within the NEPMN is presented in Table 9.

Table 9. Proposed biological monitoring for the National Environmental Pesticide Monitoring Networks (NEPMN)

Species	*Organ or tissue*	*Trace elements**	*Number of sites*	*Monitoring frequency*	*Status*
Human, G	*hair*	*Pb, Cd, Hg, As*	*75 cities*	*biennial*	*proposed-new*
Rat	*hair, liver*	*Pb, Cd, Hg, As*	*pilot study, then 75 cities*	*biennial*	*proposed-new*
Cow, pig, sheep	*edible tissue and dairy products*	*Pb, Cd, Hg, As, Se, and Sn*	*1,200 slaughter houses*	*bimonthly*	*USDA program*
Pigeon	*feather, liver, kidney*	*Pb, Cd, Hg, As*	*pilot study, then 75 cities*	*biennial*	*proposed-new*
Starling	*feather, liver, kidney*	*Pb, Cd, Hg, As*	*53*	*biennial*	*modified-FWS program*
Eagle	*feather, liver, kidney*	*Pb, Cd, Hg, As*	*dead birds*	*when available*	*FWS program*
Poultry	*edible tissue and eggs*	*Pb, Cd, As, Hg, Se, and Sn*	*1,200 slaughter houses*	*bimonthly*	*USDA program*
Food plants	*edible parts*	*Pb, Cd, As, Hg, Se, and Sn*	*35 cities*	*bimonthly*	*FDA program*
Mosses and lichens, G	*whole plant*	*Pb, Cd, As, Ni*	*100 air monitoring sites*	*quarterly*	*proposed for EPA-new*
Fish (freshwater, few edible species)	*liver, muscle*	*Hg, As*	*50*	*biennial*	*modified FWS program*
Fish (marine, few edible species)	*muscle, liver*	*Hg, Pb, Cd*	*pilot study*	*biennial*	*modifed FDA and NOAA*
Mytilus edulis, *G*	*soft parts*	*12 trace elements*	*pilot study*	*annual*	*"Mussel watch" global-new*
Oyster, crab, lobster	*edible tissue*	*Pb, Cd, Hg, As*	*selected coastal sites*	*annual*	*modified FDA, FWS, NOAA*

G—Part of global surveillance programs of GEMS and "Mussell watch."

**Key: Sb = Antimony; As = Arsenic; Be = Beryllium; B = Boron; Cd = Cadmium; Cr = Chromium; Co = Cobalt; Cu = Copper; Pb = Lead; Hg = Mercury; Ni = Nickel; Se = Selenium; Sn = Tin; V = Vanadium.*

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The complete report, entitled "Biological Monitoring of Toxic Trace Metals," is in four parts:

- *Volume 1. Biological Monitoring and Surveillance (Order No. PB 81-103 475; Cost: $18.50)*
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