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REVIEW

Past, present, and future of environmental specimen banks

Akio Koizumi · Kouji H. Harada · Kayoko Inoue · Toshiaki Hitomi · Hye-Ran Yang · Chan-Seok Moon · Peiyu Wang · Nguyen Ngoc Hung · Takao Watanabe · Shinichiro Shimbo · Masayuki Ikeda

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Abstract Environmental specimen banks are an essential part of the infrastructure of environmental sciences. They have various functions: (1) evaluation of governmental environmental policy-making and regulations; (2) a resource for animal health evaluation; (3) research tools to investigate time trends in ecosystems; (4) detection of newly emerging chemicals in the time trends; (5) validations of computer models for environmental phenomena; (6) source identification of contaminants; (7) a tool for food safety; (8) evaluation of genetic selection pressure due to environmental changes. In this review paper, we present a detailed description of the Kyoto University Human Specimen Bank (history, protocol and questionnaires) and provide brief outlines of other representative environmental specimen banks. We then review two illustrative cases in which environmental specimen banks have unveiled insidious contaminations of polybrominated diphenyl ethers and perfluorooctanoic acids. Finally, we give a perspective of new functions for environmental specimen banks in the next 20 years.

Keywords Environmental specimen banks · Food duplicate sample · Human breast milk · Human blood

A. Koizumi (✉) · K. H. Harada · K. Inoue · T. Hitomi · H.-R. Yang
Department of Health and Environmental Sciences, Graduate School of Medicine, Kyoto University, Yoshida Konoe, Sakyo, Kyoto 606-8501, Japan
e-mail: koizumi@pbh.med.kyoto-u.ac.jp

H.-R. Yang
Research Institute of Public Health and Environment, Seoul Metropolitan Government, Seoul 137-130, Korea

C.-S. Moon
Department of Industrial Health, Catholic University of Pusan, Busan 609-757, Korea

P. Wang
Department of Health Education, School of Public Health, Peking University, Beijing 100083, People's Republic of China

N. N. Hung
Department of Science and Technology, Hanoi Medical University, Hanoi, S.R. Vietnam

T. Watanabe
Miyagi University of Education, Sendai 980-0845, Japan

S. Shimbo
Department of Food and Nutrition, Kyoto Women's University, Kyoto 605-8501, Japan

M. Ikeda
Kyoto Industrial Health Association, Kyoto 604-8472, Japan

Introduction

The rapid development of new materials, new production methods, and new pharmaceuticals and commercial products in the 21st century has resulted in the release and/or emission of a myriad of chemicals into the environment. The environmental fates of only a few of the estimated 70,000 chemicals commonly used in industry have been characterized. Since monitoring lags far behind the rate of new development, regulatory decisions should be made as soon as possible to minimize the effects on ecological systems, including wild animal health.

An environmental specimen bank (ESB) is an organization and facility that is engaged in the systematic long-term preservation of representative environmental specimens. Specimens from ESBs have been used for retrospective analysis and evaluation for regulatory decision-making. As such, a well-designed ESB can be a valuable resource of specimens for real-time and retrospective monitoring. Specimens maintained in ESBs have enabled investigators to extend their current research on present-day situations into the past as well as extrapolate it to the future. They enable future exposure assessments for given chemicals to be made under various scenarios.

In the last 30 years, formal ESBs have been constructed in many countries, including the USA, Germany, Sweden, and Japan. A human specimen bank has also recently been established in Kyoto University (i.e., the Kyoto University Human Specimen Bank) [1]. An important aspect of this specimen bank is that it provides the means to reconstruct human exposures from the 1970s through to 2008. The bank contains human samples collected not only in Japan but also in various Asian countries, including China, Korea, Thailand, Vietnam, Malaysia and the Philippines, and is thus expected to provide a means of monitoring temporal as well as geographic trends in environmental contamination.

The major aim of this review is to introduce the Kyoto University Human Specimen Bank. Features of representative ESBs—in Japan, the USA, Germany and Sweden—are also compared to demonstrate individual functions of the ESBs. Finally, we discuss the future functions of ESBs in the environmental sciences.

Kyoto University Human Specimen Bank and other representative environmental specimen banks throughout the world

As of 2008, there are more than a dozen ESBs in the world, with one also currently under construction in France. Here, we provide a brief description of a number of these as well as their protocols (Table 1).

Kyoto University Human Specimen Bank

The Kyoto University Human Specimen Bank was established in 2004 at the Kyoto University Graduate School of Medicine [1]. The stored samples originate from four research activities. The first group of samples was collected in Japan as part of the nation-wide heavy-metal monitoring projects led by Prof. Ikeda [2–6] during the late 1970s up to the 1990s. Beginning in 1980s, samples were systematically collected in Japan and other Asian countries within the framework of a consistent sampling design in which participants donated blood, urine and duplicate 24-h food samples. Personal information and biochemical data were obtained by questionnaire and biochemical analysis and included data on age, gender, blood pressure, past and present illnesses, medication use, aspartate aminotransferase, alanine, gamma-glutamyl transferase, total cholesterol, triglycerides, high-density lipoprotein cholesterol, urinary protein, and red blood cells in urine [8]. In the duplicate food sampling protocol, the foods are cooked and meal menus recorded. The samples are then transferred to the laboratory within 48 h and stored at −30°C until processed. In the processing of food samples, each food composite homogenate is weighed and homogenized together with the drinking water. One-liter (approx. 1 kg) portions of the total homogenate are stored in ten 100-ml bottles at −30°C. Concurrent and long-term trends in Pb and Cd exposures are reported in detail [2–6].

The second group of samples comprises samples collected in Akita prefecture during the 1980s. The samples consist of breast milk, blood, and serum samples donated by the Hiraga General Hospital in the rural area of Akita. These samples were originally collected to monitor farmers' exposure to pesticides [7].

The third group of samples was collected by Prof. Koizumi and his colleagues from 2004 to 2006 [1]. Blood and breast milk samples were collected nationwide in Okinawa, Kochi, Hyogo, Kyoto, Takayama (Gifu), Fukui, Tokyo, Miyagi, Akita, and Shizunai (Hokkaido). In this project, commercially available packed breakfast, lunch, and dinner samples were collected from those sampling sites. Breast milk sampling was conducted until 12 weeks post-partum. Blood and breast milk donors also submitted self-reported questionnaires (Table 2). Within the framework of this study, food samples were homogenized as a set of breakfast, lunch, and dinner samples, and drinking water was collected at the sampling sites in the same manner as in the first study.

The fourth group of samples was collected in 2007 and 2008 in Japan (Miyagi, Takayama, and Kyoto), Beijing in China, Seoul, and Busan in Korea and Hanoi in Vietnam. In this project, blood or breast milk samples were collected domestically. However, blood and meals were sampled in the same way as in the third group of samples mentioned above. The donors of blood and food completed self-reported questionnaires (Table 2) and food record sheets (Table 3). All breast milk donors, irrespective of nationality, followed the same protocol: samples were collected up to 12 weeks post-partum, and donors filled out questionnaires (Table 2).

The total quantities of samples are shown in Table 1. Meta data describing the donor's personal information are shown in Table 1.

The Kyoto University Human Specimen Bank was designed so that human exposure assessments can be made on samples taken from the 1980s to the present. When distribution requests are received, the protocol will be reviewed by the committee of our sample bank. If the request is approved, our sample bank will release the specimens requested to the researcher(s) without any fees other than shipping.

Table 1 Current environmental specimen banks in 2008

Description	Kyoto University Human Specimen bank	es-Bank	Time capsule NIES
Home page	http://hes.pbh.med.kyoto-u.ac.jp/kuhsb/	http://www.ehime-u.ac.jp/~cmes/esbank/esbank.htm	http://www.nies.go.jp/timecaps1/index.htm
Foundation	Founded in 2004 by Department of Health and Environmental Sciences, Kyoto University Graduate School of Medicine	Founded in 2002 by Center for Marine Environmental Studies	Founded in 2004 by National Institute for Environmental Studies
Storage	−30°C	−25°C	−20 to −150°C
Sample description	Human blood and serum sampled with 1-day meals. Those samples have been collected from 1970s to 2008 in Japan, China, Korea, Philippine, Thailand, and Vietnam. While there are some blood samples and meal samples, which have been collected independently, most of the samples have been collected in a food duplicate design	Wildlife, sea water, soils from various locations of the world	Fishes, shellfishes and marine sediments
	Breast milk samples have been collected from 1980s to the present in Japan, China, Korea, and Vietnam		Airborne particulate matters
	Urine samples have been collected in the 2000s in Japan		Human breast milk collected in Tokyo from 2001 to 2007, 30 samples per year
Sample quantity or sampling	Blood or serum: 28,000 Meals: 3,500 days	This bank has collected the tissues and organs of 1,000 species with 100,000 wild life and environmental samples	Bivalves have been collected all over Japan from 2003. They have been collected at eight sites annually and other more than 100 sites Fish and sediments in Tokyo bay collected at 20 sites annually from 2003
	Breast milk: 3,000	Details are unknown for human breast milk samples	
	Urine: 14,000		Airborne particulate matters from six sites
			Human breast milk samples, totally about 600
Meta data	Serum and food samples are accompanied by personal information, including age, sex, occupation, food habit, and meal menu. Breast milk samples were collected with questionnaires between 0 to 12 post-partum weeks		No description on the home page
Design	Human exposure monitoring: Most of blood and meals samples were collected in a food duplicate design (see text)	Global marine monitoring	No specific designs
Functional category of the bank	Retrospective human exposure monitoring for Asian countries	Retrospective ecological monitoring	Long-term storage for future studies

	NBSB	German ESB for human tissues	Swedish ESB
Home page	http://www.nist.gov/public_affairs/gallery/specimen.htm	http://www.umweltprobenbank.de	http://www.nrm.se/
Foundation	Founded in 1979 by National Institute of Standards and Technology and U.S. EPA	Founded in 1981 by University Hospital Munster and Federal Environmental Agency	Founded in 1980 by the Swedish Museum of National History
Storage	−80 to −150°C	−150°C	−30 to −80°C

Table 1 continued

	NBSB	German ESB for human tissues	Swedish ESB
Sample description	Human liver, Human blood serum, Human blood spots, human food specimens	24-h urine, whole blood and blood plasma have been collected from the beginning. Until 2005, saliva, scalp and pubic hair had been collected. Recently, collection of placenta, umbilical cord blood and amniotic fluid have initiated	Mammals, Birds, Eggs, Wings of birds, Fish, Mosses soil, sludge, breast milk and food products
	Mussels and oysters, fish livers and muscle, fish (whole)		In total approximately 8,000–9,000 specimens have been collected annually and 3,500 specimens have been processed for chemical and biological analysis
	Marine sediments, marine mammal tissues, seabird eggs, peregrine falcon eggs and feathers		
Sample quantity or sampling	While relatively small numbers of human samples (8–722), a large numbers of ecological animal samples	125 volunteers aged between 20 and 29 per location and year for 4 sites joined the donation of samples	Mammals: 20,000 Birds:21,000, eggs: 6,500 Wings of birds: 30,000 Fish: 115,000, mosses: 10,000, sludge: 8,000 Breast milk: 800, food products: 12,000
Meta data	No description on the home page	Sex, age, place of birth, medical data, and personal behavior by a standard self-reported questionnaire	Registered in database together with results made by chemical and biological analysis
Design	Domestic ecosystem monitoring with consideration of trophic levels and wild animal health status	Human body burden monitoring	Nordic ecosystem monitoring of ecological system with consideration of food chain and biological diversities
Functional category of the bank	Whole ecological monitoring in the sea around USA	Real and retrospective monitoring and long-term storage	Real-time and retrospective monitoring and long-term storage

ESB, Environmental Specimen Bank; es-Bank, Ehime University; NIES, National Institute for Environmental Studies, Japan; NBSB, National Biomonitoring Specimen Bank, USA

es-Bank

Ehime University (Matsuyama City, Japan) began collecting environmental specimens in 1965 [9]. At that time, Ehime University focused on collecting specimens for studying local environmental contamination with pesticides that had been used by regional farmers. Samples were systematically collected and stored by the staff of Ehime University, and these samples later became seeds for subsequent collections of samples on larger scales. Thousands of samples from all over the world have been collected by the research group of the center for marine environmental studies over the past three decades. A large portion of these globally collected ecological samples was upgraded to form the es-Bank in 2002. The unique scientific merit of this collection, which cannot be matched by other environmental specimen banks, is its global scope, with a large number of specimens from the Asia–Pacific region (Table 1).

Time capsule ESB (http://www.nies.go.jp/)

The National Institute for Environmental Studies (NIES) in Japan started a pilot ESB in 1979. The Environmental Specimen Time Capsule program was extended and has started storing environmental specimens and genetic resources of endangered species (Table 1). The aim of this specimen bank is to store specimens for a long period (50–100 years) to await future needs and analyses. The bank has compiled atmospheric samples as well as samples of bivalves, fish, and human breast milk. The bivalve archives are very comprehensive and very important as environmental samples. Specifically, they are expected to provide information on long-term changes in genetic diversity or the natural selection of these species due to climate change.

This ESB, which is supported nationally, is characterized by long-term storage under the strong initiative of the NIES; as such, it does not allow the distribution of samples upon request by researchers. At the present time, the time capsule ESB does not seem to have a systematic sampling design; rather, it seems to be aimed at covering a large variety of research needs in the future.

The U.S. National Biomonitoring Specimen Bank and the Marine Environmental Specimen Bank

These two banks are very well designed and have a very clear protocol [10]. There are two national ESBs that have very similar designs. The first sample bank is the CASPIR [The CDC (center for disease control) and ATSDR (Agency for Toxic Substances and Disease Registry) Specimen Packaging, Inventory and Repository], which has collected various human specimens as part of public health activities by the CDC and ATSDR. The second sample bank is maintained by the National Institute of Standards and Technology (NIST) and consists of two separate facilities: the National Biomonitoring Specimen Bank and the Marine Environmental Specimen Bank. While CASPIR maintains specimens for human health research, the NIST banks are designed for environmental research (Table 1).

The relevant ESB in the USA continuously monitors animals living in diverse environments covering Texas desert areas, Hawaii, and Alaska [11]. Activities also include monitoring endangered species. The collections cover fish, mammals, avian species, and plants. This sample bank was designed to consider the transfer of contamination through the food web and the health status of wild animals and as such, it plays a key role in quality assurance. Stored samples are presently being analyzed using newer and more sensitive analytical methods.

German Environmental Specimen Bank for human tissues (ESBHum: http://www.umweltprobenbank.de)

The ESBHum was established as part of the German Environmental Specimen bank, and it focuses on human exposure assessments by real-time and retrospective monitoring [12, 13]. Samples are processed annually to measure 20 inorganic (Sb, Th, As, Ba, Cd, Pb, Hg, Ag, Tl, Sn, U, Cu, Ca, Fe, Mg, K, Se, Na, Sr and Zn) and five organic (hexachlorobenzene, pentachlorophenol, PCB-138, PCB-153 and PCB-180) chemicals. Samples are donated annually by 500 voluntary students aged

Table 2 Self-reported questionnaire

A request to donate your blood or breast milk
-4 country environmental study-
BACKGROUND: At present, it is believed that 300 billion chemicals are registered in the world. Human beings are currently exposed to about 100,000 chemicals in their daily lives. Of those, only a small number of chemicals, that is, about 1,000 chemicals, have been fully risk-assessed, while the remaining majority of chemicals have not been investigated
Some chemicals which once were produced actively because of their usefulness are now banned, because of their hazardous effects on human health as well as the ecosystem. For example, DDT and PCBs were once considered useful chemicals but are now banned because of global environmental contamination. After banning their production, the environment is recovering very slowly. As such, long term monitoring studies of environmental contaminants are needed
AIM of the CURRENT STUDY: Asian countries in the midstream of globalization are now considered passengers in the same environmental boat. To install precautionary measures to effectively prevent environmental contamination in the Asian area, future trend prediction using computer simulation based on cutting edge theories is now considered very promising. However, only a small number of observations have been available to validate such simulation theories. If the computer simulation results are in agreement with reconstructed data, such a simulation theory is believed to be reliable to predict future levels of environmental contamination. We have established the Human Specimen Bank in Kyoto University (The Kyoto University Human Specimen Bank). Stocked samples (diet, breast milk, and blood) have been collected in Japan, Korea and China since the 1970s. Each sample has information about sampling time and geographic location. We are thus planning to reconstruct the past environment from the 1980s onwards using historical human samples in our sample bank
REQUEST to Participants: We have collected human specimens from the late 1970s onwards and stored them in the Human Specimen Bank in Kyoto University. We are going to make full use of these samples to reconstruct the past environment from the 1980s to the present. Although we have stored historical Japanese samples up to 2005 and Korean and Chinese samples up to 2000, we do not have updated samples. Thus we would like to request that you donate 5-ml of blood or ca 30 ml breast milk. These samples will be used to validate computer simulation theories and will be stored for future use in the environmental sciences
We hope you understand our aim and will cooperate with our project
The 4 countries in collaboration for environmental sciences
Director KOIZUMI Akio M.D., Ph.D. (Professor, Kyoto University, Kyoto, Japan)
YANG Hye-Ran Ph.D. (Researcher, Seoul Metropolitan Government Research Institute of Public Health and Environment, Seoul, Korea)
CHOI Kyung Ho, D.V.M., PhD. (Associate Professor, Seoul National University, Seoul, Korea)
WANG Peiyu, M.D., Ph.D. (Deputy Dean, Peking University, Beijing, China)
Nguyen Ngoc Hung, M.D., Ph.D. (Professor, Hanoi Medical University, Hanoi, Vietnam)

[Informed consent]

I am fully informed of the aim of the present study and agree to donate (5-ml blood or 30-ml breast milk) to the Human Specimen Bank in Kyoto University.

name	age	Current country	Prefecture	Current occupation
	y			

[Questionnaire] Date ________________

Container ID

Please answer the following questions.

1. Please fill out your residential histories as in the examples below.

Name of city, Country	Period	Duration
(Example) Seoul, Korea	1990-1996	6.5 years
(Example)Beijing, China	1996-1998	2 years
(Example)Hanoi, Vietnam	1998-1999	9 months

2. Occupation

1.Housewife 2.Clerical work 3.Factory worker 4.Service

5. Other (Please describe :)

Have you ever been occupationally exposed to chemicals? (Yes, No)

If yes, please name the chemicals:( )( ) ( )

3. Birth date (19yy:month): 19 ( ) ( ).

4. Height cm Weight kg

5. Number of deliveries (0, 1, 2, >=3[ ])(Circle the appropriate number)

6. Past disease history

Name of disease Age

1)______________ ________

2)______________ ________

3)______________ ________

7. Please answer which fish you eat on a regular basis.

Yellowtail	( )	times per week
Horse Mackerel or Mackerel	( )	times per week
Salmon	( )	times per week
Other fish		
1. ______________________	( )	times per week
2. ______________________	( )	times per week
3. ______________________	( )	times per week

8. Please describe any medicine(s) or supplement(s) you routinely take.

	Medicine or supplement	Frequency
e.g.	Aspirin	Once a month
	Antihistamine	Every spring season for pollen allergy
	Vitamin compound	Every day
	______________________	______________________
	______________________	______________________
	______________________	______________________

9.Smoking and drinking habits

Smoking	□ Never smoked	
	□ Ex-smoker	Number of cigarettes/day( )for years
	□ Current smoker	Number of cigarettes/day( )for years
	□ Passive current smoker	
Drinking	□ Never drank	
	□ Occasional drinker	Kind of alcoholic beverage: How often? (Once a month, twice a month, once a week) (select most appropriate one) How much? ______ ml
	□ Regular Drinker	Kind of alcoholic beverage: How often? (Once a month, twice a month, once a week) (select most appropriate one) How much? ______ ml

Thank you for your cooperation

If you have any questions, please write them below.

Table 3 An example of a food record sheet

NAME :
CONTACT NUMBER :
DATE :
Interviewer :

① Meals	② Time (hours)	③ Place	④ Food name	⑤ Amounts	⑥ Ingredients	⑦ Cooking method	⑧ Weight (g)	⑨ Product name	⑩ Manufacturer
Breakfast	0710	Home	Cooked rice with black rice	½ bowl	Rice	Boiling	105.93		
					Black rice		1.07		
			Curry	150 ml	Pork(lean)	Boiling	24		
					Potato		42		
					Onion		24		
					Carrot		14		
					Curry sauce		48		
			Drinking yogurt	1 bottle			139	Apple yogurt	Pasteur
			Instant coffee	1 cup	Coffee		91	Mocha	Dongsuh
Lunch	1230	Work	Cooked rice with millet	1 bowl	Rice	Boiling	191.1		
					Millet		3.9		
			Potato soup with sea tangle	250 ml	Potato	Boiling	75		
					Sea tangle		7		
					Green onion		1		
					Stock		157		
			Broiled mackerel	1 piece	Mackerel	Panbroiling	51		
			Buckwheat curd	2 pieces	Buckwheat curd	Seasoning	41		
					Green onion		1		
			Seasoning of bean sprout	1 dish	Bean sprout	Seasoning	54		
			Kimchi	1 dish	Kimchi		57		
			Drip coffee	1 cup	Coffee		212		
Snack	1600	Work	Steamed sweet potato	1 each	Sweet potato	Steaming	36		
Snack	1700	Work	Instant coffee	1 cup	Coffee		106	Mocha	Dongsuh
Dinner	2000	Home	Cooked rice with black rice and buckwheat	½ bowl	Rice	Boiling	135.6		
					Black rice		5.76		
					Buckwheat		2.88		
			Sea weed soup with clam	200 ml	Sea weed	Boiling	42		
					Clam		3		
					Stock		101		
			Roasted anchovy	3 chopsticks	Anchovy	Roasting	18		
			Kimchi (Green onion)	2 chopsticks		Seasoning	28		
			Kimchi	1 dish		Seasoning	42		

Definition of categories: ①, Present as breakfast, lunch, dinner, and snack; ②, meal time; ③, place eaten (e.g., at home, at work, at MacDonald's, other fast food restaurant, etc.); ④, name of food eaten (e.g., cooked rice with black beans, Miso soup with mushrooms); ⑤, amount eaten (e.g., 2/3 rice bowl, 1 soup bowl, 1 each of beef burger, 1 bottle of yogurt); ⑥, food ingredients [e.g., miso, mushroom, onion, beef (record which part, if possible), seasoning, etc]; ⑦, cooking method, such as steaming, frying, boiling, etc; ⑧, weight measured by scale balance; ⑨, commercial brand name or product name and ⑩, company name are required, if subject to consumed processed food (e.g. Drinking yogurt, Meiji)

20–29 years, who live in four cities (Munster, Halle, Griefswald, and Ulm). The participants provide 24-h urine, blood, and other human specimens. Detailed personal information is attached to the samples. Given this context, the ESBHum can be said to be designed for health-related environmental monitoring.

The Swedish Specimen Bank, Swedish Museum of Natural History

This ESB was initiated in 1980 by the Swedish Environmental Protection Agency to study residue levels of pollutants and their effects on biota in terrestrial, freshwater, and marine environments [14]. The aim of this sample bank is to collect, prepare, store, and supply specimens for a variety of tasks in order to provide information for updating environmental agendas.

At the present time, the Swedish ESB stores specimens on 260,000 organisms. Approximately, 8,000–9,000 specimens are collected annually. The Swedish monitoring programs are tightly linked to banking and monitoring, and 3,500 specimens are consumed annually to investigate time trends, spatial monitoring, and screening of new substances.

In concert with ESB activities, the Swedish EPA established a program in 1989 for the bio-monitoring of top marine predators. This program aims to monitor the population, reproduction, development, and health status of three types of seals and a white-tailed sea eagle. To support this program, the ESB stores tissues and organ samples from these animals. The Swedish ESB is also currently collecting plants, mosses, sediments, sludge, and human foodstuffs.

Lessons taught by the use of ESB specimens in modern environmental problems

The ESBs have become an essential part of the infrastructure of modern environmental sciences and decision-making and have played key roles in a wide range of aspects related to the environmental sciences, such as (1) evaluations of governmental environmental policy-making and regulations; (2) as a resource for animal health evaluation; (3) as research tools to investigate time trends in ecosystems; (4) detection of newly emerging chemicals in time trends; (5) validations of computer models for environmental phenomena; (6) source identification of contaminants; (7) as a tool for food safety; (8) evaluation of genetic selection pressure due to environmental changes. Here, we briefly outline the roles of modern ESBs in recent environmental issues.

Polybrominated diphenylethers

It is known that, contrary to the case with organochlorine compounds, the use of diphenylethers (PBDEs) increased in the European Union (EU) during the 1980s. These products were widely used as flame retardants, especially in polymers used in electronics and textiles. Similar to the organochlorine compounds, PBDEs were found in ecological biota [15]. Thus, the first screening was conducted using archived breast milk samples in 1997 [16, 17], and the first astonishing evidence that emerged revealed an exponential increase in PBDEs in Swedish breast milk from 1972 to 1997 [18]. This increasing trend of PBDEs in human breast milk [19, 20] and serum [1, 21] was subsequently confirmed in several other countries.

The unique feature of our sampling design is that serum and duplicate food samples were collected from the same person. This enabled us to obtain definitive evidence that dietary intakes of PBDEs estimated from duplicate food samples in 1995 did not differ from those collected in 1980 [22], while PBDE levels in serum were significantly higher in 1995 than in 1980 [1]. These results suggest the importance of inhalation as a primary route of exposure.

The initial alarming evidence generated by Swedish researchers showed the importance of continuous monitoring using breast milk [23] and raised concerns internationally, resulting in new regulations in many countries, since PBDEs are suspected to have a variety of toxic effects on wildlife and humans [24].

Perfluorooctane sulfonate and perfluorooctanoate

Perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) are two classes of chemicals that have been used in a variety of applications, such as in lubricants, paints, cosmetics, and fire-fighting foams. The former has been an important perfluorinated surfactant, but in 2002, after 50 years of production, The 3M company phased out its manufacture. Once released into the environment, PFOS is postulated to be stable and persistent due to its resistance to degradation in ecological systems and its bioconcentration in food webs. As postulated, PFOS and PFOA were found in a variety of wildlife [25–28]. In Japan, nationwide surveys have demonstrated high-level contamination of PFOS in an airport and extremely intense PFOA contamination in Osaka Bay and the Kanzaki River [29, 30].

There have been few studies on PFOS and PFOA levels in humans. Data from early studies in the USA demonstrate that PFOS and PFOA serum levels have not changed over the past 20 years, although they did increase up to the 1980s [31].

In 2004, we investigated the time trend and special distribution of PFOS and PFOA in Japan using specimens stocked in the Kyoto University Human Specimen Bank [32, 33]. The analyses revealed an exponential increase in serum PFOA concentrations in Japan from 1980 to 2000, while PFOS levels reached a plateau during that time (Fig. 1, cited from Harada and Koizumi [34]). Experiments to reconstruct time trends and spatial differences have been made in China [35] and other countries and have confirmed increasing levels over the past 30 years [34].

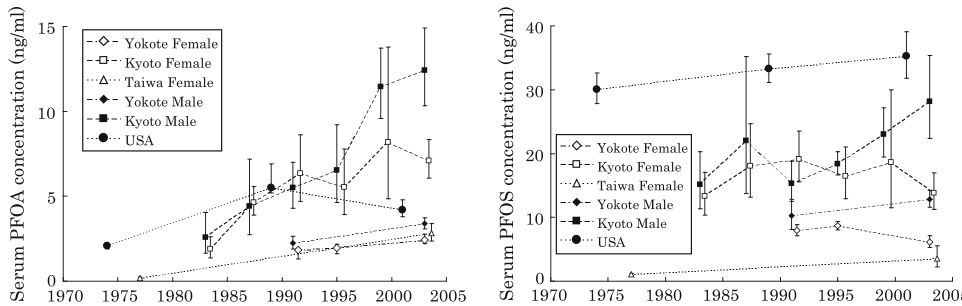

Fig. 1 Time trends in perfluorooctane sulfonate (*PFOS*) and perfluorooctanoate (*PFOA*) serum levels in Japan and the USA. Cited from Harada and Koizumi [34]. Data are geometric means and geometric standard errors

In our previous studies, we had found that there was a local emission source of PFOA in the Osaka region [29, 36]. The human serum levels of PFOA in the Osaka region were significantly higher than those in other regions [33]. We thus conducted a study to determine to what extent dietary exposure can explain the serum levels in residents of a highly PFOA-contaminated area (Osaka) and a non-contaminated area (Sendai) by duplicate food samples and paired serum samples stocked in the Kyoto University Human Specimen Bank [37]. The result revealed that the dietary route, including drinking water, cannot explain the high levels of serum PFOA in Osaka residents, suggesting that inhalation should also be taken into account when explaining excess PFOA exposures. These results showed the usefulness of paired sampling of food duplicates and blood samples to reconstruct human exposures.

It should be mentioned that there are several reports on the decline of PFOA and PFOA concentrations in human blood following the withdrawal of production of PFOA and PFOS by the 3M Company [38, 39]. We are currently planning to test whether such declines are global trends or not.

Other studies

There have also been several studies that have reconstructed long-term exposures to persistent organic compounds other than routine monitoring substances, such as PCBs and organochlorine pesticides or insecticides. For example, there is a report on phthalate [40].

Future perspectives of ESB functions

Environmental specimen banks have become an essential part of the fundamental research infrastructure for environmental sciences. In the next 20 years, further breakthroughs in technologies will occur. In terms of environmental studies, two of these will have a large impact. The first one is a technology which enables us to analyze isotopic separation, and the second is a high-throughput pyrosequencing technology. Those advances in technologies will create new functions for ESBs.

Fine isotopic profiling

^{13}C and ^{14}C are natural isotopes that are incorporated in CO_2 by plants. Labeled isotopes will be transformed to glucose via photosynthesis in plants. However, photosynthetic enzymes prefer to utilize ^{12}C and radioactive isotope ^{14}C will be degraded to ^{14}N in fossil fuels. Thus, the greatest anthropogenic source of CO_2 production, i.e., the incineration of fossil fuels, will yield ^{13}C- or ^{14}C-depleted CO_2. This in turn results in the production of ^{12}C glucose and other biological products. Accordingly, ^{13}C versus ^{12}C or ^{14}C versus ^{12}C ratios in diets or human compositions are variable according to the extent to which anthropogenic CO_2 was absorbed in recent years [41, 42]. Other isotopic analyses also give us interesting information. For example, lead from a smelter emission from a local smelter plant had ^{206}Pb versus ^{207}Pb ratios of 0.993, which is significantly smaller than the ratio in natural lead [43]. Such mineralogical signatures will provide information for identifying emission sources in transboundary contaminant transfers. Isotopic ratios of ^{206}Pb and ^{204}Pb have given a clear demarcation for the separation of geochemical signatures of authoritarian lead from other lead [44]. However, such clear signatures are now becoming less clear [44]. In terms of lead measured in Chinese studies, there are several overlapping geochemical signatures of isotopic ratios. Thus, the dominance of coal combustion as a source of lead has made it difficult to perform geological identification of the sources in China [45].

In the next few decades, isotopic analysis linked with the banked samples will provide a new area of research for environmental sciences.

DNA profiling

In recent times, many genetically modified organisms (GMOs) have become commercially available in many countries. The rapid progress of GMOs has enabled the conferring of new characteristics, such as herbicide tolerance, resistance to insects, among others into plant genomes. The foreign pieces of DNA consist of a transcription promoter, a coding sequence, and an expression terminator. Examples of transgenic plants include soybeans and maize. In recent years there has been an ongoing debate on the risks associated with the introduction of GMOs into agriculture. Consequently, research evaluating the effects of GMOs has become increasingly important. Such GMO assessments are carried out by detecting inserted foreign DNA in transgenic plants. DNA is the preferred analyte for both raw ingredients and processed food. A long-term time trend of the environmental fate of foreign DNA needs to be traced using food samples.

The testing of samples in specimen banks will be very informative in determining such long-term trends. Ecological samples are especially useful when GMOs are being monitored—i.e., the ecological fate and influences of GMOs on ecological biota can be assessed rigorously [46]. In particular, rapid advances in high-throughput sequencing technology enable large-scale sequencing without any prior assumptions, and horizontal or vertical transmission of the genetic elements of genetically engineered genomes can be traced.

Another monitoring protocol would be to investigate the selection pressure posed by global environmental changes. Rapid environmental changes will increase natural selection pressures and induce alterations at genome levels, as previously reported [47]. Such effects can be tested by real biota samples collected over the long term. Ecological environmental specimen banks are suitable for conducting such studies.

Conclusions

In the last 20 years, ESBs have emerged as part of the fundamental research infrastructure required for environmental sciences. In their early phase of development, ESBs were expected to monitor local ecological or human exposures. The expansion of environmental problems on both geographical and time scales has resulted in ESBs differentiating into purpose-oriented groups, with some becoming more oriented to the ecological environment while others trending towards human exposure determination.

The increase in environmental problems has led to a need for global environmental monitoring. Increases in the demands for ESBs now require that sample exchanges, supplies, banking and other relevant activities associated with ESBs be standardized by an internationally accredited guideline. Such guidelines, including those on legal issues, ethical issues (especially for human samples), and technical issues, have recently been proposed [48].

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References

1. Koizumi A, Yoshinaga T, Harada K, Inoue K, Morikawa A, Muroi J, et al. Assessment of human exposure to polychlorinated biphenyls and polybrominated diphenyl ethers in Japan using archived samples from the early 1980s and mid-1990s. Environ Res. 2005;99:31–9.
2. Watanabe T, Koizumi A, Fujita H, Kumai M, Ikeda M. Dietary cadmium intakes of farmers in nonpolluted areas in Japan, and the relation with blood cadmium levels. Environ Res. 1985;37:33–43.
3. Watanabe T, Nakatsuka H, Ikeda M. Cadmium and lead contents in rice available in various areas of Asia. Sci Total Environ. 1989;80:175–84.
4. Watanabe T, Nakatsuka H, Shimbo S, Iwami O, Imai Y, Moon CS, et al. Reduced cadmium and lead burden in Japan in the past 10 years. Int Arch Occup Environ Health. 1996;68:305–14.
5. Watanabe T, Zhang ZW, Moon CS, Shimbo S, Nakatsuka H, Matsuda-Inoguchi N, et al. Cadmium exposure of women in general populations in Japan during 1991–1997 compared with 1977–1981. Int Arch Occup Environ Health. 2000;73:26–34.
6. Ikeda M, Zhang ZW, Shimbo S, Watanabe T, Nakatsuka H, Moon CS, et al. Exposure of women in general populations to lead via food and air in East and Southeast Asia. Am J Ind Med. 2000;38:271–80.
7. Sugaya T, Watanabe K, Sasaki S. Levels of organochlorines and polychlorinated biphenyls in human body. J Jpn Assoc Rural Med 1984;33:140–146
8. Chiba K, Miyasaka M, Koizumi A, Kumai M, Watanabe T, Ikeda M. Comparison of food constituents in the diet of female agricultural workers in Japan with high and low concentrations of high-density lipoprotein in their sera. J Epidemiol Community Health. 1985;39:259–62.
9. Tanabe S. Environmental Specimen Bank in Ehime University (es-BANK), Japan for global monitoring. J Environ Monit. 2006;8:782–90.
10. Wise SA, Koster BJ. Considerations in the design of an environmental specimen bank: experiences of the National Biomonitoring Specimen Bank Program. Environ Health Perspect. 1995;103[Suppl 3]:61–7.
11. Becker PR, Wise SA. The U.S. National biomonitoring specimen bank and the marine environmental specimen bank. J Environ Monit. 2006;8:795–9.
12. Emons H, Schladot JD, Schwuger MJ. Environmental specimen banking in Germany—present state and further challenges. Chemosphere. 1997;34:1875–88.
13. Wiesmuller GA, Eckard R, Dobler L, Gunsel A, Oganowski M, Schroter-Kermani C, et al. The environmental specimen bank for human tissues as part of the German Environmental Specimen Bank. Int J Hyg Environ Health. 2007;210:299–305.
14. Odsjö T. The environmental specimen bank, Swedish Museum of Natural History—a base for contaminant monitoring and environmental research. J Environ Monit. 2006;8:791–4.
15. Sellström U, Jansson B, Kierkegaard A, de Wit C, Odsjö T, Olsson M. Polybrominated diphenyl ethers (PBDE) in biological samples from the Swedish environment. Chemosphere. 1993;26:1703–18.
16. Darnerud PO, Atuma S, Aune M, Cnattingius S, Wernroth ML, Wicklund-Glynn A. Polybrominated diphenyl ethers PBDEs

in breast milk from primiparous women in Uppsala County, Sweden. Organohalogen Compd. 1998;35:411–4.
17. Noren K, Meironyte D. Contaminations in Swedish human milk. Decreasing levels of organocholorine and increasing levels of organobromine compounds. Organohalogen Compd. 1998;38:1–4.
18. Noren K, Meironyte D. Certain organochlorine and organobromine contaminants in Swedish human milk in perspective of past 20–30 years. Chemosphere. 2000;40:1111–23.
19. Akutsu K, Kitagawa M, Nakazawa H, Makino T, Iwazaki K, Oda H, et al. Time-trend (1973–2000) of polybrominated diphenyl ethers in Japanese mother's milk. Chemosphere. 2003;53:645–54.
20. Thomsen C, Lundanes E, Becher G. Brominated flame retardants in archived serum samples from Norway: a study on temporal trends and the role of age. Environ Sci Technol. 2002;36:1414–8.
21. Sjödin A, Jones RS, Focant JF, Lapeza C, Wang RY, McGahee EEr, et al. Retrospective time-trend study of polybrominated diphenyl ether and polybrominated and polychlorinated biphenyl levels in human serum from the United States. Environ Health Perspect. 2004;112:654–8.
22. Wada Y, Koizumi A, Yoshinaga T, Harada K, Inoue K, Morikawa A, et al. Secular trends and geographical variations in the dietary intake of polybrominated diphenyl ethers (PBDEs) using archived samples from the early 1980s and mid 1990s in Japan. J Occup Health. 2005;47:236–41.
23. Hooper K, She J. Lessons from the polybrominated diphenyl ethers (PBDEs): precautionary principle, primary prevention, and the value of community-based body-burden monitoring using breast milk. Environ Health Perspect. 2003;111:109–14.
24. Ward J, Mohapatra SP, Mitchell A. An overview of policies for managing polybrominated diphenyl ethers (PBDEs) in the Great Lakes basin. Environ Int. 2008;34:1148–56.
25. Hansen KJ, Johnson HO, Eldridge JS, Butenhoff JL, Dick LA. Quantitative characterization of trace levels of PFOS and PFOA in the Tennessee River. Environ Sci Technol. 2002;36:1681–5.
26. Kannan K, Choi JW, Iseki N, Senthilkumar K, Kim DH, Masunaga S, et al. Concentrations of perfluorinated acids in livers of birds from Japan and Korea. Chemosphere. 2002;49:225–31.
27. Kannan K, Corsolini S, Falandysz J, Oehme G, Focardi S, Giesy JP. Perfluorooctanesulfonate and related fluorinated hydrocarbons in marine mammals, fishes, and birds from coasts of the Baltic and the Mediterranean Seas. Environ Sci Technol. 2002;36:3210–6.
28. Kannan K, Newsted J, Halbrook RS, Giesy JP. Perfluorooctanesulfonate and related fluorinated hydrocarbons in mink and river otters from the United States. Environ Sci Technol. 2002;36: 2566–71.
29. Saito N, Harada K, Inoue K, Sasaki K, Yoshinaga T, Koizumi A. Perfluorooctanoate and perfluorooctane sulfonate concentrations in surface water in Japan. J Occup Health. 2004;46:49–59.
30. Saito N, Sasaki K, Nakatome K, Harada K, Yoshinaga T, Koizumi A. Perfluorooctane sulfonate concentrations in surface water in Japan. Arch Environ Contam Toxicol. 2003;45:149–58.
31. Olsen GW, Huang HY, Helzlsouer KJ, Hansen KJ, Butenhoff JL, Mandel JH. Historical comparison of perfluorooctanesulfonate, perfluorooctanoate, and other fluorochemicals in human blood. Environ Health Perspect. 2005;113:539–45.
32. Harada K, Saito N, Inoue K, Yoshinaga T, Watanabe T, Sasaki S, et al. The influence of time, sex and geographic factors on levels of perfluorooctane sulfonate and perfluorooctanoate in human serum over the last 25 years. J Occup Health. 2004;46:141–7.
33. Harada K, Koizumi A, Saito N, Inoue K, Yoshinaga T, Date C, et al. Historical and geographical aspects of the increasing perfluorooctanoate and perfluorooctane sulfonate contamination in human serum in Japan. Chemosphere. 2007;66:293–301.
34. Harada K, Koizumi A. Environmental and biological monitoring of persistent fluorinated compounds in Japan and their toxicities. Environ Health Prev Med. 2009;14:7–19.
35. Jin Y, Saito N, Harada KH, Inoue K, Koizumi A. Historical trends in human serum levels of perfluorooctanoate and perfluorooctane sulfonate in Shenyang, China. Tohoku J Exp Med. 2007; 212:63–70.
36. Morikawa A, Kamei N, Harada K, Inoue K, Yoshinaga T, Saito N, et al. The bioconcentration factor of perfluorooctane sulfonate is significantly larger than that of perfluorooctanoate in wild turtles (*Trachemys scripta elegans* and *Chinemys reevesii*): an Ai river ecological study in Japan. Ecotoxicol Environ Saf. 2006; 65:14–21.
37. Kärrman A, Harada KH, Inoue K, Takasuga T, Ohi E, Koizumi A. Relationship between dietary exposure and serum perfluorochemical (PFC) levels—a case study. Environ Int 2009;35:712–7.
38. Kärrman A, Ericson I, van Bavel B, Darnerud PO, Aune M, Glynn A, et al. Exposure of perfluorinated chemicals through lactation: levels of matched human milk and serum and a temporal trend, 1996–2004, in Sweden. Environ Health Perspect. 2007;115:226–30.
39. Olsen GW, Mair DC, Church TR, Ellefson ME, Reagen WK, Boyd TM, et al. Decline in perfluorooctanesulfonate and other polyfluoroalkyl chemicals in American Red Cross adult blood donors, 2000–2006. Environ Sci Technol. 2008;42:4989–95.
40. Wittassek M, Wiesmuller GA, Koch HM, Eckard R, Dobler L, Muller J, et al. Internal phthalate exposure over the last two decades—a retrospective human biomonitoring study. Int J Hyg Environ Health. 2007;210:319–33.
41. Vitousek PM. Beyond global warming—ecology and global change. Ecology. 1994;75:1861–76.
42. Ghosh P, Brand WA. Stable isotope ratio mass spectrometry in global climate change research. Int J Mass Spectrom. 2003;228: 1–33.
43. Gallon C, Tessier A, Gobeil C, Carignan R. Historical perspective of industrial lead emissions to the atmosphere from a Canadian smelter. Environ Sci Technol. 2006;40:741–7.
44. Duzgoren-Aydn NS, Weiss AL. Use and abuse of Pb-isotope fingerprinting technique and GIS mapping data to assess lead in environmental studies. Environ Geochem Health. 2008;30:577–88.
45. Gulson B, Mizon K, Korsch M, Taylor A. Changes in the lead isotopic composition of blood, diet and air in Australia over a decade: globalization and implications for future isotopic studies. Environ Res. 2006;100:130–8.
46. Deagle BE. DNA-based Methods for Studying the Diet of Marine Predators. PhD thesis, University of Tasmania. 2006. Available at: http://eprints.utas.edu.au/1046/.
47. Balanya J, Oller JM, Huey RB, Gilchrist GW, Serra L. Global genetic change tracks global climate warming in *Drosophila subobscura*. Science. 2006;313:1773–5.
48. Repositories ISfBaE. 2008 best practices for repositories—collection, storage, retrieval and distribution of biological materials for research. Cell Preserv Technol. 2008;6:3–58.