NIES Annual Report
2014
AE - 20 - 2014

National Institute for Environmental Studies
http://www.nies.go.jp/

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Foreword

This annual report is the official record of activities at the National Institute for Environmental Studies (NIES) in Fiscal Year (FY) 2013 (April 2013 to March 2014). FY 2013 marked the third year of the third NIES five-year plan (FY 2011–2015). It was also the third year in which our institute has been engaged in Research on Disaster Environment, which was initially undertaken in the aftermath of the Great East Japan Earthquake. In March of FY 2012, we revised our five-year plan to include this research. In this, NIES Annual Report 2013, we will take the opportunity to report on the research being undertaken at NIES as part of this revised five-year plan.

Under the strategy outlined in the third NIES five-year plan, research is first undertaken in the eight pillar fields of environmental research at our institute – global environment; material cycles and waste management; environmental risk; regional environment; environmental biology and ecosystems; environmental health; social and environmental systems; and environmental measurement and analysis. This research across a wide spectrum, from basic to issue-driven research, is carried out by NIES in its capacity as a leading institute in the region.

The second aspect of our research strategy is the implementation of 10 research programs for those topics which we consider to require an urgent or priority response, or research which is issue-driven or requires the efficient deployment of research resources in order to be addressed.

The third aspect involves the maintenance of medium- to long-term initiatives in step with the sustainment and furtherance of environmental research. This includes maintaining the equipment and facilities needed for initiatives such as global environmental monitoring - including that by satellites - and those initiatives that use ground-based systems, commercial airlines, and shipping to monitor and analyze the global carbon cycle. Other examples of such initiatives include the maintenance of a GHG emissions inventory; the storage and provision of environmental specimens; the maintenance of reference laboratory functions; and the creation and updating of many kinds of environmental databases. Another important topic at NIES is the advancement of research using the NIES Supercomputer. Also, the Japan Environment and Children's Study (JECS) is continuing in a satisfactory manner.

Research on Disaster Environment, undertaken in the aftermath of the Great East Japan Earthquake, comprises the fourth aspect of our strategy. This research is being implemented around four themes (1) Establishment of treatment and disposal technologies and systems for radioactively contaminated off-site wastes (2) Clarification of the environmental dynamics of radioactive substances, analysis of human exposure, and impact assessment for organisms and ecosystems (3) Promotion of surveys and research for renewal and environmental creation of the post-disaster regional environment, and (4) Promotion of surveys and research on the environmental change and associated impacts which accompany earthquake and tsunami disasters. Moreover, preparations for a NIES Fukushima Headquarters are also underway, with the establishment of the Fukushima Project Office at NIES in October 2013 - and we are currently

cooperating in the setting up of the planned Fukushima Prefecture Center for Environmental Creation (provisional name) through which we intend to increase our presence and on-the-ground activities in the area.

Many people have an image of environmental research as being about "recovery from adverse situations". However, the actual nature of current environmental research is to seek to create the best possible future, taking into account current circumstances and constraints. In fact, environmental research can be considered an indispensible part of creating a society in which humankind—in both Japan and the wider world—in the 21st century can be genuinely happy and comfortable. NIES is committed to rallying its collective resources to work toward this future to the full extent of its abilities.

We hope that this report will go some way to facilitating a greater understanding of our institute's activities, and we invite your full and frank feedback and opinions about those activities.

SUMI, Akimasa
President
September 2014

Contents

During the 1950s and 1960s, Japan experienced serious environmental pollution problems accompanying rapid economic growth. The Environment Agency was established in 1971 as part of the Japanese government to develop measures to counteract serious problems associated with environmental pollution, such as Minamata disease, which was caused by poisoning from organic mercury in factory wastewater, and chronic bronchitis and asthma caused by sulfur oxides from factories in large industrial complexes. Understanding that research on environmental sciences was necessary and could address public needs, the Environment Agency established the National Institute for Environmental Studies (NIES) in Tsukuba Science City, about 50 km north of Tokyo, in 1974. It is now Japan's primary institute for comprehensive research in environmental science.
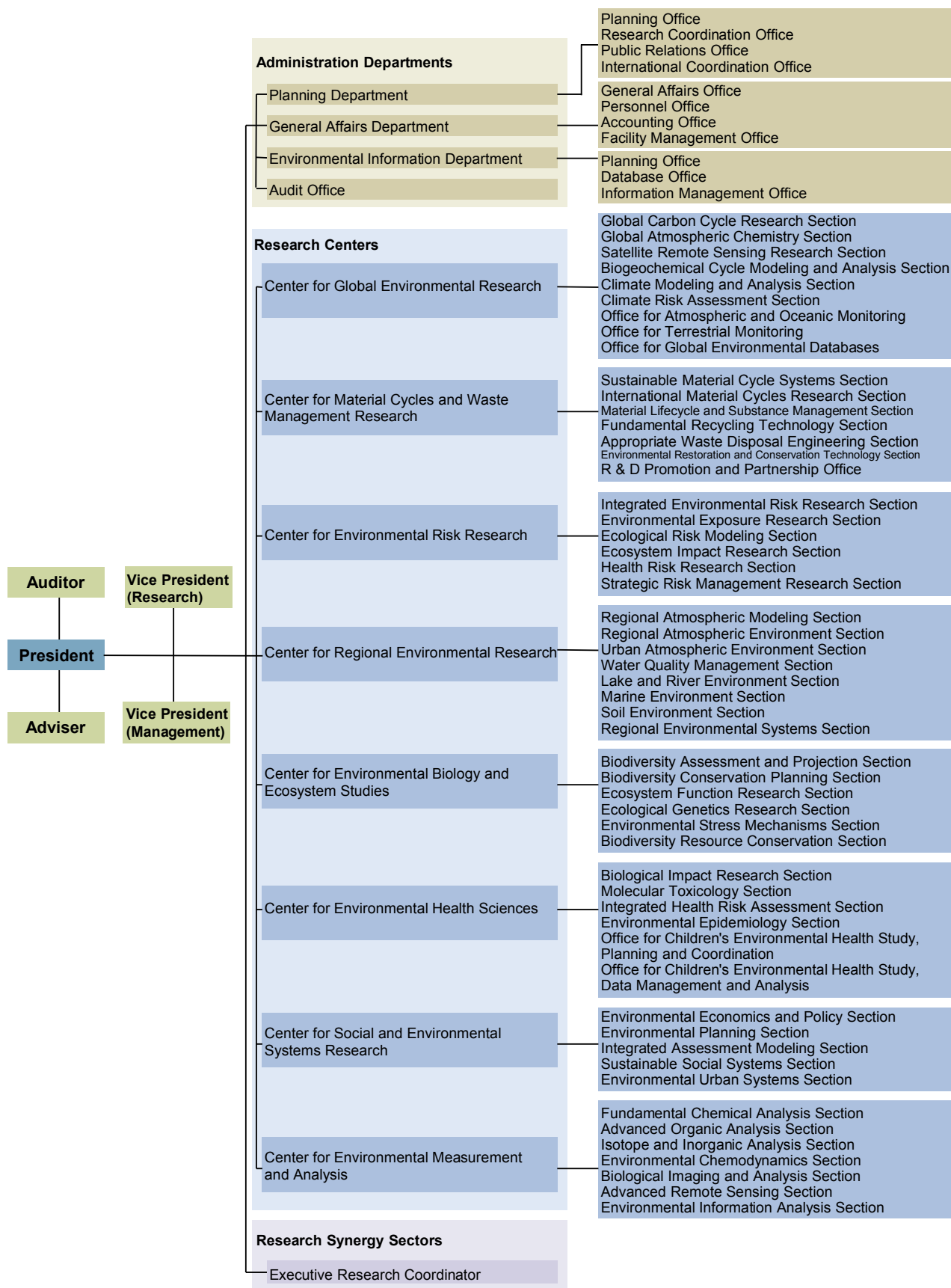
During the two decades following the establishment of NIES, rapid technological progress, structural changes in industry, and lifestyle changes, created additional issues for environmental science to confront. Moreover, global environmental problems such as climate change; depletion of the stratospheric ozone layer; acid deposition; destruction of tropical rain forests; and desertification, attracted greater concern worldwide. NIES subsequently underwent a major reorganization in 1990, including the establishment of the Center for Global Environmental Research, to enable it to conduct more intensive research on conservation of the natural environment and on global environmental changes and their effects.

January 2001 saw the transition of the Environment Agency into the Ministry of the Environment as part of structural changes within the Japanese government, and the establishment of a Waste Management Research Division at NIES. That year also marked the establishment of NIES as an Incorporated Administrative Agency, giving it a degree of independence from the national government. The change in the administrative status of the institute allows more prompt and flexible responses to societal demands. Concurrently, NIES prepared a five-year plan (2001–2005) in line with the objectives of the Ministry of the Environment.

Following the second five-year plan (2006-2010), the third five-year plan (2011–2015) was adopted in 2011. Eight fundamental fields of environmental research are identified, and the research centers to be responsible for these areas are specified (Fig. 1). Research is carried out under our designated research programs and we also actively pursue ties with many institutions both in Japan and overseas.

Research activities to respond to and recover from the Great East Japan Earthquake have been ongoing since the direct aftermath of the disaster. Intermediate outcomes of this research have been summarized as "An Overview of Research on Disaster Environment" and are available from our homepage. In March 2013 the five-year plan was revised following a directive of the Minister of the Environment. Our mid-term objectives were modified to facilitate effective, integrated research on disasters and the environment.

Fig. 1   Organization

Administration Departments
- Planning Department
  - Planning Office
  - Research Coordination Office
  - Public Relations Office
  - International Coordination Office
- General Affairs Department
  - General Affairs Office
  - Personnel Office
  - Accounting Office
  - Facility Management Office
- Environmental Information Department
  - Planning Office
  - Database Office
  - Information Management Office
- Audit Office

Research Centers
- Center for Global Environmental Research
  - Global Carbon Cycle Research Section
  - Global Atmospheric Chemistry Section
  - Satellite Remote Sensing Research Section
  - Biogeochemical Cycle Modeling and Analysis Section
  - Climate Modeling and Analysis Section
  - Climate Risk Assessment Section
  - Office for Atmospheric and Oceanic Monitoring
  - Office for Terrestrial Monitoring
  - Office for Global Environmental Databases
- Center for Material Cycles and Waste Management Research
  - Sustainable Material Cycle Systems Section
  - International Material Cycles Research Section
  - Material Lifecycle and Substance Management Section
  - Fundamental Recycling Technology Section
  - Appropriate Waste Disposal Engineering Section
  - Environmental Restoration and Conservation Technology Section
  - R & D Promotion and Partnership Office
- Center for Environmental Risk Research
  - Integrated Environmental Risk Research Section
  - Environmental Exposure Research Section
  - Ecological Risk Modeling Section
  - Ecosystem Impact Research Section
  - Health Risk Research Section
  - Strategic Risk Management Research Section
- Center for Regional Environmental Research
  - Regional Atmospheric Modeling Section
  - Regional Atmospheric Environment Section
  - Urban Atmospheric Environment Section
  - Water Quality Management Section
  - Lake and River Environment Section
  - Marine Environment Section
  - Soil Environment Section
  - Regional Environmental Systems Section
- Center for Environmental Biology and Ecosystem Studies
  - Biodiversity Assessment and Projection Section
  - Biodiversity Conservation Planning Section
  - Ecosystem Function Research Section
  - Ecological Genetics Research Section
  - Environmental Stress Mechanisms Section
  - Biodiversity Resource Conservation Section
- Center for Environmental Health Sciences
  - Biological Impact Research Section
  - Molecular Toxicology Section
  - Integrated Health Risk Assessment Section
  - Environmental Epidemiology Section
  - Office for Children's Environmental Health Study, Planning and Coordination
  - Office for Children's Environmental Health Study, Data Management and Analysis
- Center for Social and Environmental Systems Research
  - Environmental Economics and Policy Section
  - Environmental Planning Section
  - Integrated Assessment Modeling Section
  - Sustainable Social Systems Section
  - Environmental Urban Systems Section
- Center for Environmental Measurement and Analysis
  - Fundamental Chemical Analysis Section
  - Advanced Organic Analysis Section
  - Isotope and Inorganic Analysis Section
  - Environmental Chemodynamics Section
  - Biological Imaging and Analysis Section
  - Advanced Remote Sensing Section
  - Environmental Information Analysis Section

Research Synergy Sectors
- Executive Research Coordinator

Auditor
President
Adviser
Vice President (Research)
Vice President (Management)

NIES is currently furthering preparations for the establishment of a branch in Fukushima Prefecture. As part of this initiative the following three research programs were also established: (1) Environmental Recovery Research Program (2) Environmental Renovation Research Program and (3) Environmental Emergency Management Research Program, in order to further contribute to recovery and environmental creation in Fukushima.

As of April 1, 2014, the NIES permanent staff number 265, and there are 541 non-permanent researchers (Table 1; Figs. 2 to 4). The total budget for FY2013 was 15,663 million yen (Table 2).

Table 1 Numbers of permanent staff

Administration Departments	56	21.1%
Research Centers	203	76.6%
Research Synergy Sectors	1	0.4%
Executive	5	1.9%
Total	265	100%

 (As of April 1, 2014)

Table 2 Budget for the third five-year plan

(Unit: million yen)

	Category	2011–2015 Budget (5 years)	Fiscal Year 2013 Budget
Revenue	Grants for Operating Costs	68,519	11,688
	Subsidies for Facilities	1,540	332
	Commissioned Work	18,057	3,611
	Other	147	32
	Total	88,264	15,663
Expenditure	Project Costs	50,918	8,351
	Facility Improvements	1,540	332
	Expenses for Commissioned Work	18,057	3,611
	Personnel Expenses	15,516	2,896
	General Administrative Expenses	2,232	473
	Total	88,264	15,663

Note: The budget for each annual work plan will be requested and decided for each fiscal year, based on the five-year plan.
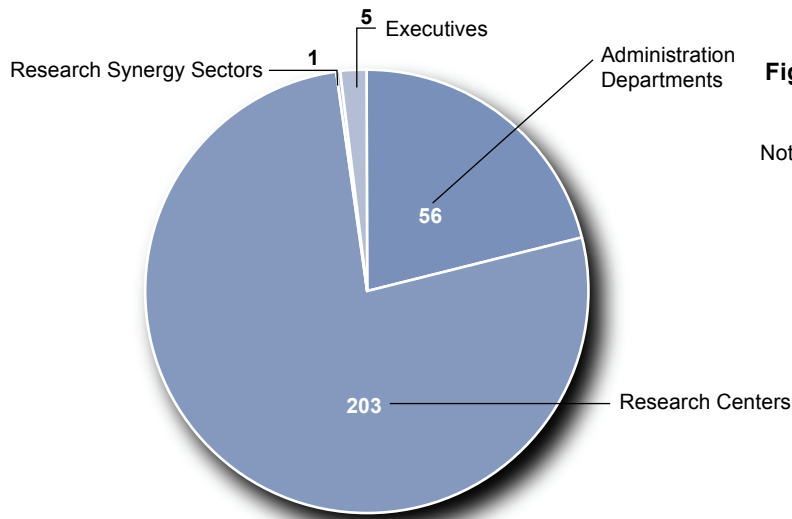
Fig. 2 Number of Permanent Staff
265

Notes: Data is as of April 1, 2014

Pie chart labels: Executives 5, Research Synergy Sectors 1, Administration Departments 56, Research Centers 203
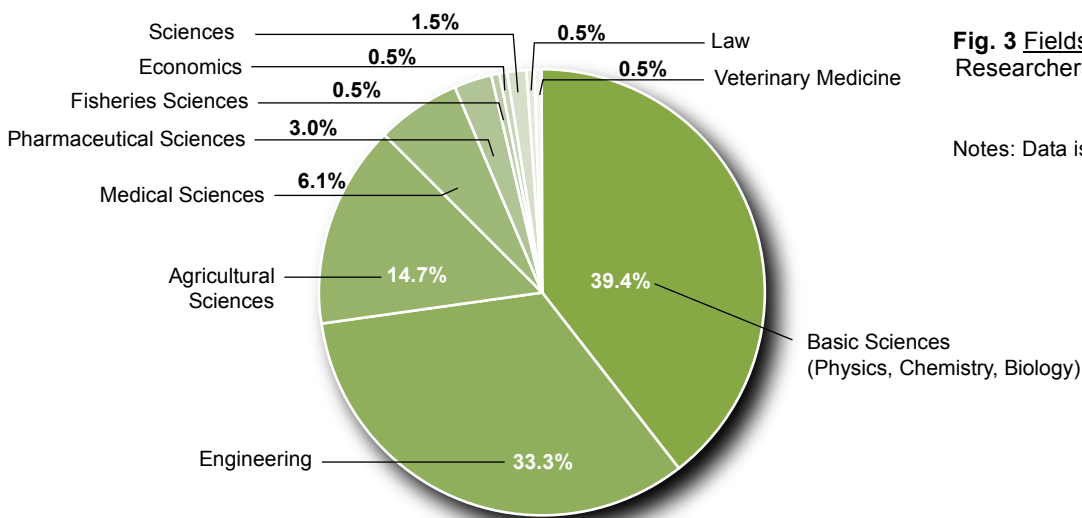
Fig. 3 Fields of Expertise
Researchers holding doctorates
96.0%

Notes: Data is as of April 1, 2014

Pie chart labels: Sciences 1.5%, Economics 0.5%, Fisheries Sciences 0.5%, Pharmaceutical Sciences 3.0%, Medical Sciences 6.1%, Agricultural Sciences 14.7%, Engineering 33.3%, Law 0.5%, Veterinary Medicine 0.5%, Basic Sciences (Physics, Chemistry, Biology) 39.4%
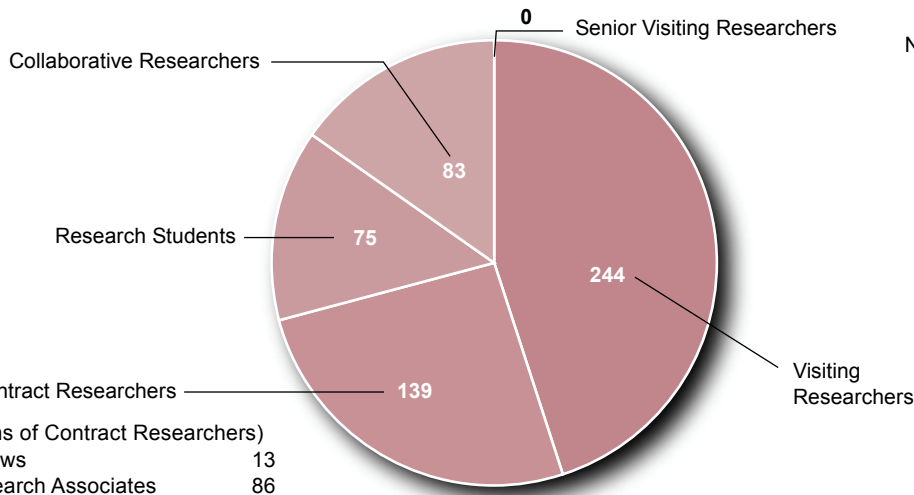
Fig. 4 Number of Visiting Researchers, etc
541

Notes: As of April 1, 2014 (However, the figures for Visiting Researchers, Research Students, Collaborative Researchers, and Senior Visiting Researchers reflect the total number accepted in FY2013).

Pie chart labels: Senior Visiting Researchers 0, Collaborative Researchers 83, Research Students 75, Contract Researchers 139, Visiting Researchers 244

(Items of Contract Researchers)
Fellows 13
Research Associates 86
Junior Research Associates 11
Research Assistants 29

Center for Global Environmental Research

Ground-based GHG monitoring station established at Ochi-ishi in 1994.
Ambient CO_2 concentrations—with a 10% increase—have been observed at the station in the 19 years since it opened.

Outline of the Center for Global Environmental Research (CGER)

The global environment is the most basic and essential factor for the existence of human life. For instance, climate change, including global warming, which is caused by increasing concentrations of anthropogenic greenhouse gases (GHGs) in the atmosphere, together with changes in the stratospheric ozone layer, has serious impacts on all ecosystems, including on humans.

Considering the scale and seriousness of the predicted impacts, it is vital that we take measures to conserve the global environment in order to create sustainable societies. Because it takes a relatively long time for environmental impacts of human activities to start to manifest themselves, it is essential that we take a long-term perspective and recognize the importance of mid- and long-term continuous research.

Therefore, on the basis of an accurate understanding of today's environmental conditions and their variations, CGER performs future projections and impact risk assessments of global environmental change. It also conducts research into measures to preserve the global environment. In cooperation with other research centers, CGER implements climate change research with a special emphasis on observing and clarifying global variations in GHG concentrations in the atmosphere. It also aims to elucidate historical climate change and predict future change, and it performs global risk assessments and research on international adaptation and mitigation policies.

Furthermore, CGER conducts strategic environmental monitoring, develops and maintains environmental databases comprising data from the natural sciences as well as the social and economic sciences, and supports the promotion of global environmental research, both domestically and overseas. CGER also continues to monitor GHGs by satellite and to process, validate, and disseminate the data obtained. Along with the research activities mentioned above, CGER implements proactive and predictive research on the global environment, develops new technologies, and conducts pioneering and fundamental research.

Finally, CGER supports integrated and efficient collaborative research among domestic and international organizations, facilitates mutual understanding and the distribution of research results among researchers, and disseminates the various scientific findings to raise public awareness of global environmental problems.

Outline of the Climate Change Research Program

One of the key issues in climate change research is to clarify the mechanisms by which natural GHG sinks and emission sources vary and to improve the accuracy of predictions on changes in future sink strength. In the context of international climate policy, the development of risk management strategies on a global scale

has become a major issue. At the same time, it is acknowledged that, to achieve a low-carbon society, each country must reduce its GHG emissions. However, important issues such as policy options and international cooperation remain unresolved. An important objective of the Climate Change Research Program of the third NIES five-year plan is, therefore, to assemble and disseminate scientific knowledge with the aim of finding solutions to various climate change problems.

To this end, we are seeking to characterize the variations in GHG concentrations that are known to cause global warming. To do this, we are using comprehensive model analyses from integrated observations obtained from ground-based observation sites, ships, aircraft, and satellites. We are also seeking to provide the scientific knowledge needed to preserve natural GHG sinks.

Among the issues being debated towards social decision-making in risk management are climate change countermeasures and the pathways leading to these targets. To facilitate this decision-making process, we study not only the risks related to global warming (i.e. climate change) but also other global-scale risks such as water security and ecosystem conservation risks. We are also examining risk-management options and risk-management strategies in the context of public risk awareness.

Below, we present information on several of CGER's research activities in FY 2013.

Progress of methane observations in the atmosphere in the Asian region, and comparison of CO_2 flux estimations obtained by using top-down and bottom-up methods

In this project we have been observing GHG concentrations in the atmosphere over the Asian region. Although Asia is a large source of methane, there are insufficient methane concentration data to study the flux over this region. Moreover, because methane concentrations have been increasing globally since 2007, we need to study methane flux characteristics all over the world. This year, GOSAT (Greenhouse gases Observing SATellite) started to provide methane concentration data (see "NIES GOSAT project" below), in addition to observations by Asian sites such as Nainital (NAI) and Karnal (KAR) in India, Dunum Valley (DV) in Malaysia, Guiyang (GUI) in China, Comilla (CLA) in Bangladesh, and also Siberia. We found that methane concentrations over India and Bangladesh were considerably higher than in the other three areas, despite that the fact that Siberia and China themselves have relatively high concentrations (Fig. 1). In the forested areas of Malaysia, methane concentrations were as low as the background levels observed over the Pacific. We also use two cargo ships to monitor methane distributions along their routes in parts of the Asian region, including the Philippines, Thailand, Malaysia, and Indonesia. In this region we have observed some methane peaks close to highly populated areas.

Fig. 1 Air sampling sites and ship routes, and comparison of CH_4 concentrations among sites in the Asian region
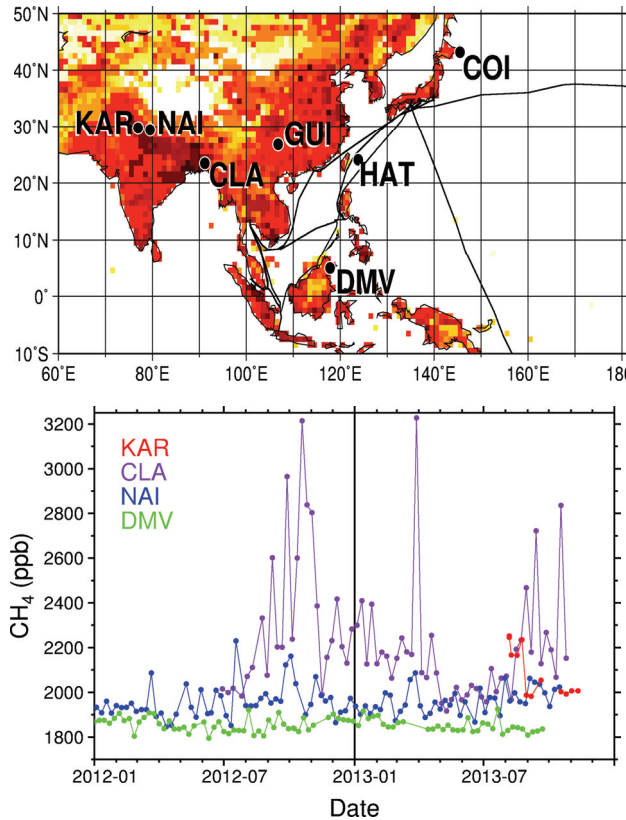
To estimate regional fluxes in GHGs we used two kinds of approach, namely top-down and bottom-up. The top-down approach consists of GHG observations from multiple platforms, including a satellite (GOSAT) and inverse modeling. The bottom-up approach uses GHG flux observations at terrestrial sites and over the ocean. From the GOSAT project we obtained 64 regional CO_2 flux maps. To compare these results with those of ocean and terrestrial flux modeling, we adjusted the model calculation regions to those of 64 inverse calculation regions and then compared the CO_2 fluxes in each ocean or terrestrial region. In the terrestrial flux comparison the two sets of results gave gross primary productions of similar strength, but for net ecological production there was some discrepancies in tropical areas.

Fig. 2 Comparison of oceanic fluxes of CO_2 between the top-down and bottom-up methods
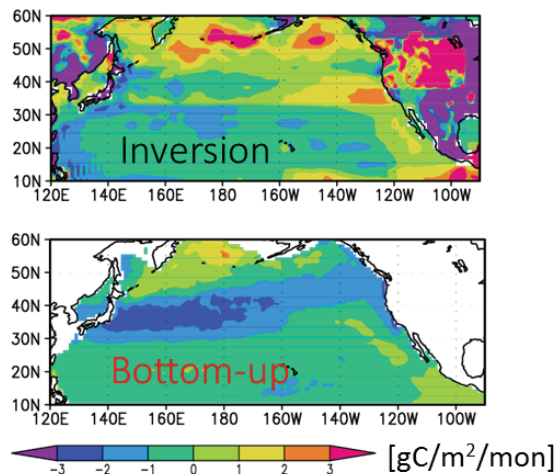
Comparison of the ocean flux estimation models revealed that the top-down approach (i.e. the inversion method; Fig. 2) gave an unrealistic flux distribution over the Pacific. One of the reasons for this was the relatively low ocean flux compared with the terrestrial flux. Moreover, the precision and density of CO_2 concentration observations by GOSAT over the ocean were not high. At present, the bottom-up method is based on long-term monitoring of the ocean flux by using cargo ships; the results were therefore reliable. We need further studies comparing the flux estimations by the top-down and bottom-up methods to evaluate and verify the precision of the two methods.

Assessment of impact of climate change on global water resources

Water is an indispensable resource for humans and society. By using the latest radiative forcing scenarios (future climate projections) and socioeconomic scenarios developed through the cooperative efforts of the international research community, we ran detailed simulations of five possible developmental directions ("world views") and examined water availability and use in the 21st century. Projected water availability depends greatly on the climate scenario (i.e. future temperature and precipitation changes due to global warming). In contrast, projected water use depends heavily on the socioeconomic scenario (future possible changes in population, economic activity, and technology).

Fig. 3 Changes in the water sufficiency index under different world views. The index, ranging between 0 and 1, shows whether a sufficient volume of water is available when it is needed. The top left panel shows the index in 2000. The five other panels show the five socioeconomic scenarios termed Shared Socio-economic Pathways (SSPs) with climate policy implementation in 2050 as compared with 2000. SSP1 expresses the world view of Sustainability; SSP2 is Middle of the Road; SSP3 is Fragmentation; SSP4 is Inequality; and SSP5 is Conventional Development. The darker the red (low value), the more scarce the water is. Blue indicates improved water availability, and white indicates unchanged water availability. (adapted from Hanasaki et al. 2013).
Note: The legends do not depict interval scales, so the distances between values are not proportional to the values.
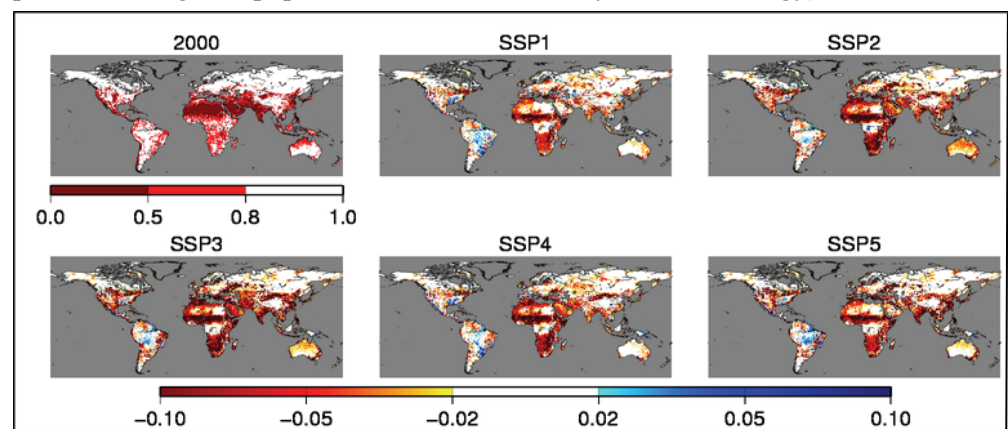
Figure 3 shows changes in the water sufficiency index in about 2050 for each of the five world views as compared with the present. A higher index indicates improved water availability, and a lower index implies more serious water scarcity. Under the Shared Socioeconomic Pathway (SSP)3 (Fragmented world) scenario, large parts of the world, including Asia and North America, are dark red, suggesting that there will be a more serious water scarcity problem, with less water available than needed, in the future compared with the present. In contrast, under the SSP1 (Sustainable world) scenario most areas except Africa are white, which implies that water availability will not change from the present level. The fact that under all scenarios the water sufficiency index for Africa decreases can be attributed (in addition to global warming impacts) to a drastic increase in water

use due to population and economic growth. Among the five scenarios, only in SSP1 is water availability in the 21st century maintained at the present level (except in Africa); under all of the other scenarios water scarcity increases, pointing to the need to take global action against global warming and toward a transition to a sustainably society. We are currently studying the effects of adaptation policies.

Comprehensive climate policy assessment and development of visions and scenarios toward a low-carbon society

Our aim in this study is to provide scientific knowledge from the perspectives of modeling and analysis, scenario development, and negotiation processes, in order to achieve a low-carbon society at the local, national, regional, and global levels. To achieve this aim, the study consists of three sub-themes: (1) scenarios and implementation strategies for a low-carbon society (LCS) in Asia; (2) quantitative assessment of climate change mitigation policies in Japan and the world; and (3) study of international institutions and negotiation processes for the development of the LCS.

In sub-theme 1, we quantified "10 actions" toward LCS in Asia by using the global computable general equilibrium (CGE) model to be developed under sub-theme 2. This analysis considered not only the introduction of advanced energy-saving and renewable energy technologies, but also socioeconomic changes such as dematerialization and compact city development. Asia's share of global GHG emissions would change from 38% in 2005 to 43% in 2050 under the BaU (Business as Usual) scenario. Under the LCS scenario, the volume of GHGs would decrease dramatically, but Asia's share in 2050 would increase to 53%. These analyses indicate that the challenges in Asia will be very important to achieving the LCS globally. We used these results and individual scenarios for each country to exchange information with other Asian countries about policies and measures toward the LCS. The results were introduced at a side event at UNFCCC's COP (Conference of the Parties) 19 in Warsaw.

In sub-theme 2, we used an integrated assessment model that we developed, namely the AIM (Asia-Pacific Integrated Model), to assess future societies. In 2013 we quantified five new global socioeconomic scenarios, or SSPs (Shared Socio-economic Pathways). SSP1 to SSP5 are classified in terms of mitigative capacity and adaptive capacity. To represent the various aspects of society, such as energy, technology, resources, and land use, we revised the global CGE model. GHG emissions in 2050 will range from 66 to 104 GtCO$_2$eq, and those in 2100 will be from 55 to 131 GtCO$_2$eq. We will use these scenarios as a basis for the development of long-term scenarios on climate change mitigation and adaptation.

In sub-theme 3 we ran a second online questionnaire survey on a plausible international framework for the post-2020 period; this framework is to be agreed upon under the Durban Platform. The survey revealed the following: 1) From a legal perspective, most respondents expected a package of "a legal instrument such as a protocol" and a series of "non-legal instruments such as COP decisions." They considered this kind of legal format to be agreeable, and they expected that the framework would aim for environmentally effective consequences in terms of climate mitigation. 2) The responses converged into six types of agreement option, three of which (a protocol with specific mitigation contributions, a protocol with general mitigation contributions, and a protocol for the implementation of national legislation) gained the most support from respondents. For all of these options, COP decisions are indispensable components that will stipulate the detailed rules and procedures for the proposed 2015 agreement.

Long-term monitoring of GHGs and other trace gases

Atmospheric GHGs (e.g. CO_2, CH_4, and N_2O) and other chemical species (CO, NO_x, and SO_x) are monitored from various platforms to determine the long-term variations in the concentrations of these gases and their spatial distributions. We have two ground-based stations, at Hateruma Island (over 1000 km southwest of the Japanese mainland) and at Cape Ochi-ishi (in northeastern Hokkaido). Commercial ships operating between Japan and Australia, New Zealand, North America, and Asian countries are used to observe the latitudinal or longitudinal distributions of GHGs and the partial pressures of CO_2 in the surface waters of the Pacific. Routine samplings are conducted from aircraft over three sites in Siberia to measure the vertical distributions of GHGs. UV-A and UV-B on the ground are monitored, and real-time UV indexes obtained at 15 sites in Japan are available to the public via our web page. To detect the effects of global warming on the marine environment, the distributions of tropical reef corals and the DNA clades of the symbiotic algae zooxanthellae around Japan are monitored.

The trend curve calculated for the CO_2 mixing ratio at Hateruma exceeded 400 ppm at the end of 2013 (Fig. 4). The CO_2 mixing ratio has increased by 40 ppm over the past 20 years; this corresponds to an absolute value of 10%. The growth rate of CO_2 has also increased, from 1.6 ppm/year in the 1990s to 2.3 ppm/year after 2010. The recent inter-annual variations in the growth rate showed large variability, with a 2- to 3-year cycle, but there was no obvious relationship with the El Niño–La Niña cycle.

Fig. 4 Time series of CO_2 mixing ratios at Hateruma Station. Red dots, observation data; blue solid line, fitting curve; green solid line, trend curve; purple solid line, growth rate
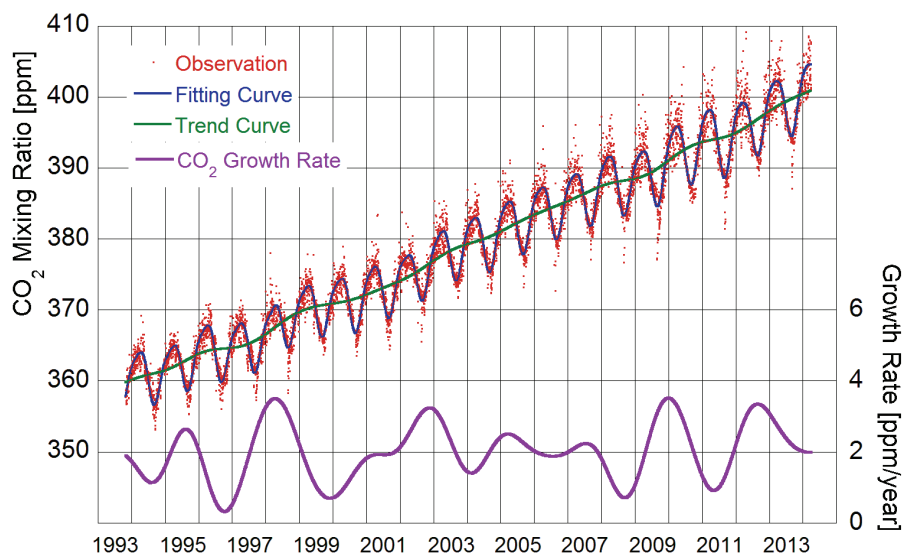
Carbon dioxide flux monitoring of terrestrial ecosystems

Long-term monitoring of carbon, water, and energy exchange between larch forests and the atmosphere, as well as of biological processes in these forests, has been conducted by CGER in NIES to determine how the forests respond to climate change and how the responses depend on the process of recovery from natural and artificial disturbances. The Fuji Hokuroku Flux Observation Site is located in a mature larch forest at the foot of Mt. Fuji. Clear seasonal changes in carbon uptake were observed here and were related to the phenology of the larch trees. Continuous observation of the flux of CH_4, one of the most significant GHGs, has also been conducted over the forest canopy at the Fuji Hokuroku Site through application of the relaxed eddy accumulation (REA) method. The REA method was developed for such gases as CH_4 and for biogenic volatile organic compounds that could not be measured in the air at the high frequencies needed to apply the covariance measurement technique.

At the Teshio Carbon Cycle and Larch Growth Experiment Site in Hokkaido, 14 ha of forest was clear-cut and larch samplings were planted in 2003. The clear-cutting resulted in decreased photosynthesis and increased decomposition of dead roots and soil organic carbon. In 2013, ten years after the clear-cutting and planting, the forest was a weak sink of CO_2.

Long-term monitoring of alpine vegetation began in 2011 to detect the influence of global warming on the phenology, production, and species distribution of alpine ecosystems. Two focused-monitoring areas were selected after feasibility studies in the previous 2 years: one in the Japan North Alps extending over Nagano and Toyama prefectures, and the other on Mt. Rishiri in Hokkaido. Several observation points were selected in each area, and automatic digital camera systems were installed at every point to collect images representing

day-to-day changes in snow area, leaf expansion, flowering, and leaf coloring on the slopes of the mountain. Image data are acquired in the laboratory by using a real-time data transmission system and broadband networks. Phenological changes at the beginning of the growing season were clearly observed in response to the spring snowmelt and the ecosystem type.

Some of the data obtained from our terrestrial monitoring are available to the public on the CGER web page.

Global environmental databases

Since the early 2000s the Office for the Global Environmental Database at CGER has been constructing and providing databases on several topics related to Earth's global environment. There are five major tasks in this project: (1) construct, maintain, and renew the database servers that provide our databases; (2) construct databases and provide the public or researchers with data gathered by global environmental monitoring project at our institute; (3) construct databases on social environmental sciences related to global warming; (4) develop convenient tools to analyze global environment datasets; and (5) achieve international cooperation on database-related issues.

In March 2013, the homepage of the Global Environmental Database was updated to offer a "data search" service. Users can use this service to look up a wide range of data in multi-disciplinary and multi-project combinations. This year, we have been finalizing a new database, the "Global Environmental Database" (GED), to provide quality-controlled open data on global environmental monitoring projects in original format or NASA Ames format. GED also offers a graphic function that allows data to be viewed at a glance. We renewed the design of the existing content, which covers multiple environmental issues such as global warming (GHG observations, carbon sources or sinks, material flows, and the effects and measurement of global warming); the atmospheric environment (the stratospheric ozone layer, UV, air pollution, and acid rain); marine and freshwater environments; biology; satellite remote-sensing and geographic information systems; and other related topics. We renewed the site formerly called "GGTU (Greenhouse Gases Trend Update)" and changed it to a "Real Time Data" menu of GED to attract users' attention to the most up-to-date information. We have also added an "Analysis Support" menu to provide offline tools and online applications for data analysis and visualization (e.g. for trajectory analysis). We plan to release a new GED home page in early FY2014. A prototype is shown in Figure 5.

**Fig. 5** Prototype of the new home page of the Global Environmental Database (http://db.cger.nies.go.jp/)
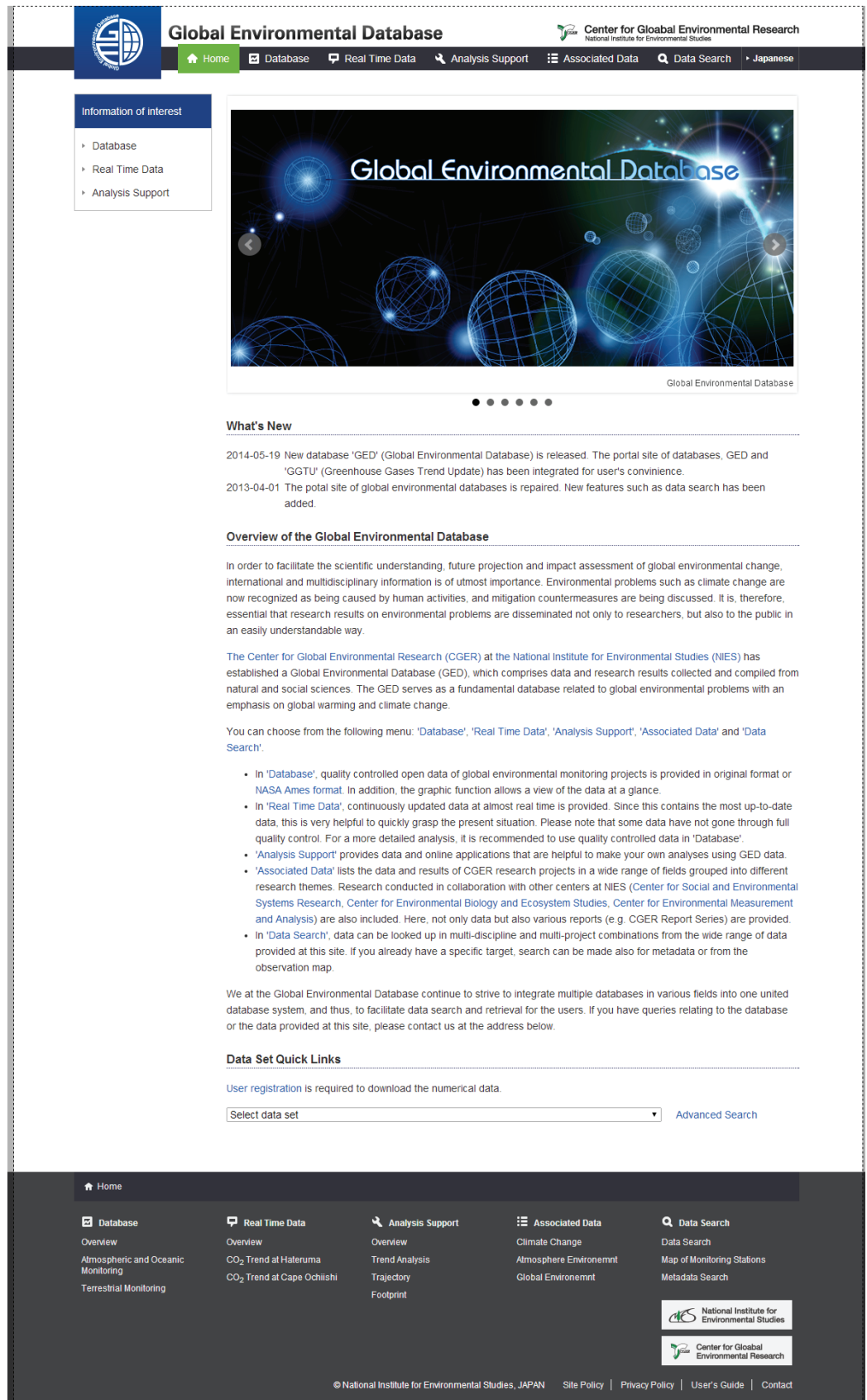
NIES GOSAT project

GOSAT completed its five-year nominal operation period on January 23, 2014, and has now moved into its extended operation period. We continue to process GOSAT data at the NIES GOSAT Data Handling Facility, and to distribute GOSAT data products online to researchers and the general public via the GOSAT User Interface Gateway (GUIG, http://data.gosat.nies.go.jp/). In addition to the data products already made available to users, we newly released the following data products to registered GOSAT RA (Research Announcement) researchers: TANSO-CAI (Thermal And Near-infrared Sensor for carbon Observation–Cloud and Aerosol Imager) Level 2 cloud properties (version 01.00), GOSAT Level 4A regional monthly CH_4 fluxes, with their uncertainties, and Level 4B model-simulated three-dimensional distributions of CH_4 concentrations (both version 01.00 for the period from June 2009 to May 2010, and version 01.01 for the period from June 2009 to May 2011). We have also opened data product for the entire past observation period to general users. This includes updated Level 4 CO_2 fluxes and simulated three-dimensional distributions (from version 02.01 to version 02.02 for the period from June 2009 to October 2011); updated TANSO-CAI Level 3 global radiance distribution (from version 09.** to version 01.00); and TANSO-FTS (Fourier Transform Spectrometer) SWIR (Short Wavelength Infra-Red) band Level 2 XCO_2 and XCH_4 column concentrations (versions 02.20 and 02.21; Fig. 6). The update of XCO_2 and XCH_4 corresponds to the Japan Aerospace Exploration Agency's update of TANSO-FTS Level 1B data from versions 150.150 and 150.151 to versions 160.160 and 161.160.

The GOSAT Project website and GUIG continue to be maintained, and we have updated important information on GOSAT data products for GOSAT data users. Four issues of the GOSAT Newsletter, in Japanese and English, were published on the GOSAT website in FY 2013.

Fig. 6 GOSAT TANSO-FTS SWIR Level 2 data (version 02.21), showing samples of XCO_2 and XCH_4 column concentrations averaged in every 2.5° mesh for August 2013 (JAXA, Japan Aerospace Exploration Agency; MOE, Ministry of the Environment)
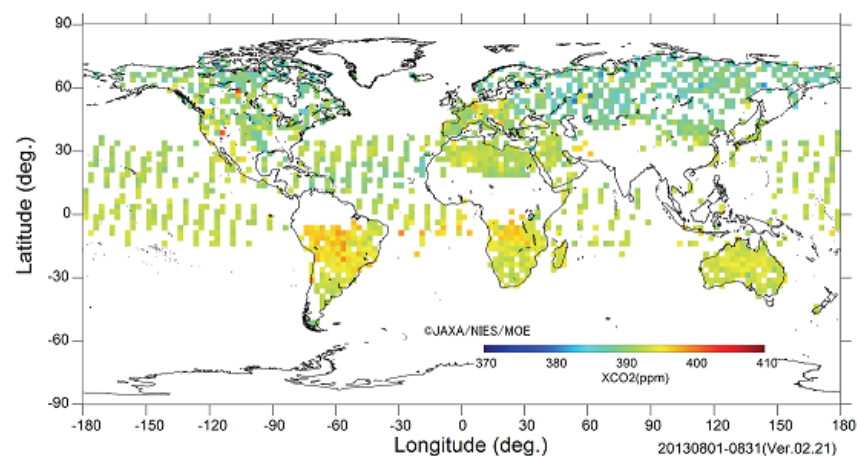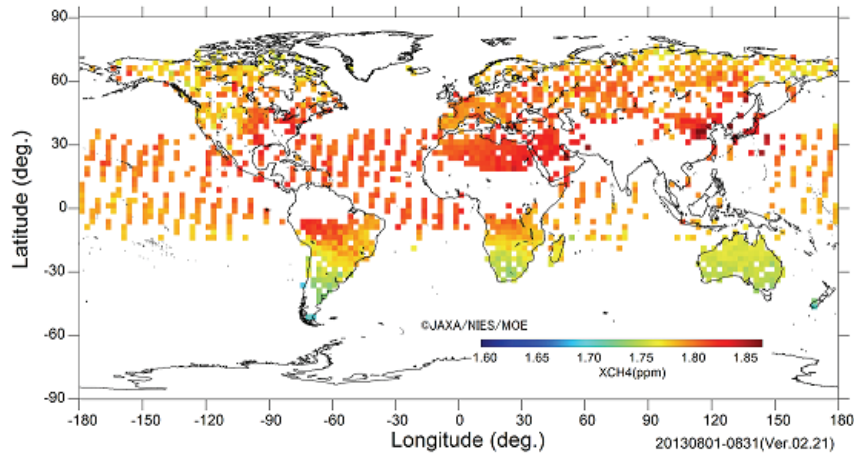
NIES GOSAT-2 Project

FY 2013 is the first year of the NIES GOSAT-2 Project. GOSAT-2 is the successor to GOSAT and is being developed by Ministry of the Environment, Japan; the Japan Aerospace Exploration Agency; and NIES. Its major observation targets are carbon dioxide, methane, carbon monoxide, and black carbon in the atmosphere. The launch of GOSAT-2 is scheduled for FY 2017.

The major achievements of the NIES GOSAT-2 Project in FY 2013 were as follows:

1) Most requirements for the GOSAT-2 Data Handling Facility (DHF-2) were defined. Preliminary design of DHF-2 will start in FY2014.

2) Development of the GOSAT-2 FTS-2 simulator continued.

3) Long-term plans for GOSAT-2 validation were drafted. Several tools for validation data analysis were developed.

4) Potential atmospheric models to be used in GOSAT-2 data processing were investigated.

5) Applications for the flux data from GOSAT and GOSAT-2 were investigated.

6) Several meetings of the GOSAT-2 Science Team Preparation Committee were held. Issues discussed included cloud masking and calibration of GOSAT-2 instruments.

7) Several outreach activities, including exhibitions at UNFCCC COP19 and GEO-X (the 10th plenary meeting of the Group on Earth Observation), were conducted.

For more information, contact: gosat-2-info@nies.go.jp.

Center for Material Cycles and Waste Management Research

The Bio-Eco Engineering Research Laboratory

Aquatic plant purification system

Johkasou system for domestic wastewater treatment

Since its foundation in 2001, the Center for Material Cycles and Waste Management Research has aimed to realize a society with optimal material cycles, that is, reduced use of natural resources, reduced generation of waste, increased recycling of materials, and appropriate waste management. In accordance with the third NIES five-year plan (covering the period 2011–2015), the center is playing a major role in promoting a research program on "Sustainable Material Cycles," which comprises three research projects. It is also conducting the necessary research on material cycles and waste management in response to national policies and promoting fundamental research.

1. Sustainable Material Cycles Program

We engage with environmental issues on three fronts: international environmental issues that affect Japan and extend throughout the rest of Asia; issues affecting developing countries in Asia; and domestic issues. Our initiatives are related to the scientific and technical aspects of the efficient use and appropriate management of resources and waste. On this basis, we intend to actively support sustainable material societies—both in Japan and overseas—that reconcile climate change policy and implementation strategies.

1.1 Appropriate management of materials with hazard and resource potential in harmony with international material cycles (Research project 1)

Understanding international material flows and system analysis
In today's globalized economy, each country has indirect and hidden flows associated with economic activity, and natural resource consumption through supply chains accelerates environmental impacts in places far removed from their place of consumption. International trade drives biodiversity threats in developing nations and induces high levels of energy consumption and environmental emissions (e.g. greenhouse gas or air-pollutant emissions) in producer countries. Figure 1 summarizes the flows of nickel among countries in eight regions of the world and Japan. The worldwide flow of nickel through trade in 2005 was 2.7×10^6 t. The flows are colored to represent the types of commodity (ore, raw materials, materials, products, and waste and scrap). The flows to Japan and Europe are immediately apparent. Flows from South East Asia to Japan are comparatively large and consist of nickel laterite ore for ferronickel production and intermediate products (e.g. mixed sulfide) for nickel production. There are other comparatively large flows of, for example, raw materials from Oceania and the Commonwealth of Independent States to Europe; these flows include ferronickel and metal nickel. The figure shows the vital importance of the actions of Japan and Europe in control of the nickel supply chain and environmental impacts induced by its production.

Fig. 1 Global material flows of nickel in 2005. CIS, Commonwealth of Independent States

Commodities	[t-Ni]	[%]
Ore	197,480	7.3
Raw Material	**1,394,787**	**51.7**
Material	427,807	15.9
Products	387,793	14.4
Waste & Scrap	175,775	6.5
Total	2,697,385	100
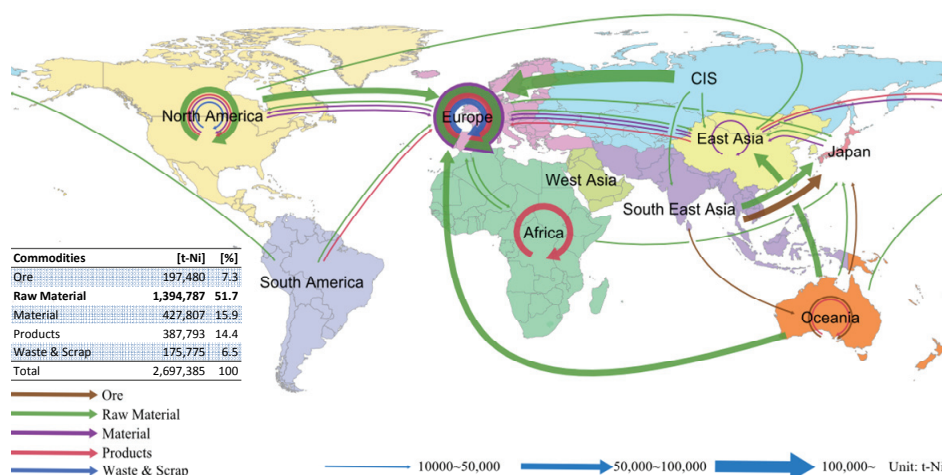
Field study of product and material cycles for managing resources and chemical risks

In January 2011 we began environmental investigations of E-waste recycling workshops in order to obtain useful data for the environmentally sound management of E-waste in developing countries by identifying critical control processes. In January 2012, we collected soil and sediments in and around a village in northern Vietnam that had E-waste recycling workshops. Primitive recycling methods, including open storage of E-waste, dismantling and crushing of electronic products, hand-sorting of recyclable materials, and manual removal of coatings from copper wire, were used in and around the E-waste workshop. Furthermore, open-burning of E-waste was performed on the paths between paddy fields around the village. We analyzed not only the chemicals potentially present in the E-waste, such as brominated and chlorinated flame retardants (FRs), phosphorus-containing FRs, and heavy metals such as Pb and Cu, but also unintentionally present hazardous chemicals associated with E-waste and its recycling, such as dioxin-related compounds (DRCs), to elucidate the status of contamination with these chemicals and their diffusion from sources. The concentrations of brominated FRs such as PBDEs (polybrominated diphenylethers), phosphorus-containing FRs such as TPhP (triphenyl phosphate), heavy metals such as Pb and Cu, and DRCs such as brominated dioxins in soil and sediments collected from around the E-waste recycling areas tended to be higher than in samples from control areas. Our results suggest that, although the compounds derived from E-waste may have had low potential for pollution through diffusion at this site, E-waste recycling is one of the biggest sources of these compounds. Alternative and new FRs such as PBDPP (resorcinol bis(diphenyl phosphate)) and BPA-BDPP (bisphenol A bis(diphenyl phosphate)) have already appeared in the waste streams of electronics products.

Proposal of management measures toward an international sound material cycle society

As part of our investigation of the trade of recyclable resources from Japan we

investigated the export of mixed metal scrap. From a safety perspective, we reviewed past cases of fire in mixed metal scrap, but in most cases we found no clear cause for the fires. In an effort to control the hazardous potential of scrap, we used commercial mixed metal scrap to explore ways of sampling hazardous compounds in the scrap and thus better managing the application of the Japanese Basel Act. With regard to the concept of environmentally sound management (ESM) of the Basel Convention, we discussed considerations including resource potential, safety and other environmental concerns (such as GHGs). The identification of hazardous potential was also important. With a focus on hazardous and resource potential, we suggested that a structure with three levels of ESM, as well as a technical standard and economic incentives, are needed to implement ESM step-by-step in developing countries as well as in Japan.

1.2 Establishment of appropriate technological systems for municipal waste in Asia (Research project 2)

Development of semi-aerobic landfill technologies appropriate for Asia
We set up a pilot-scale constructed wetland for leachate treatment at a landfill in Thailand. Introducing a combination of indigenous cattail and various media into the constructed wetland effectively reduced the amount of leachate through evapotranspiration; it also enabled stable removal of organics, nitrogen, and heavy metals from the leachate. This low-cost and low-energy operation of constricted wetlands suggests that the technology is feasible for treating leachate in tropical Asian landfills. Aeration systems such as the use of semi-aerobic landfills might help reduce both the amount of leachate and the impact of GHGs. Field investigations of GHG emissions at waste landfills in Japan indicated that aerobization of landfilled waste had a strong influence to reduce gas emission. Although the path of waste degradation changed dramatically from anaerobic to aerobic, methane emissions still continued at low levels. This was ascribed to a temporal difference in the apparent carbon stream in the landfill in aerobic systems, as dissolved organics partially converted to anaerobic gas at saturated zone before discharging via the leachate.

Development of on-site wastewater treatment technologies for developing nations
Parallel experiments using three types of reactor—a newly developed anaerobic reactor with siphon-driven agitation, an unmixed conventional reactor, and a continuously mixed conventional reactor—revealed that the newly developed reactor achieved successful operation under a higher organic loading rate and also improved solids dispersion. We tested the anaerobic digestibility of nine species of harvested aquatic plants used for water purification; *Egeria densa* had the highest digestibility. A kinetic model of organic matter degradation versus retention time based on a continuous anaerobic digestion experiment using *E. densa* indicated that hydrolysis was the limiting step and a long retention time was required for sufficient degradation.

Development of tools for planning of waste management systems

Food waste has become a topical issue globally – and this includes developing countries. Ho Chi Minh City in Vietnam has launched a pilot study of source separation in a model area. Food wastes—including non-biodegradable wastes such as shells and bones—accounted for 62% of household waste. A monitoring survey revealed that 78% of biodegradable waste was appropriately separated as food waste, but a large proportion of flower and garden waste was also separated as food waste, even though it was not categorized as such in the pilot study. The waste separated as food waste had a 74% moisture content and 18% volatiles, whereas the waste separated as other waste had a 50% moisture content and 32% volatiles (Fig. 2). These results suggest that other waste can be managed at incineration plants and, because of its relatively high heating value, can be used to generate electricity. Other separated waste would have had 9100 kJ kg^{-1} lower heating value with optimum source separation.

Fig. 2 Proximate composition of separated food and other wastes in Ho Chi Minh City
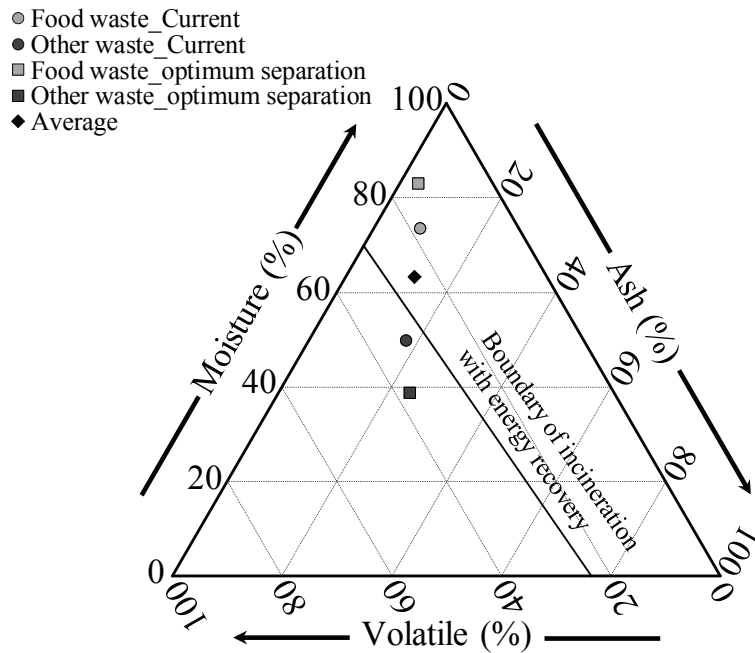
1.3 Establishment of material cycle systems by utilizing regional characteristics (Research project 3)

Proper material cycle systems on various geographical scales need to be established for a sound material cycle society. This project aims to contribute to regional communities by designing regional systems. It also aims to contribute to the science of material cycles by establishing methodologies for estimating appropriate geological scales for such cycles and formulating concepts of regional and local material cycles. In the third year of the project, we surveyed and compiled data on issues and solutions relating to the establishment of regional material cycle systems, with the aim of taking into account complex political mechanisms among regional stakeholders. We also used mathematical

models to analyze regional material cycle systems; our aim was to evaluate both imbalances in the supply and demand of recycled biomass resources and the environmental burdens under a population decrease.

Designing a framework for constructing regionally appropriate material cycle systems

Solutions to regional issues are not necessarily implemented in a systematic, holistic way, because different stakeholders have different motivations, perceptions, and behavior patterns. Any optimum solution found through systems analysis therefore needs to be complemented by a well-designed strategy. To develop such a strategy it is important to understand the structure of regional issues and the relationships between stakeholders and to have a list of potential solutions to regional issues. We surveyed two cases of regional recycling and compiled the information into structured issue and solution libraries (Fig. 3). An example of an issue with the potential to impede regional recycling of biowaste was the case in which members of the public did not follow the rule of sorted

Fig. 3 Visualization of the structure of stakeholder and regional issues in a case of bio-waste recycling
(The numbers on the arrows are issue IDs.)
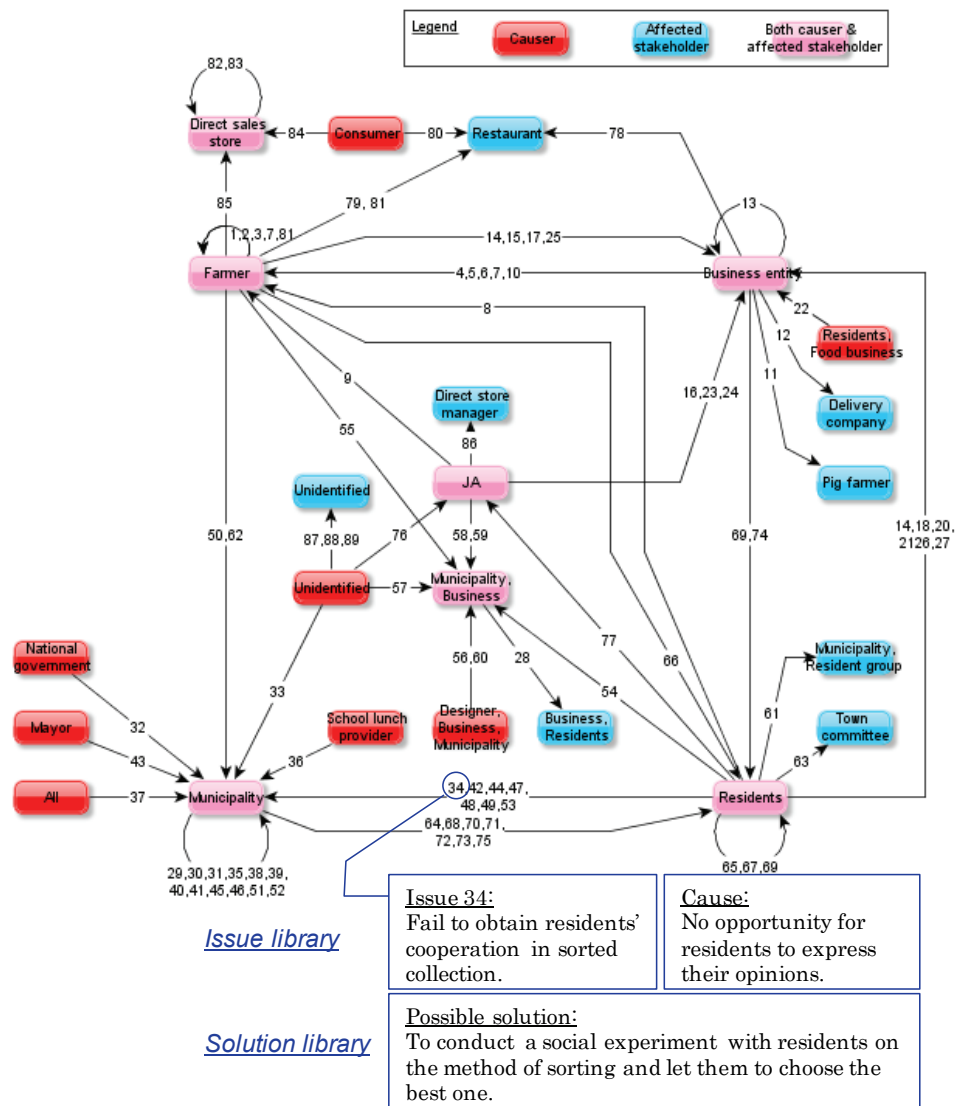
collection set down by their municipality because they felt they had not been given the opportunity to express their opinions on the rule. A possible solution was, according to the solution library that we compiled, that the public could decide on the sorting rule to be applied, taking into account their views on convenience and inconvenience.

Design, assessment, and implementation of regionally appropriate material cycle systems

We used a model calculation to analyze the balance and imbalance between the supply and demand of regional resources, focusing on the amount of nitrate. Calculations for the whole of Japan revealed the areas with balanced supply and demand. We found that the percentage of areas in balance increased by 15% if neighboring municipalities cooperated. We also analyzed the costs and environmental burdens generated from regional waste management systems in the case in which the regional population decreased and waste incineration plants were merged while recycling was promoted. We thus determined the largest unit cost and unit discharge of CO_2 that could be spent on a new recycling facility.

2. Waste management research needed in response to national policies

2.1 Evaluation of waste incineration systems and development of an energy recovery technology

We investigated the treatment performance of various waste incineration facilities in terms of energy recovery and the discharge ratio of incineration ash to treated waste volume. We conducted the same evaluation on a new treatment system combined with a waste incinerator and a biogas production facility for energy conversion from food wastes. In addition, we used a systems analysis approach to determine the economic and technological conditions required to install the combined system in a city.

We also developed a multizonal equilibrium model to represent the behavior of lead during the incineration of municipal solid waste. To evaluate whether the calculation model was reasonable and useful, we compared the calculated result with the actual mass flow of lead in the incineration. From this comparison, we suggested some points of improvement in our calculation model so as to better represent the behavior of lead.

2.2 Development of a quality control engineering system for wastes towards an advanced sound material cycle society

We evaluated the leaching behavior of inorganic ions by using a column leaching test; the column was packed with residues from construction and demolition waste. The influence of column size on the leaching behavior of chloride ions with high leachability was small, whereas the concentration of leached calcium

ions with low leachability decreased as the column lengthened. To estimate the inner leachate quality at a seashore landfill site, we formulated concentration boundary conditions that were flow rate dependent.

We performed a drilling survey of a landfill in which incineration ash was the main item disposed of in order to elucidate metal distributions and changes in chemical form within waste landfills. The variation in the contents of heavy metals such as Cr, Cu, Mn, Ni, Pb, and Zn was very large among samples taken from 7 m depth.

2.3 Establishment of appropriate measures for regional environmental restoration and domestic liquid-waste treatment

We examined the effects of water-saving devices on water consumption and characteristics of domestic wastewater. Water-saving devices reduced water consumption by 22% and increased the biochemical oxygen demand (BOD) of domestic wastewater. Although the BOD concentration of effluent from a *Johkasou* on-site wastewater treatment facility increased by 44.6%, the effluent load was not significantly increased (11.2%) because of the low volume of wastewater. Applying an anaerobic–aerobic circulation process improved BOD reduction efficiency, and a 24.8% BOD load reduction was achieved.

In addition, we investigated the composting and agricultural application of excess biomass produced during wastewater treatment by using hyperthermophilic fermentation (HTF) and hydrothermal reaction (HTR). Experimental cultivation of a rice crop fed with composts produced by HTR suggested that the feedstock type strongly affected the crop yield: serious nitrogen starvation and reduced crop yield occurred when the crop was fed with wood-derived compost.

In contrast, compost produced by using HTF gave stable crop production, which was increased with the dose rate of compost. Crops fed with HTF compost at 500 kg/ha yielded 5000 kg/ha.

2.4 Development and evaluation of treatment technologies and analytical methods for the countermeasures toward legacy wastes and materials with recycling difficulties

For appropriate management of asbestos, we examined the validity of, and problems associated with a rapid-screening method for asbestos in disaster debris by polarized light microscopy. We also confirmed that friable asbestos components in soils containing disaster debris did not exceed the risk level of 10^{-6}.

To find appropriate treatment technologies for persistent organic pollutants (POPs), we conducted combustion experiments on four kinds of

organophosphorus flame retardant (two monomer types and two oligomer types) used as alternatives to bromine flame retardants. We confirmed that the POPs were properly treated under controlled combustion conditions. They were decomposed mainly at the primary combustion stage, and overall destruction efficiencies were more than 99.999%.

In an examination of technologies for recycling hard-to-recycle materials, we confirmed that the chlorine-volatilization process, which is effective for removing lead from cathode-ray-tube glass, was also capable of removing arsenic and antimony from liquid crystal displays. We found that this process also controlled the leaching of these elements from glass.

To establish a procedure for performing field surveys of inappropriate landfill sites, we collected data that would enable us to assess landfill dam stability by physical investigation or by sampling soils at the landfill site. We also collected information on groundwater leakage to assess the durability of seepage control works in cooperation with the managers of industrial waste landfill sites.

2.5 Development, standardization, and application of methods for testing the environmental soundness of chemicals in recycled products

To enable steel slag to be used in marine applications, we investigated the leaching of alkaline substances from slags and the subsequent rise in pH of seawater. We used a large-scale tank experiment (L 6.5 m × W 0.5 m × H 1.2 m) to develop draft leaching tests for judging the acceptability of slag in marine environments. We intend to develop a flow-through-type test for more detailed evaluation and a single batch test for quality checking.

We evaluated an up-flow percolation test based on ISO/TS 21268-3, and a ring test was performed by three other institutes to ensure the adaptability of the percolation test for characterizing soil-like recycling materials. The behavior of substances such as arsenic and fluorine showed good accordance in terms of maximum concentration and cumulative amounts leached, with less than a 20% deviation from the average.

3. Promotion of seed and fundamental research

3.1 Systems approach to, and policy study of, life-cycle resource management

We used material flow analysis (MFA) based on a global system boundary encompassing 231 countries and regions to quantify the global transfer of three critical metals (neodymium, cobalt, and platinum) considered vital for low-carbon technologies. International trade data and the metal contents of trade commodities, were used to quantify the global flows of the metals and uadratic programing was applied to ensure the material balance of the metals within each country and

region. The results showed that in 2005 international trade led to global flows of 18.6 kt of neodymium, 154 kt of cobalt, and 402 t of platinum. We identified the main commodities and the top 50 bilateral trade links embodying these metals. Furthermore, we summarized the flows among countries in eight regions of the world (North America, Latin America, Western Europe, Africa, Middle East, Central-Eastern Europe and Russia, Asia, and Oceania).

We conducted an international survey on stakeholders' perception on extended producer resonsibility (EPR) and product stwardship (PS). The items covered in this survey includes the aims of EPR/PS, application and rationale of EPR/PS, type of responsibility, scope of 'producer', and opinions about statements relating to EPR/PS. 426 responses obtained showed that different stakeholders in different countires perceived the concept of EPR and PS in various ways.

3.2 Study of fundamental technologies required for material cycles and waste treatment

We developed a chemical compound–profiling method based on hazardous effects, as determined from i*n vitro* bioassays of wastes and recycled materials. We predicted the physicochemical properties of 22 organophosphorus flame retardants and their environmental fates, and selected some POP-like chemicals from them on the basis of their persistence and long-range transport potential.
In a study of a dual-fuel production system, we developed a bench-scale semi-automatic reactor for recovering bio-oil from waste grease. We also established stable operationing conditions for producing biogas from residues discharged in the oil recovery process.

A lifetime-improvement technique that we developed last year for lead acid batteries was applied to other rechargeable batteries. The technique successfully prolongs battery lifetime.

In developing a low-temperature gasification and reforming technology, we selected combinations of catalytic metallic salts and support matrices that were effective in terms of cost and conversion efficiency. We then evaluated the conversion performance of these combinations in methanation and the reverse water-gas shift reaction from syngas produced by biomass gasification.

3.3 Strategic establishment of information research fundamentals for resource circulation and waste management

We discussed and documented a roadmap for creating databases on resource circulation and waste management during the five-year period of the current mid-term plan. This year we released a database of 32 elements in inorganic industrial wastes (bottom ash, sludge, slag, and fly ash). In addition, we continued collecting data for material flow databases and waste composition

databases. For the former, we collected and compiled long-term data on the amounts of municipal solid waste generated, treated, recycled, and disposed of in Japan. For the latter, we collected and compiled data on the amounts of materials and elements in electronics waste.
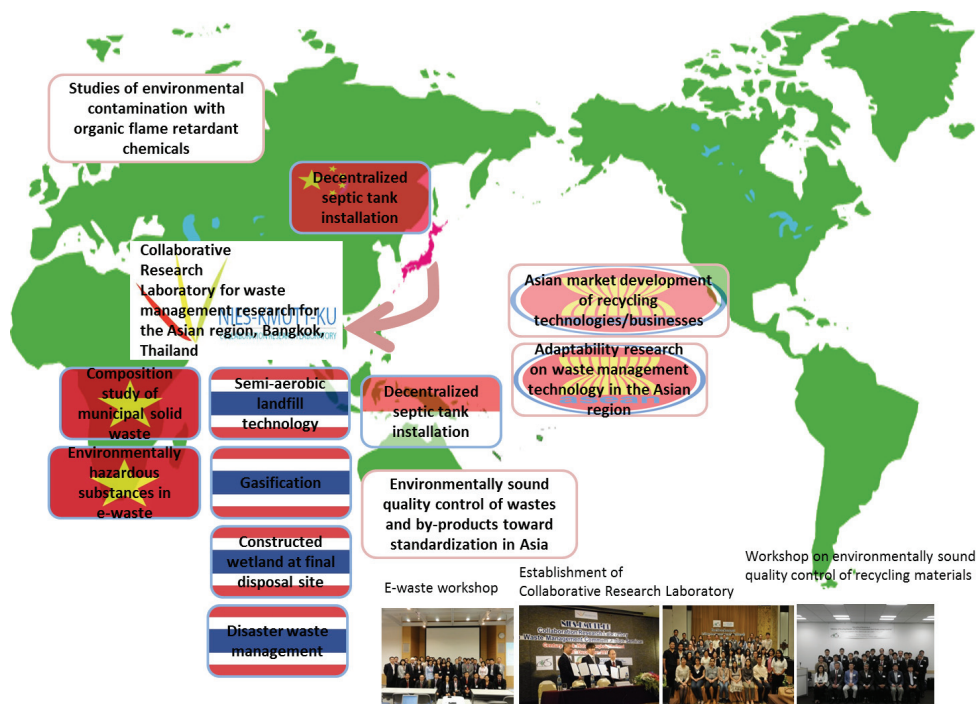
4. Promotion of a collaborative R&D project

4.1 R&D promotion and partnership activities in the Asian region

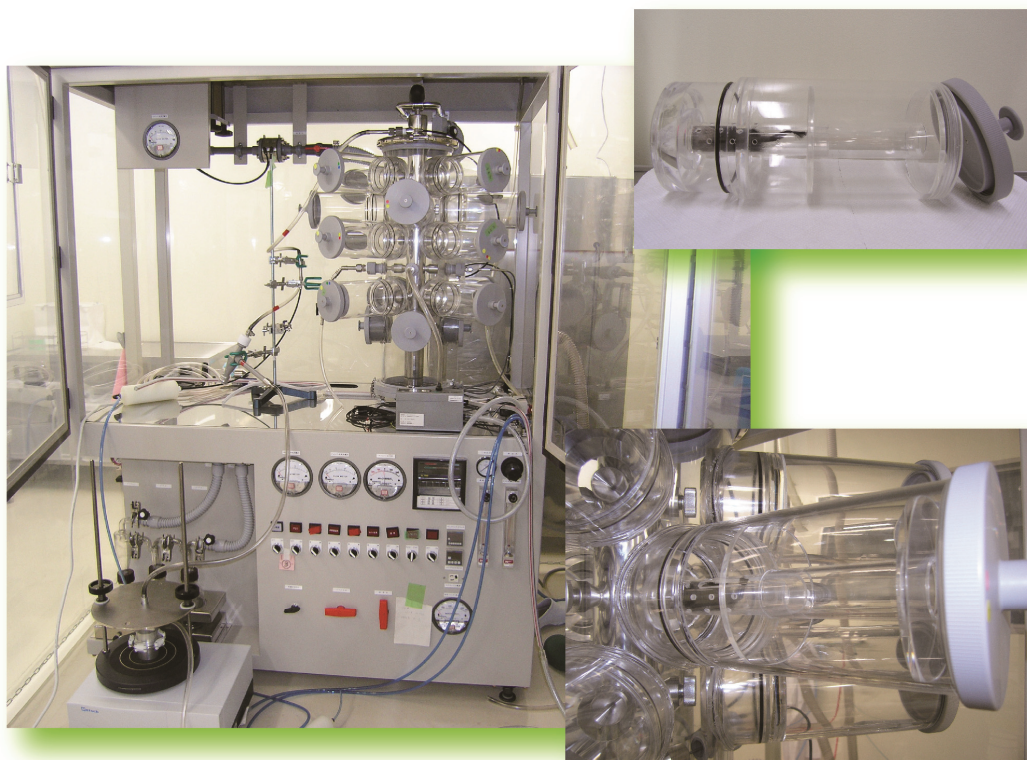This year (FY 2013) was the second year since we launched the Collaborative Research Laboratory in Bangkok, Thailand, in a partnership with two Thai universities that lead the field in waste management. This laboratory allows us to conduct more field-based research and to build the research capacity of researchers from Japan and Thailand. With researchers from Thailand and Singapore, we held a workshop on gasification of waste. We also launched a research project on flood-waste management in mid-scale Asian cities; the 2 year project project will be supported by the Asia-Pacific Network for Global Change Research. Its aim is to support mid-scale city municipalities that encounter floods frequently to plan and prepare for flood-waste management. The Asian region is very vulnerable to natural disasters such as floods and earthquakes. We also plan to further help countries in this region—especially developing countries—to collect case studies to mitigate risks posed by flood waste to the environment and human health. As well as our collaborative work in Thailand, we have strengthened our partnership with Singapore's Nangyang Technological University's Residues and Resource Reclamation Center to enable further research collaboration, especially on the establishment of environmental quality standards for recyclable materials such as slags, incineration ash, and construction and demolition waste.

A summary of our overseas research, including our collaborative research, is given in Figure 4.

Fig. 4 Promotion of overseas research and collaboration with overseas research institutes

Studies of environmental contamination with organic flame retardant chemicals

Decentralized septic tank installation

Collaborative Research Laboratory for waste management research for the Asian region, Bangkok, Thailand

NIES-KMUTT-KU

Composition study of municipal solid waste

Environmentally hazardous substances in e-waste

Semi-aerobic landfill technology

Gasification

Constructed wetland at final disposal site

Disaster waste management

Decentralized septic tank installation

Asian market development of recycling technologies/businesses

Adaptability research on waste management technology in the Asian region

Environmentally sound quality control of wastes and by-products toward standardization in Asia

Workshop on environmentally sound quality control of recycling materials

E-waste workshop

Establishment of Collaborative Research Laboratory

Center for Environmental Risk Research

A nose-exposure chamber designed for short-term inhalation experiments using small laboratory animals such as rats and mice. Animals are constrained in each holder and exposed to aerosolized carbon nanotubes for a short time.

Our research in the field of environmental risk is focused on chemical substances in the environment. To "use and produce chemicals in ways that minimize significant adverse effects on human health and the environment" (World Summit on Sustainable Development 2002), we are focusing on various ways of advancing the evaluation and management of environmental risks. We are elucidating the routes and dynamics of chemical exposure and developing exposure evaluation methods; developing techniques for ascertaining the status and effects of exposure to chemicals in the environment; studying mechanisms for assessing, and developing methods for evaluating ecological risks; studying mechanisms and methods for evaluating adverse effects on human health and assessing health risks; examining policies and management on environmental risks; and gathering information on environmental risks.

In FY 2011, the Center for Environmental Risk Research started the "Research Program on Risk Assessment and Control of Environmental Chemicals." We have been continuing this key innovative research into the evaluation and management of chemical substances. In addition, we have continued to develop environmental research infrastructure for ecotoxicological tests through our reference laboratory, and we are gathering information related to the risks posed by environmental chemicals in our chemical substances databases.

1. Research Program on Risk Assessment and Control of Environmental Chemicals

In recent years, programs for managing chemical substances have incorporated assessments of their impacts on living organisms in the environment. However, the concept of ecosystem protection is not fully entrenched in risk assessment. Accordingly, we need to focus on the development of techniques for evaluating ecological risk. Conventional techniques for hazard assessment might not allow a full evaluation of the effects of nanomaterials on human health and ecosystems. Strategic approaches to managing a variety of chemicals need to be established to enable more effective control of the risks they pose. To address these issues, we have been conducting a research program on innovation in the evaluation and management of chemical substances. This program consists of three research projects (described below as projects 1 to 3), on risks to ecosystems, nanomaterials toxicology, and management strategies for the risks posed by numerous chemical substances, respectively. The project teams work with each other and also work on fundamental research to support environmental action plans.

1.1 Research into methodologies for ecological risk assessment and management of chemical substances (Project 1)

We have been investigating ways of estimating the adverse effects of chemical substances on ecosystems in terms of their potential to make populations of living

organisms extinct or to degrade ecosystem functions. For this purpose, we have made a tri-trophic (three-species) biotic community model that uses the algae–zooplankton–fish system. We call this model the "Tri-trophic Ecological Risk Assessment Model" (TERAM). The model includes the temporal dynamics of chemical exposure to each species, interspecific interaction between adjacent trophic levels (prey–predator interaction), the kinetics of the toxicant (i.e. bioaccumulation) in the fish's body, dose–response functions for various endpoints, and the age structure of fish stocks. As case studies, we have conducted population dynamics simulations for several agrochemicals on the basis of ecotoxicity data and environmental concentrations measured in the Kokai River (Ibaraki, Japan).

Furthermore, we have developed a method of analyzing the relationships between species composition in real ecosystems and levels of exposure to chemicals, as predicted or measured over a wide geographic range by exposure analyses. We have been investigating ways of comprehensively assessing ecological risk by using a biodiversity database on large spatial scales.

Fig. 1
Response traits in relation to environmental factors affect community structure and biodiversity. Moreover, effect traits connected to the response traits induce changes in ecosystem functioning and ecosystem services. We examined the freshwater aquatic invertebrate populations and the hazard levels of herbicides at 203 sites in 32 Japanese rivers. The monitoring sites and relative concentrations of pretilachlor are shown in the map at the lower left. The relationships between the hazard levels of the chemical and population density (top graph) or community structure (CWM) and ecosystem functioning (FDis) (bottom graph) of feeding groups are also shown.
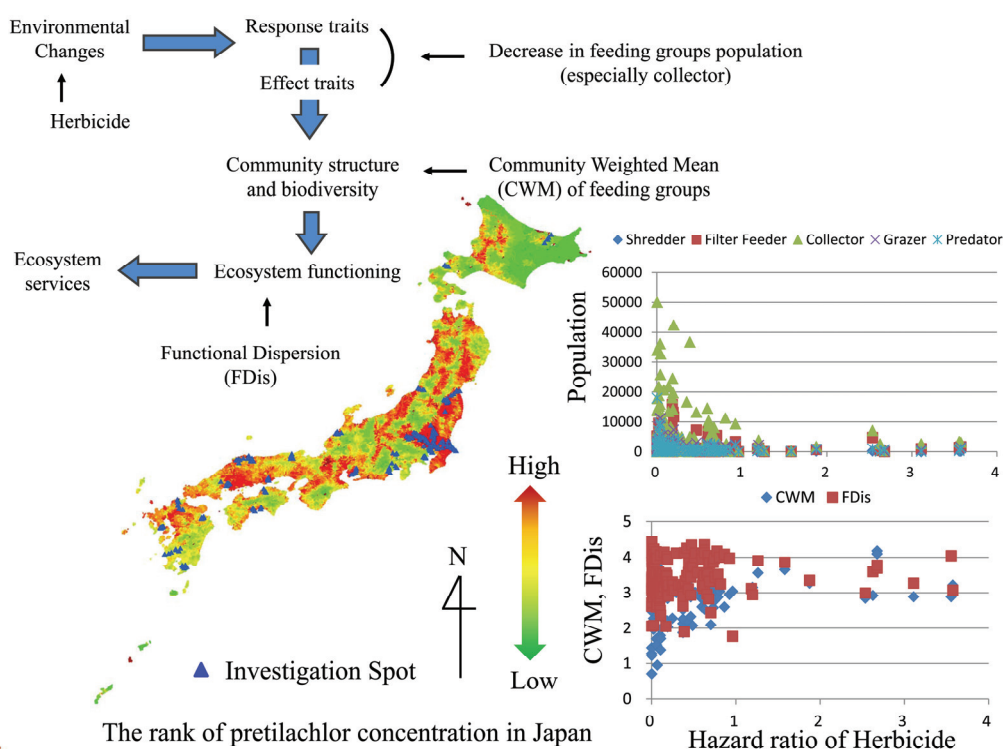
For this purpose, we used a trait-based approach to analyze communities of aquatic invertebrates, and we compared the patterns of trait distribution with herbicide concentrations. To estimate herbicide concentrations in Japanese rivers, we employed the output of a PeCHREM/G-CIEMS (Pesticide Chemicals High-Resolution Estimation Method/Grid-Catchment Integrated Modeling System) model, on which we jointly worked in project 3 (see section 1.3). A

principal component analysis was performed to identify invertebrate traits that were linearly associated with herbicide hazard levels and other river environmental factors. We calculated community weighted means (CWMs) and functional dispersion indices (FDis) in order to examine whether or not herbicide exposure had changed the community structure and ecosystem function.

We compared the hazard levels (concentrations relative to toxicity endpoints) of herbicides, as predicted by G-CIEMS, with the CWM and FDis of each feeding group of benthic invertebrates (Fig. 1). The results showed that an increase in hazard levels in the rivers decreased the variances of CWM and FDis. In the communities analyzed, species intolerant to herbicides were replaced by tolerant species. Furthermore, because tolerant species tended to share similar types of traits with intolerant species, the values of CWM and FDis converged. To conserve ecosystem functions, we need to find the best plan for controlling herbicides and other agricultural chemicals to maintain functional diversity across species in communities.

1.2 Development of a methodology for evaluating toxicity of nanomaterials and research into nanomaterials safety (Project 2)

Our second and current nanotoxicology project started in FY 2011. In our first nanotechnology project from FY 2006 to FY 2010 we used laboratory animals and mammalian cells to investigate the health effects of nanoparticles such as the ultrafine particles in diesel exhaust, carbon nanotubes, and heat-treated asbestos. The current project focuses on the mechanisms of toxicity of carbon nanotubes, the *in vitro* and *in vivo* toxicity of silver nanoparticles and dendrimers, and the use of embryos and sac fry of fish in the ecotoxicological evaluation of titanium dioxide (TiO_2) nanoparticles. In addition, as part of this second project, we intend to develop an *in vitro* system of nanoparticle exposure at the air–liquid interface for toxicity screening of various types of nanoparticles and nanomaterials.

In the carbon nanotube study, mice were injected intrathoracically with multi-walled carbon nanotubes; histopathological changes in the lung tissues and cytokine levels in the thoracic fluid were examined. Lung changes such as increased thickness of the pleura and deposition of new connective tissue were correlated with increases in the levels of monocyte chemotactic protein-1 (MCP-1) and transforming growth factor-β (TGF-β) in the thoracic lavage fluids.

In the silver nanoparticle study, we used murine J774.1 macrophages to investigate the toxicity mechanisms of silver nanoparticles (AgNPs) in mammalian cells. Silver was distributed mainly in metallothioneins in cells exposed to $AgNO_3$ and in high-molecular-weight proteins in cells exposed to AgNPs. Confocal laser microscopic examination revealed that the AgNPs were colocalized with lysosomes. The results suggested that AgNPs were gradually dissolved in the lysosomes of the macrophages without inducing robust

metallothionein synthesis and caused milder inflammatory stimulation than did AgNO₃. We also examined the neurodevelopmental toxicity of silver nanoparticles in an *in vitro* neurosphere assay system, using rat mesencephalic neural stem cells. Exposure to silver nanoparticles inhibited cell migration in a dose-dependent manner, with a linear relationship between migration inhibition and the logarithm of the particle concentration (25 to 2500 ng); the half-maximal inhibitory concentration was 800 ng/mL. Because successful migration is crucial for establishing the neural cytoarchitecture essential for brain function, it will be very important to examine this potential effect on neurodevelopment *in vivo*.

We gave PAMAM (polyamidoamine) dendrimers (Fig. 2), which are spherical nanomaterials branched in fractal form, to mice intranasally and then investigated the brains of the mice for changes in neurological biomarkers. One day after PAMAM administration, the olfactory bulb, hippocampus, and cerebral cortex were collected for microarray and real-time RT-PCR analyses. We found significant alterations of the expression of genes involved in the serotonin–anxiety pathway, TGF-β receptor signaling, prostaglandin-synthesis regulation, complement-coagulation cascades, and chemokine-signaling pathways in the brain tissues of the PAMAM-exposed animals. These findings indicate that exposure to PAMAM dendrimers could have neuronal effects by modulating the expression of genes involved in brain-derived neurotrophic factor signaling pathways in mice.

Fig. 2 Structure of a PAMAM (polyamidoamine) dendrimer with a central core of 1,4-diaminobutaine (Figure kindly provided by Dr. K. Kurokawa.)
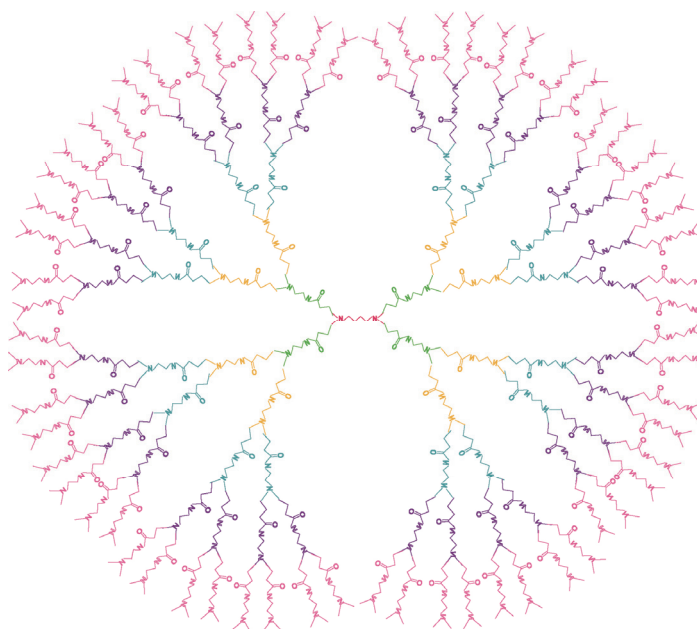
In addition to the toxicological experiments we performed using mammalian cells and laboratory animals, we developed a simulation model to calculate the efficiency of deposition of nanoparticles or fine particles on the surfaces of cells cultured in a Cultex *in vitro* exposure system (Cultex Laboratories, Hannover, Germany). In this system, the apical surface of the cells is exposed to air, whereas

the basolateral surface is located in the culture medium. We also used electron microscopy to measure the deposition efficiency of nanoparticles at the air–liquid interface of cultured cells. The calculated values were in good agreement with the experimental data.

TiO_2 nanoparticles have been widely used in construction materials and cosmetics and are presumably released into the environment, where they could affect aquatic ecosystems. We used a fish embryo model to evaluate the ecotoxicity of TiO_2 nanoparticles. The viability of fish was decreased by TiO_2 nanoparticles or fine particles, but only in the presence of ultraviolet irradiation. The decrease in viability was highly correlated with the total surface area of TiO_2 particles, suggesting that the specific surface area is an important metric for determining the toxicity of these particles.

The overall goal of this project is to develop a health-risk-assessment framework and to help formulate international guidelines for the safety evaluation of nanomaterials. To this end, toxicity testing methods that are suitable for nano-sized particles need to be established, focusing on the shape, dispersibility, and surface charge of nanomaterials.

1.3 Research into strategic approaches to managing the risks posed by chemical substances (Project 3)

Chemical substances differ widely in their effects and characteristics. In this project, we are investigating strategic approaches to managing the risks posed by various chemical substances. The project is based on two major study themes, namely (1) methods of assessing the environmental fates and spatiotemporal distributions of chemicals, and (2) control strategies for chemicals in society. Theme (1) is further divided into three sub-themes. Sub-theme 1-1 focuses on developing a model for predicting spatiotemporal changes in the emissions and levels of agricultural chemicals. Assessment methods that consider temporal variations in emissions and risks to the aquatic environment are studied as major examples of this theme; PeCHREM/G-CIEMS (see section 1.1) models are used. Sub-theme 1-2 focuses on developing and studying emissions and exposure scenarios over the entire life cycles of substances, from manufacture to disposal. Flame retardants and PFOS (perfluorooctane sulfonate) have been selected as the current targets of the study. Sub-theme 1-3 focuses on developing a global multimedia model (the Finely Advanced Transboundary Environmental model; FATE) for predicting the fate of persistent organic pollutants (POPs). We are exploring the development of an assessment methodology based on the global distributions of these substances. Theme 2 focuses on strategies for managing the different dimensions of risk posed by various chemical substances in society. We are exploring the topic in relation to chemical spatiotemporal variation, characteristics of chemical life cycles, the uncertainties of scientific knowledge, and the variable nature of chemical impacts and social receptivity. We intend to

collate the results of these research activities so as to propose a basis for a methodology and ideas for efficiently evaluating and managing the risks posed by chemical substances.

In FY 2013, as part of sub-theme 1-1, we advanced our validation of the PeCHREM/G-CIEMS models by adding more paddy field pesticides to the list of those examined in previous years. For 71% of 45 pesticides we observed agreement within less than one order of magnitude between the 99th spatial percentile of the calculated temporal maximum concentration in each river segment and the observed maximum concentration. As part of sub-theme 1-2 we investigated the emission of semi-volatile compounds from products by using experimental measurements and mathematical modeling. As part of sub-theme 1-3, we improved the FATE model by incorporating a new module that computes POPs biotransfer to marine organisms, including higher-order consumers. In theme 2 we continued our discussion of the possible differences between scientific and societal understanding of the basic concept of risk.

This year we specifically report our achievements under sub-theme 1-2, in which we investigated the emission flux of semi-volatile compounds from products by using experimental measurements and mathematical modeling. We selected brominated flame retardants as model compounds. Emission flux of polybrominated diphenylethers (PBDEs) from TV casings and hexabromocyclododecane (HBCDs) from curtains was measured by using three methods (Fig. 3). Both a diffusive sampler and an emission chamber were considered capable of capturing the total emissions from products, whereas our mockup-room experiments likely captured the emissions remaining in room air but not those deposited on, or adsorbed to, surfaces such as walls and floors. Our mathematical modeling of diffusive emission from product surfaces considered diffusion within polymers, partitioning at the polymer surface, and transport in the air-side boundary layer near the surface. This model underestimated the measured flux by several orders of magnitude in the case of decabromodiphenylether, suggesting that other emission routes need to be incorporated and evaluated. We are continuing to develop and validate the emission models, which should help improve our understanding of the fate of these compounds indoors.

Fig. 3
Comparison of indoor emission fluxes of brominated flame retardants, as measured by three methods. DS, diffusive sampler; CH, chamber experiment; MH, mockup-room experiment. PBDE, polybrominated diphenylether; HBCD, hexabromocyclododecane. The TV casings containing PBDE and the curtains containing HBCD were not identical among the three emission experiments.
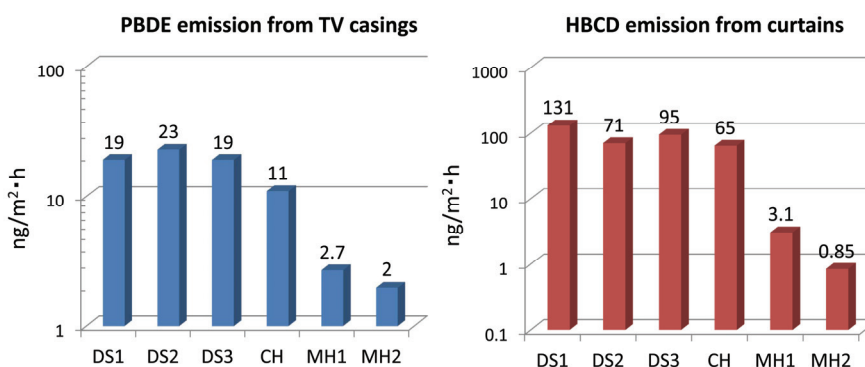
2. Fundamental research to support environmental action plans

To minimize the risks posed by chemical substances we have been running fundamental research projects to develop a comprehensive view of risks to human health and ecosystems. We have also been developing techniques for assessing and managing these risks on the basis of transparent and scientific evidence in line with environmental action plans.

2.1 Development of a new method for estimating emissions of chemical substances to the environment

We aim to develop a new technique for estimating the emissions of chemical substances into the environment by taking into consideration various factors that have not been considered sufficiently. Such factors include emissions from various processes, as well as the changes in these emissions over time. In FY 2013, we established general mathematical representations of chemical emissions from products in various processes, including product use (Fig. 4). The equation includes time of production and time after production as parameters. Wear and loss of product material were considered. On the basis of this equation, we developed the basic design for a system that estimates emissions by considering factors such as the time course of production volume, the distribution of product life, and changes in emission factors. We conducted preliminary case studies to see how these factors affect emission over time.

Fig. 4
Basic representation of chemical emission from products

■ Emission of a substance from products at process *i* (continuous function)

$$\int_{-\infty}^{t_0} \underline{AP(t)} \times \underline{AR_i(t)} \times \{1 - \underline{LT_i(t, t_0 - t)}\} \times \{1 - \underline{FA_i(t, t_0 - t)}\}$$

Volume of products made at *t* — Arrival ratio to process *i* — Cumulative ratio of products transited to next process — Cumulative ratio of product abrasion

$$\times exp\{-\underline{FE_i(t, t_0 - t)} - \underline{FD_i(t, t_0 - t)}\} \times \underline{fe(t, t_0 - t)}\, dt$$

Cumulative ratio of substance emission — Cumulative ratio of substance disappearance — Emission factor

2.2 Research into development and use of a method for predicting the toxicity of chemicals

Under the requirements in countries within the OECD (Organisation for Economic Co-operation and Development) for the assessment of new and existing chemicals, (quantitative) structure–activity relationship [(Q)SAR] models are used to ensure conformity with regulations.

We developed interspecies QSARs for algae and daphnia and for fish and daphnia by using measured acute toxicities for more than 100 aromatic amines and phenols, along with some descriptors. Aromatic amines and phenols show acute fish and daphnia toxicities that are polar narcotic, with some exceptions. However, studies on algae have been limited. We evaluated the QSARs by means of multiregression analyses using the Akaike information criterion (AIC);

descriptors that give the lowest-AIC QSAR can be assumed to explain most accurately the differences in toxicity between species. The high coefficients of determination and low standard errors of the model results suggested that including molecular weight and the indicator variables improved the goodness-of-fit of the lowest-AIC QSARs.

We also developed an approach to extrapolating chronic ecotoxicity from acute ecotoxicity data. This approach uses association analysis to predict the probability that chronic toxicity exceeds a threshold value in the screening of chemicals. From the acute ecotoxicity of a chemical, the approach estimates the false-negative rate (i.e., a probability of yielding wrong prediction that chronic toxicity does not exceed a threshold value when it actually exceeds) for the chemical during the screening process. This approach yields candidate values for assessment factors that maximize the rate of correct screening under given financial limitations.

2.3 Development of biological testing techniques based on mechanisms of action of chemicals

Human health and ecosystems are likely affected by combined exposure to various environmental chemicals, including unintended products. To reduce the risk of combined exposure, we are assessing the total impact of multiple environmental chemicals by *in vivo* and *in vitro* bioassays:

i. Anatomization of the mutagenic or carcinogenic potency of environmental chemicals: By using *in vivo* and *in vitro* bioassay systems, we have analyzed how polycyclic aromatic hydrocarbons contribute to the total mutagenicity or carcinogenicity of chemicals in ambient air.

ii. Analysis of the endocrine-disrupting activities of chemical substances: By using a yeast two-hybrid bioassay system, we have subjected various chemicals detected mainly in aquatic environments to screening for ligand-dependent transcriptional activity.

3. Development of infrastructure for environmental research

To establish infrastructure for assessing and managing the risks posed by chemical substances, we performed the major task of establishing a reference laboratory and developing databases to gather environmental-risk-related information, as follows.

3.1 Establishment of a reference laboratory for ecological hazard assessment

We performed the following projects aimed at furthering our role as a core laboratory that develops standardized eco-toxicity tests in Japan and abroad,

promotes techniques for eco-toxicity testing, improves the reliability and accuracy of toxicity data for environmental risk assessment, and supports the development of infrastructure such as testing laboratories in Japan.

i. **Collaboration and cooperation with institutions inside and outside Japan.** We are collaborating with the relevant institutions from Japan and abroad to develop new test methods using the latest research trends and social scenarios associated with environmental risk. In FY 2013, we investigated 15 industrial samples by using whole-effluent toxicity testing in collaboration with nine testing laboratories.

ii. **Promotion and improvement of eco-toxicity tests.** We are working on promoting elementary knowledge and techniques for eco-toxicity tests and improving the reliability and accuracy of test data. As part of these activities, we held our fifth and sixth practical training seminars (in June and October) to teach elementary knowledge and techniques for eco-toxicity testing on fish and daphnids (water fleas) through lectures, practical training, and tours of our laboratory. Both training seminars were attended by more than 30 participants from various organizations (companies, research institutes, and universities) in order to learn about eco-toxicity testing and they benefit from the enjoyable seminars. They also took advantage of the opportunity to form new relationships.

iii. **Development of, and support for, infrastructure for eco-toxicity tests.** We have developed an efficient system for maintaining and supplying the organisms (e.g. medaka and water fleas) used in tests in Japan and abroad. We provide these organisms to other testing laboratories.

3.2 Development of chemical substance databases and dissemination of data

As part of this project we continuously updated and improved our chemical substance database and a publicly-accessible website, Webkis-plus, as well as another, related database and a website named EnvMethod, which covers methods for analyzing various chemical substances in the environment. We have also been developing new databases and websites featuring the results of our research efforts. In FY 2013 our database work was focused on the following:

i. We updated and improved the Webkis-plus database. The latest information was added, including shipment volumes of agricultural chemicals; environmental concentrations from a survey by the Ministry of the Environment titled "The State of Chemical Substances in the Environment;" amounts of chemical substances manufactured and imported; PRTR (Pollutant Release and Transfer Register) emissions and transportation amounts; and the results of risk evaluations.

ii. We updated and improved the EnvMethod database. Details of the analytical methods used in the environmental surveys in "The State of Chemical Substances in the Environment" were added to the database.

Center for Regional Environmental Research

Observation of vertical changes in turbulence intensity on the continental shelf of the East China Sea using a TurboMAP (Turbulence Ocean Microstructure Acquisition Profiler)

Sediment core sampling on the shore of Tonle Sap (Great Lake) in Cambodia

1. Outline of the Center for Regional Environmental Research

Human activities have a substantial impact on both human life and ecosystems through environmental media such as atmosphere, water, and soil. To provide a sound scientific basis for minimizing the environmental impact due to human activities, the Center for Regional Environmental Research is investigating the mechanisms by which regional environmental issues develop at multiple scales (local, urban, and trans-boundary) in both Asia and Japan. Furthermore, we are studying solutions to these regional environmental issues and the application of these solutions to the real world.

The Center consists of seven sections (Regional Atmospheric Modeling Section; Regional Atmospheric Environment Section; Urban Atmospheric Environment Section; Water Quality Management Section; Lake and river Environment Section; Marine Environment Section; Soil Environment Section; and Regional Environmental Systems Section) and has two Principal Researchers.

In FY 2013, we implemented many research projects covering a wide range of regional environmental issues. Our main research projects were: one Priority Research Program (East Asian Environment Research Program); two Advanced Research Programs (Basin Ecosystem Functions Research Program and Eco-city Systems Research Program); and three cross-discipline research projects (Coordinated Study of Environmental Emissions and Behavior and Effect of Metals in High-tech Products Focusing on their Lifecycles, Flux Estimation from Sediment in Nutrients and Global Warming Gas by MRI and Stable Isotope Analysis, and A Study of PM in Urban Atmosphere for Reduction of PM and Evaluation of Toxicity and Health Impact of PM Based on Chemical Composition). Of particular importance were research projects concerning multimedia modeling and long-term monitoring of radioactive substances emitted from the Fukushima Daiichi Nuclear Power Plant. Most of the projects are collaborations with other centers at NIES. Additionally, there are two long-term monitoring programs: Regional Atmospheric Modeling Program and GEMS (Global Environment Monitoring System)/Water Program, which is a collaboration with the Center for Environmental Biology and Ecosystem Studies.

Below, we give brief accounts of some of the important results of the Center's research in FY 2013.

2. Research Programs

East Asian Environment Research Program

Japan is closely connected to Asia both geographically and economically, and rapid development is expected in Asia in the future. Therefore, as part of East Asia, Japan needs to help preserve the East Asian environment in order to

promote environmental security and a sustainable society throughout all of Asia. In this context, the East Asian Environment Program conducts research on multi-scale air pollution in East Asia (Project 1) and on wide-scale anthropogenic impacts on marine ecosystems in the East China Sea and the seas around Japan (Project 2). Project 1 aims to clarify the current status and formation mechanisms of trans-boundary air and water pollution in East Asia by means of field observations and model simulations. Project 2 aims to reveal the relationships between environmental burdens and their impacts, and to suggest solutions that will benefit marine ecosystems. We expect that the program as a whole will help to solve wide-scale environmental issues in East Asia.

Project 1: Analysis and evaluation of multi-scale air pollution by integration of observations and modeling

In Project 1, we are examining air quality issues ranging from local to hemispheric scales, with particular emphasis on trans-boundary transport of air pollutants and their impact on human health and ecosystems in East Asia.

The Ozone Monitoring Team has been analyzing the observations of tropospheric nitrogen dioxide (NO_2) made by satellite sensors over past decades and has used them to detect interannual variability in nitrogen oxides (NO_x) emissions from boreal forest fires in Siberia. One of the major constraints on ozone production is the availability of NO_x in fire plumes, because NO_x is a key precursor for ozone production. However, the levels of NO_x and their variability and distributions near fire-prone regions have not previously been extensively examined, because measurements are generally not conducted close to fires. Moreover measurements at remote downwind sites are of limited use because of the short lifetime of NO_x, and measurement of NO_x itself is not widely done by operational monitoring networks. We detected substantial enhancements of NO_2 levels over eastern Siberia in 1998, 2002, and 2003, when there were large fires. The locations of these enhancements corresponded well to the distributions of NO_x in the Global Fire Emissions Database (GFED), which is one of the best biomass burning inventories available (Fig. 1). However, the amount of NO_2 over fire-prone regions tends to be lower than that estimated by chemistry-transport models incorporating NO_x emissions from the GFED inventory, highlighting the need to test the emission factors and the diurnal cycles of NO_x emission from the fires.

The Aerosol Measurement Team has set up an aerodyne aerosol mass spectrometer (Q-AMS) in the city of Fukuoka, one of the biggest cities in western Japan, to monitor aerosols produced within the city and distinguish them from those transported over long distances from the Asian continent. We analyzed the aerosol chemical composition and size distribution (SD) from the spring data. When the sulfate concentration was high and the peak mode of the SD was about 700 nm in terms of vacuum aerodynamic diameter (dva), the air mass, the trajectory of which was calculated by using the NOAA ARL HYSPLIT (National Oceanic and

Atmospheric Administration Air Resources Laboratory Hybrid Single Particle Lagrangian Integrated Trajectory) model, was transported from the Asian continent toward Japan. When the organic signal and nitrate concentrations were high and the peak modes of SD were around 200 nm and 700 nm in dva, the air mass was transported from the Kyushu/Fukuoka area. Analysis of the chemical composition and the SD suggested the origin of the air mass. The organic signal of the aerosol chemical composition is considered to be a marker of aging, which in turn is an indicator of the duration of air mass transport. The organic signal was analyzed by using the Positive Matrics Factorization (PMF) method. The PMF method uses oxygenated organic aerosol (OOA), which is observed in aged organic species, and hydrocarbon-like organic aerosol (HOA), which is observed in fresh (non-aged) organic species. The percentage of OOA was about 85%, and that of HOA was about 15%, when the air mass was from the Asian continent. The percentage of OOA was about 70%, and that of HOA was about 30%, when the air mass was from the Kyushu/Fukuoka area. Thus the OOA content was dominated, and the transboundary air pollution influenced, largely by the air quality in Fukuoka.

Fig. 1 (Left) Enhancement of NO_2 levels as a result of forest fires in Siberia in summer 2002. (Right) Distributions of NO_x emissions estimated by using the GFED inventory
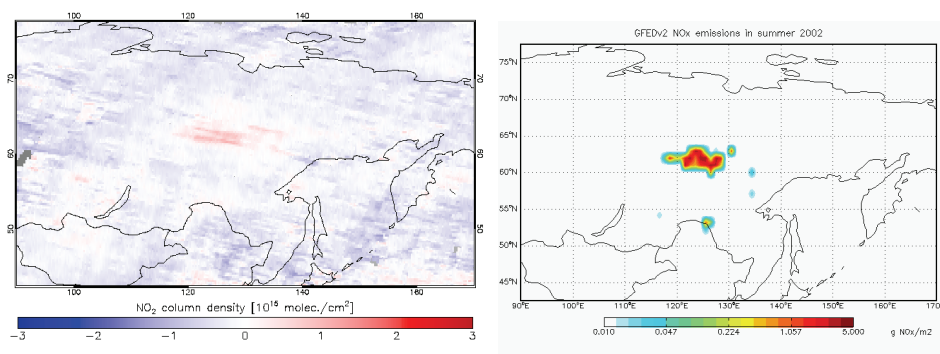
The Modeling Team has completed the preparation of emissions data for the production run that includes REAS (Regional Emission Inventory in Asia) ver. 2.1 for anthropogenic emissions in Asia, JATOP (Japan Auto Oil Program) data on anthropogenic emissions in Japan, GFED ver. 3.1 for biomass burning emissions, and MEGAN (Model of Emissions of Gases and Aerosols from Nature) ver. 2.1 for biogenic emissions. We performed simulations with this emissions dataset for 2010 and 2012, years for which substantial numbers of observations are available. The calculations were done with the WRF–CMAQ (Weather Research and Forecasting Congestion Mitigation and Air Quality) modeling system, which was developed last year and has horizontal resolutions of 60 km for the whole East Asian region and 15 km for the area around Japan. To validate the modeling system, we compared the calculated O_3 and $PM_{2.5}$ concentrations with the observation data. The modeling system showed good overall performance in simulating the concentration of surface O_3 and its seasonal transition over East Asia. However, some overestimations occurred around Japan in summer; these might have been related to excessive transport of O_3 from the stratosphere or to a small velocity of deposition of O_3 into the surface of the

ocean. The modeled concentrations of total $PM_{2.5}$ showed a reasonable west to east transition in Japan but were underestimated by dozens of percent, mainly because of the underestimation of sulfate and organic aerosol levels. We have performed several trial runs to correct these biases in the concentration of O_3 and $PM_{2.5}$ but our work on the problem is currently ongoing.

Project 2: Study of wide-scale anthropogenic impacts on marine ecosystems in the East China Sea and the seas around Japan

There is concern that increasing anthropogenic pollutant loads from terrestrial East Asia may cause wide-scale degradation of marine environments, as exemplified by the occurrences of red tides on the continental shelf of the East China Sea (ECS). This project aims to develop integrated numerical models that can simulate the impact of human activity in China's Yangtze River basin on the environment in the ECS and the seas around Japan. For this purpose, we intend to (1) estimate natural and anthropogenic emissions of nitrogen (N) and phosphorus (P) in the basin and their discharges to the marine environment, and (2) clarify the mechanisms of transport of these emissions to the continental shelf in the ECS and their impact on marine ecosystems. We made the following progress in our research in FY 2013.

To estimate anthropogenic emissions of N in the Yangtze River basin, we estimated the total sources of N in the river basin, including N fertilizer application, human and animal wastes, bio-fixation, crop residues, and atmospheric N deposition. For this purpose, we collected decadal statistical data for 1981, 1991, 2001, and 2011 at the county level and yearly statistical data for the period 1978–2011 at the provincial level. The results showed that total N sources have increased by 0 to 50 kg/ha over most of the area of the Yangtze River basin during the last 40 years. Moreover, they have increased dramatically, by 50 to 300 kg/ha, in the Sichuan Basin, the Han River Basin, Poyang and Dongting lakes Basin, and the Yangtze Delta (Fig. 2). N fertilizer is the major contributor of N emissions to the basin, but this varies regionally. For example, in Qinghai Province in the upper reaches of the Yangtze River basin, animal waste is the major source, having contributed about 86% in the 1980s and 79% in the 2000s. In Sichuan Province, in the upper-middle reaches, N fertilizer and animal wastes are both major sources of N emissions, having contributed about 35% and 32%, respectively, in the 1980s and 39% and 30% in the 2000s. In the middle and lower reaches, N fertilizer is, as expected, the major contributor: its percentage contribution was 45% in the 1980s and 55% in the 2000s in Hubei Province in the middle reaches, and 54% in the 1980s and 61% in the 2000s in Jiangsu Province in the lower reaches. Generally, total N emissions in the whole basin increased dramatically in the 1990s and then stabilized at a high level in the 2000s. Notably, atmospheric N deposition has increased over the middle and lower reaches in recent decades. For instance, the percentage atmospheric N deposition went from 4% in the 1980s to 7% in the 2000s in Sichuan Province in the upper-middle

reaches; from 7% to 8% in Hubei Province in the middle reaches; and from 5% to 6% in Jiangsu Province in the lower reaches.

Fig. 2 Spatial changes in total N emissions from 1981 to 2011 in the Yangtze River Basin
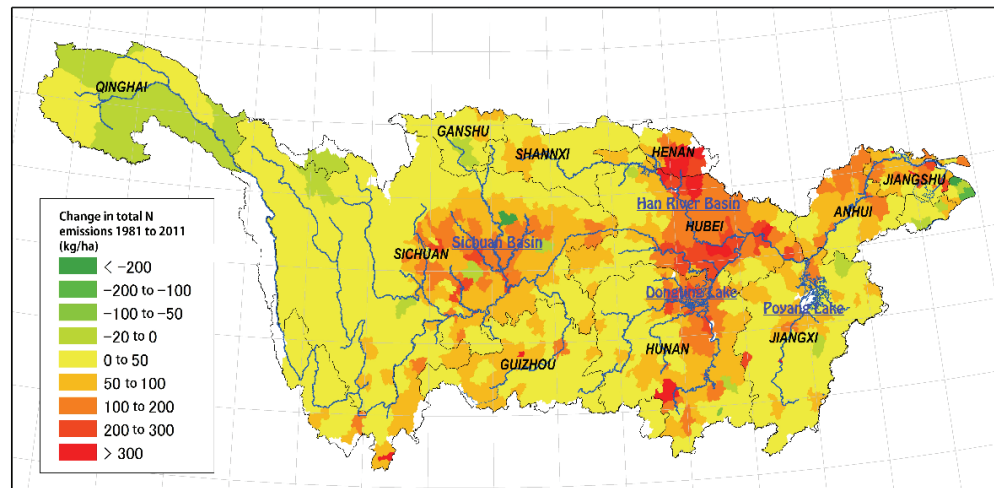

To gain an understanding of the current water quality and planktonic ecosystem in the ECS, we performed field observations over the continental shelf in July 2013. During this cruise, we found subsurface accumulation of the dinoflagellate *Prorocentrum dentatum*, with chlorophyll concentrations >20 µg/L, at about the depth of the pycnocline. This accumulation was produced by extension of the Yangtze Diluted Water over the shelf. Incubation testing in a large-scale tank with a vertical seawater density gradient showed that downward migration of this dinoflagellate from the surface stopped at the middle depth of the tank, where the seawater density was only 0.3 kg/m^3 higher than that at the surface, implying that the strong density stratification on the continental shelf of the ECS contributes partly to subsurface accumulation of the dinoflagellates.

We modified our ocean dynamic model of the ECS to consider the effects of the tidal current on vertical mixing; to allow for high spatial resolution; and to enhance the reliability of the simulation results by assimilating FRA-JCOPE2 (Fisheries Research Agency – Japan Coastal Ocean Prediction Experiment 2) reanalysis data. These improvements resulted in better reproducibility of the vertical profiles of temperature and salinity—particularly those in the bottom mixed layer. We also assessed the performance of the Mellor-Yamada turbulence scheme in the vertical mixing processes currently incorporated into our ocean model. For this assessment, we used both the turbulence intensity results obtained from our field observations in the ECS and the results obtained from numerical experiments on the bottom mixed-layer processes using the large-eddy simulation technique. Our assessment revealed that a more accurate turbulence scheme is needed to increase the reproducibility of the vertical mixing, and thus the vertical material transport processes, in the ECS.

To elucidate the responses of water quality and the planktonic ecosystems in the

ECS to changes in pollutant loadings from the Yangtze River basin, we performed sensitivity simulations with our ocean model. Simulations using reduced pollutant loadings revealed decreased occurrences of algal blooms in the Yangtze estuary and the Yellow Sea, with only moderate reductions in dinoflagellate biomass in the central ECS (Fig. 3). Our results suggest that the ECS ecosystem is highly dependent on the oceanic nutrient supply.

Fig. 3 Simulated suppressive effects of pollutant-loading reduction on the biomass of diatoms and flagellates in the ECS
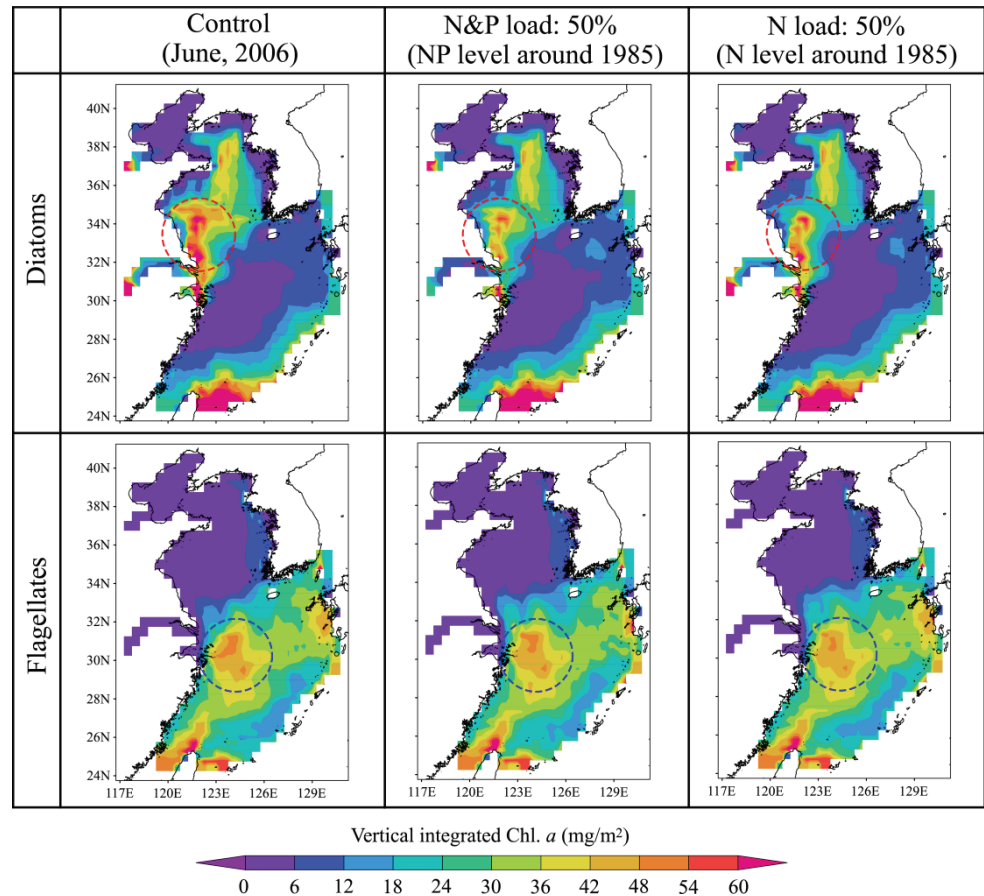
Basin Ecosystem Functions Research Program

To develop methodologies for the quantitative assessment of ecosystem function, we are focusing on material and water cycles for basin ecosystems (e.g. forests, lakes and wetlands, rivers, and coastal regions). We are also performing long-term strategic monitoring and assessing the relationships between ecosystem function and various environmental factors. On the basis of these assessments, we intend to develop methodologies and techniques for evaluating the health of basin ecosystems. One of our long-term aims is to determine the optimum conditions for the restoration and conservation of ecosystems.

Project 1: Quantitative evaluation of links between ecosystem functions and environmental factors in natural ecosystems

We investigated the vertical distributions of ammonia-oxidizing archaea (AOA) and bacteria (AOB) in the F–H horizons (thickness <2 cm) and the A horizon (0 to 5 cm) of soil samples collected in May 2012 from parts of a conifer plantation that had been intensively thinned (by 67%) or left unthinned. The abundance of the genes encoding ammonia monooxygenase subunit A (amoA) of AOA and AOB was estimated by using quantitative real-time polymerase chain reaction. AOB *amoA* gene copy numbers in the A horizon of the unthinned plantation were very low, whereas AOA *amoA* gene copy numbers were high. Thus, the ratio of AOA to AOB *amoA* gene copies in the A horizon was much higher in the unthinned plantation than in the thinned one (Fig. 4). The distribution of AOA and AOB in the A horizon clearly differed between the intensively thinned and unthinned areas. This difference might affect biogeochemical nitrogen cycles in conifer plantation soils.

Fig. 4 Vertical distribution of AOA and AOB of the F–H and A horizons in intensively thinned or unthinned conifer plantations (*n* = 3)
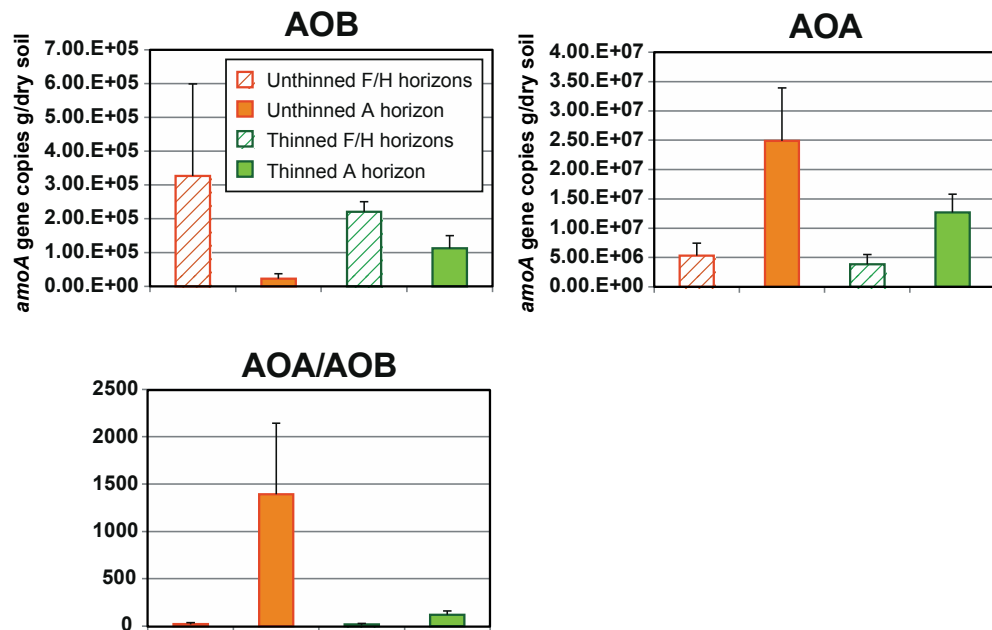
We also focused on the interactions of variations in algal species in the water column with pore-water quality and microbial community structure in the sediments by analyzing water-column monitoring data and the water quality profiles in sediments. In Lake Kasumigaura, the densities of algal cells (especially diatoms) in the water column increased dramatically in 2006, and the sediments turned anaerobic from the effects of the settled algae. Subsequently, in 2007, the concentration of ammonium ions in the sediment pore water was increased sharply by the presence of the dominant species of anaerobic microorganism, *Firmicutes*, which has proteolytic activity. The concentration of ammonium ions also increased in the water column because of excess release

from the sediments. This release may have induced the explosive water bloom in 2010. In other words, it was likely that the dramatic increase in diatom density indirectly triggered the water bloom over several years.

We investigated the effects of a green tide resulting from the invasive algal species *Ulva ohnoi* on ecological function by comparing a site where *Ulva* had accumulated with a sandy bare site on the Yatsu tidal flat. On the site where the *Ulva* had accumulated, we found an increase in sediment organic matter (SOM) between winter and summer. The increase in SOM likely occurred as a consequence of on-site decomposition of large amounts of dead *Ulva*. In contrast, no seasonal change in SOM was observed on the sandy bare site, and the amount of SOM there was lower than at the *Ulva* site. We also evaluated the sediment decomposition activity by using a cotton-strips weight loss assay (Harrison et al. 1988). The results indicated that the activity at the *Ulva* site was more than equivalent to that at the sandy bare site through the year. Although the distribution of SOM varied on the tidal flat, the stable carbon and nitrate isotopic values in a dominant macrobenthic organism (*Batillaria cumingi*) were the same at the two test sites. This indicates that the species on sandy bare sites feed on SOM derived from the sites where *Ulva* accumulates.

Project 2: Development of a strategic environmental assessment technology and its application to watershed restoration

Against the backdrop of rapid economic growth, riparian countries of the Lower Mekong Basin (LMB), including Laos, Thailand, Cambodia, and Vietnam have proposed the construction of a large number of hydroelectric dams within the basin to meet the increasing demand for electricity. Although dam construction is typically associated with adverse effects on local riverine fisheries and on the ecological services that those fisheries provide, it has been argued that a modestly eutrophic huge reservoir created as a result of dam construction can be productive enough to compensate, through aquaculture production, for the loss of fisheries. However, there remain many unanswered questions regarding the nutrient cycle of reservoirs in the tropics, although this cycle is the key to successful and sustainable fisheries.

Our previous studies have revealed positive correlations between fish yield (an indicator of fish production) and primary production, and between primary production and total phosphorus content in the waters in several existing reservoirs in the LMB. Therefore, it is important to identify the factors limiting total phosphorus content and to better understand the reaction mechanisms in the nutrient cycle (especially the phosphorus cycle) in these reservoirs.
Water and surface sediments (at 0 to 3 cm depth) were sampled from five reservoirs in Thailand and Laos to investigate the phosphorus content and its chemical forms. The water was collected close to the deepest points of each

reservoir (hereafter referred to as the reservoir's center) and on the shores. Sediment was collected from the following three environments: above the water level (i.e. in the hinterland), on the shore, and at the reservoir's center. Samples were also collected from a natural lake (Tonle Sap in Cambodia) as a reference.

Total phosphorus (TP) levels were generally low in the reservoir water, but they were consistently higher along the shore than at the reservoir's center (Fig. 5). TP was composed mostly of organic phosphorus, presumably originating from decomposing phytoplankton. The phosphorus in the shore samples likely originated from aquatic plants and other organisms, as well as from waste materials from various human activities in the hinterland.

Fig. 5 Relationship between water total phosphorus (TP) on the reservoir shore and center. The dotted line passes through the origin with a slope of 1. SI, Sirindhorn; LA, Lam Pao; UB, Ubol Ratana; HU, Huai Luang; NN, Nam Ngum; and TS, Tonle Sap
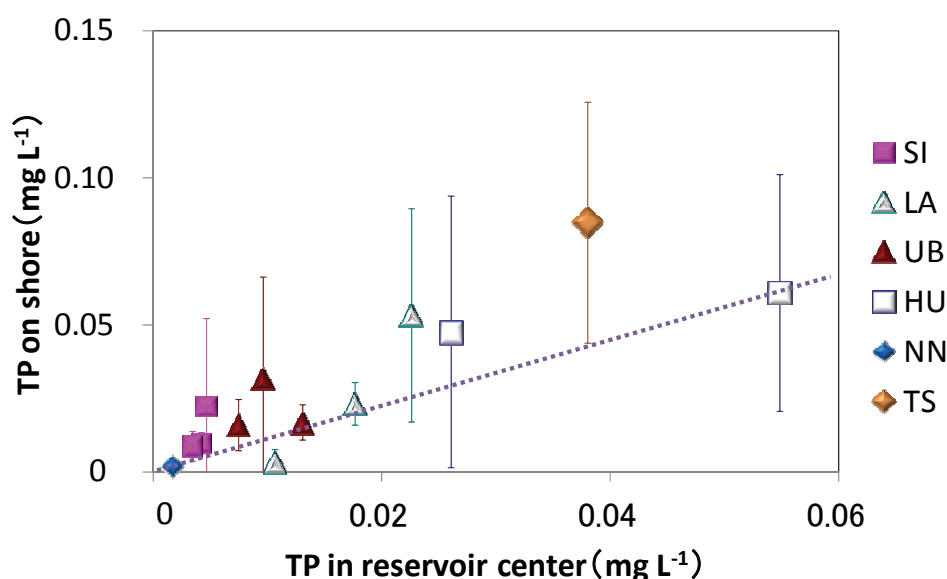
Unlike the case in the water samples, TP in the sediments increased from the shore to the reservoir's center (Fig. 6). However, the ratio of organic phosphorus (derived mainly from decomposing aquatic organisms and organic matter in the soil) to TP was higher on the shore than at the reservoir's center. This is because large quantities of organic matter are constantly supplied in the form of organisms, plant debris, and soil from the hinterland to the shore (Fig. 6). This transition from organic to inorganic phosphorus toward the reservoir's center was observed only in the reservoirs and not in Tonle Sap, where the ratio of organic phosphorus to TP was uniformly low (< 0.4), regardless of the sampling location.

From the patterns of phosphorus content and its chemical form in the water and sediment, we hypothesized that phosphorus in the lake or reservoir sediment is incorporated into the food web through various biological processes involving organisms such as bacteria, algae, protozoa, macroinvertebrates, and fishes, and spreads throughout the water body. Subsequently, organic phosphorus precipitated at the lake bottom is partially recycled by the food web after being decomposed

and mineralized by microbes. If this hypothesis is supported, then the exogenous supply of organic phosphorus from the hinterland and shore becomes the major determinant of fish production in reservoirs and lakes in the LMB. To better understand the mechanism of phosphorus incorporation into food webs and the differences in this regard between natural lakes and reservoirs, as well as to help establish strategies for managing nutrients for sustainable fisheries, we need additional studies—specifically, continued field monitoring and ecological modeling.

Fig. 6 Relationship between sediment total phosphorus (TP) and the proportion of organic phosphorus to TP in samples taken from the shore and the reservoir's center
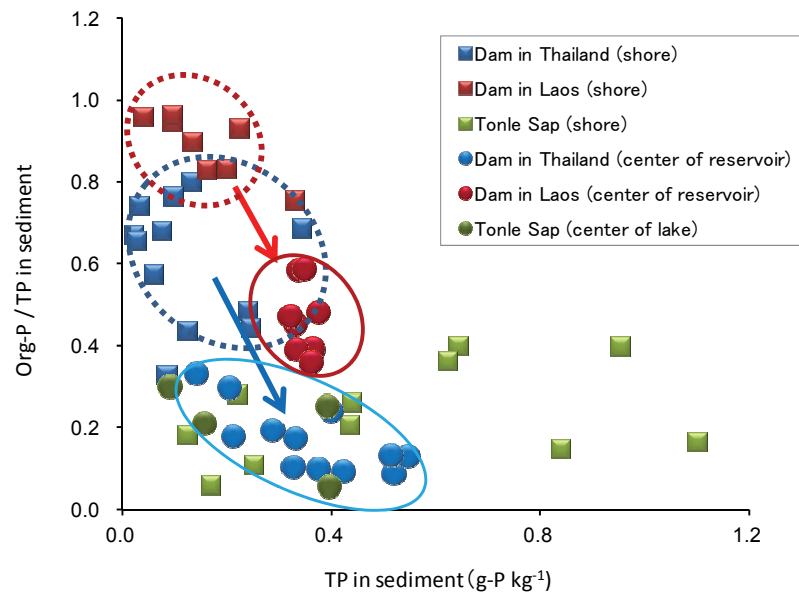
References

A.F. Harrison, P.M. Latter, D.W.H. Walton (Eds.), Cotton Strip Assay: An Index of Decomposition in Soils, Institute of Terrestrial Ecology, Symposium No. 24, Grange-over-Sands, Cumbria, UK (1988), 176

Center for Environmental Biology and Ecosystem Studies

Tibetan grassland

Potentilla nivea

Androsace tapete

Sensitivity of vegetation green-up to temperature (days/°C)
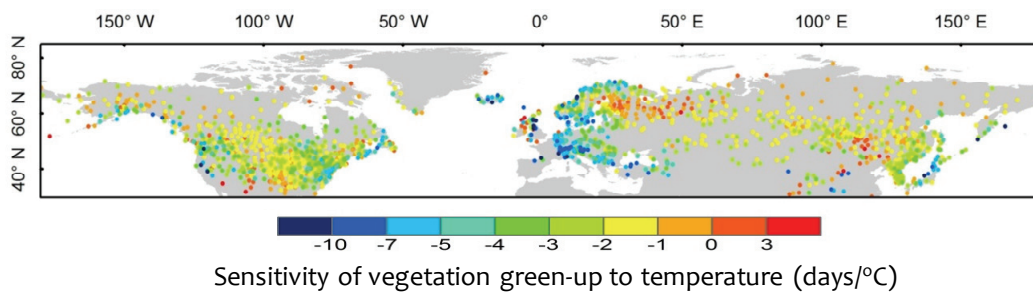
Examining the impacts of climate change on plant phenology and population dynamics in alpine grassland ecosystems.

Center for Environmental Biology and Ecosystem Studies

The Center for Environmental Biology and Ecosystem Studies (CEBES) performs various types of research aimed at understanding ecosystem structure and function and the relationships between these two factors, and the effects of human activity on biodiversity.

The center is responsible for leading the Biodiversity Research Program (one of the five Priority Research Programs in the third NIES five-year plan), with the aim of helping achieve the Strategic Plan for Biodiversity 2011–2020, including the Aichi Biodiversity Targets of the Convention on Biological Diversity. CEBES is also studying ecosystem management in the Mekong River watershed in partnership with the NIES Center for Regional Environmental Research. Moreover, CEBES conducts long-term ecological monitoring, preserves biological resources, and establishes biodiversity databases. We have also conducted research into the effects of the Great East Japan Earthquake on organisms and ecosystems.

In July 2013, CEBES signed a memorandum of understanding with the Japan Committee for the International Union for Conservation of Nature and Natural Resources (IUCN-J), agreeing to cooperate in actions to conserve biodiversity. On the basis of this agreement, CEBES joined the Niju-Maru Project, a project that is led by the IUCN-J and aims to facilitate the conservation activities of various sectors. Through this framework, we intend to disseminate our research outputs to the public and gather public feedback.

1. Biodiversity Research Program

The Biodiversity Research Program aims to elucidate the current status of biodiversity, predict its future, and propose reliable and effective methods for its conservation on scientific bases. Our tasks are to develop methods and protocols for monitoring the status of biodiversity at the genetic and landscape levels; assess the state of biodiversity on a broad scale and analyze scenarios for future prediction; and elucidate the effects of anthropogenic disturbances on biodiversity and find ways of managing these effects. The following are examples of our progress in 2013.

1.1 NGS analysis of environmental DNA from Lake Kasumigaura

The recent development of next-generation sequencing (NGS) technology has allowed us to obtain large-scale sequencing data and has become an essential tool for genome analysis. NGS is particularly useful for assessing microbial diversity in various environments through the analysis of large-scale sequences from environmental DNA (eDNA) containing various microbial genomes. Here, we used NGS analysis to confirm its usefulness for long-term plankton monitoring in

Lake Kasumigaura. We collected freshwater samples for eDNA preparation and NGS sequencing from a monitoring site. Sequence treatment and analysis were performed on the 3996 sequences obtained, and the results were assembled into taxonomic groups (Fig. 1A). Non-photosynthetic microorganisms (colorless protists) accounted for more than 40% of each sample, suggesting their ecological significance. Comparison of the NGS results with light microscopic observations of the phytoplankton revealed a good correspondence between both methods regarding the dominant species (e.g. *Cryptomonas* spp., *Cyclotella* spp., *Aulacoseira* spp., and *Chlamydomonas* spp.). Cryptophytes (Fig. 1B) were often recorded during monitoring observations, but their species diversity was unclear owing to their small size (around 10 μm) and morphological plasticity. The NGS results clearly revealed their abundant diversity. Although some green algae (Fig. 1C) were well identified by light microscopy, they were rarely detected in the NGS data. There must therefore be certain artificial biases during eDNA preparation processes such as DNA extraction or PCR amplification. NGS analysis has been demonstrated to be useful for monitoring the overall diversity of microorganisms, including even colorless protists, although important issues, such as establishing standard protocols and accumulating a reliable database for taxonomic assignment, remain to be tackled in future.

Fig. 1
(A) Taxon composition at the class level in three samples from Lake Kasumigaura, as determined by NGS data analysis. "Colorless protists" and "Others" contain various taxa.
(B) Light micrographs of cryptophyte species.
(C) Light micrographs of various green algae.
Scale bars = 10 μm
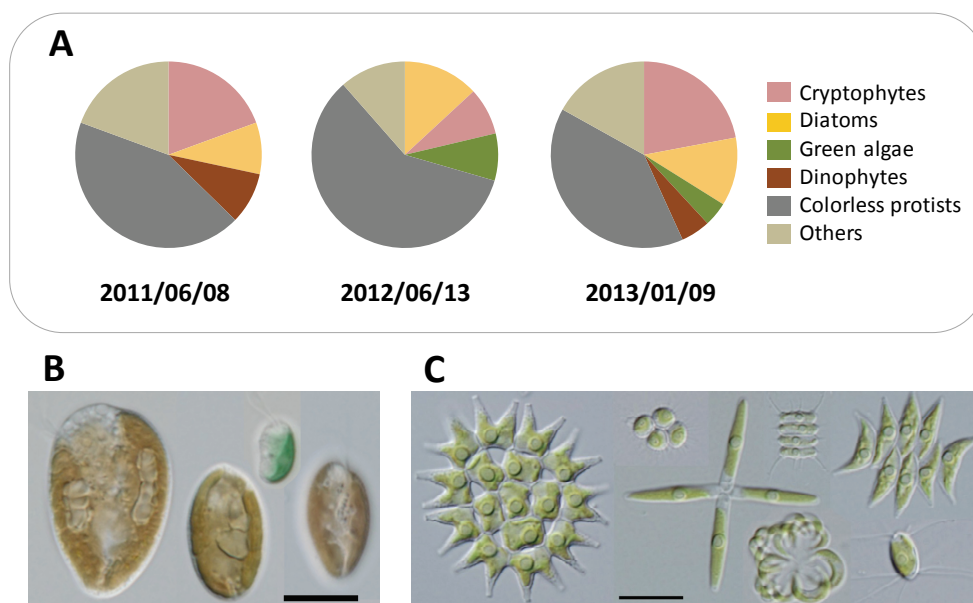
1.2 Spatial prioritization for biodiversity conservation based on an incomplete dataset

To prioritize areas for nature conservation, we need spatial distribution data on various ecosystem components, such as plant and animal species and vegetation types. The ideal would be to collect data covering entire regions of interest and all species to be considered, at high spatial resolution. However, the reality is far from ideal. Normally, both the available data and the resources to collect new

data are far from sufficient. Therefore, we analyzed the effectiveness of conservation area prioritization determined by using limited data. We used a dataset covering all of Japan at a spatial resolution of 10 × 10 km. Focal species were categorized into 10 high-order taxa, including plants, mammals, birds, and butterflies. The number of data was first reduced by filtering species. Areas were then prioritized on the basis of the reduced data, and the number of species covered by a selected area was counted. One of the main findings is that areas of high priority for covering rare species also include common species, but not vice versa: areas selected for their high abundance of common species are not adequate for conserving rare species (Fig. 2). These results demonstrate the need for more data on rare species.

Fig. 2 Relative amounts of species covered by protected areas prioritized by using a limited species distribution dataset. (A) Dataset reduced by filtering out common species. (B) Dataset reduced by filtering out rare species
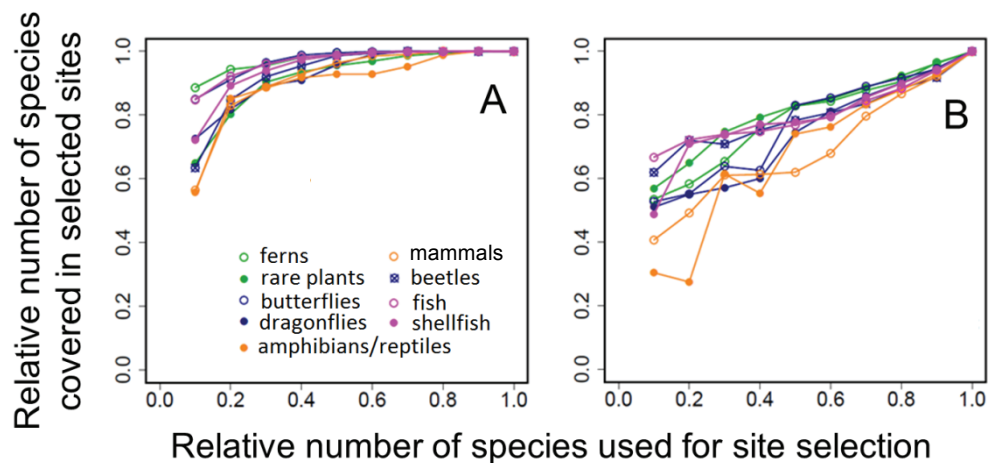
1.3 Vegetation in warmer environments shows increased temperature sensitivity of spring phenology in the Northern Hemisphere

The spring phenology of vegetation, often referred to as the leaf green-up day, is considered to be responsive to climate change, particularly temperature elevation. Changes in the spring phenology of vegetation can have various consequences on terrestrial ecosystems and, in turn, on the global climate system. Although it has long been generally accepted that temperature is the major determinant of spring phenology, little is known about how the vegetation green-up day's temperature sensitivity, defined here as the vegetation green-up days per unit temperature, is related to temperature environments. Characterizing this temperature sensitivity can provide insight into the changes in vegetation phenology occurring worldwide. We also need to be able to predict the effects of climate warming on vegetation dynamics in the future. In 2013, we collected land-surface image data taken during the period of 1982 to 2008 for all vegetated lands in the Northern Hemisphere within the latitudinal range of 30°N to 80°N. By using these images, we calculated the normalized-difference vegetation index (a vegetation greenness index) to detect the annual green-up date for the period. We then determined the duration of the pre-season period during which temperature was significantly

related to the green-up day. The temperature sensitivity of the green-up day was calculated for each pixel of the images as the change in green-up day per unit change in temperature during the pre-season period. We found that the mean annual temperature was positively correlated with the temperature sensitivity of the spring phenology (Fig. 3). Therefore, with a similar increase in temperature across a range of environments, plants in the warmer environments tended to show greater advancement of the green-up day than plants in cooler ones. This variation in the sensitivity of the green-up day should predict the response of vegetation to future climatic change.

Fig. 3 Temperature sensitivity of vegetation green-up day in relation to mean annual temperature. Each point represents vegetation of different types and locations. The red line indicates the linear regression of all the points.
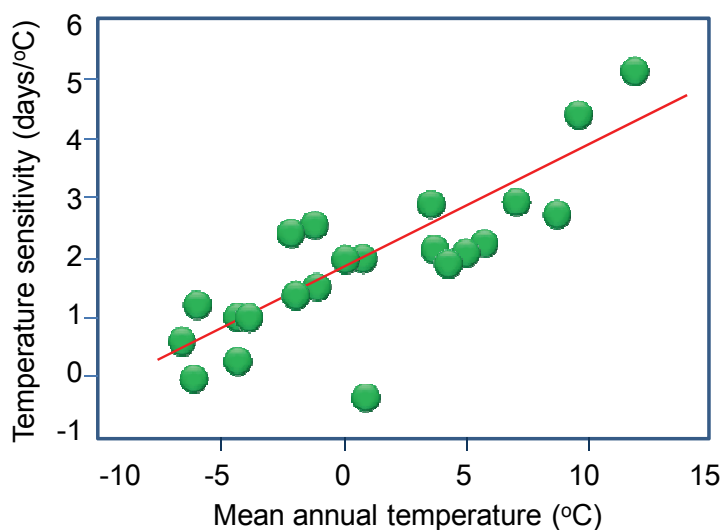
2. Fundamental Research

2.1 Mapping the legacy effects of past land use on the current distribution of mammals

Recently, there has been growing interest in ancient land use as a major determinant of current pattern of species distribution. Mammal species are thought to be particularly susceptible to such human interventions because of their limited dispersal ability, low fecundity, and potential as food resources for humans. If such legacy effects of past land use on mammals could be quantified and mapped, they would offer helpful insights into long-term and large-scale conservation planning.

We aimed to find legacy effects that were common among different genera of mammals in Japan. We used the locations of archaeological sites to obtain the ancient land-use patterns of seven historical periods over 15,000 years, and we explained the mammal distribution in Japan (at a 10-km resolution) by using multiple logistic regression models. We considered multiple types of ancient land use, including settlement, ironworking, and kiln-firing.

We found that ironworking in the Kofun and pre-modern ages had negative

effects on some genera of small mammals such as the shrew, flying squirrel, harvest mouse, and dormouse. In contrast, we detected positive effects of ironworking and kiln-firing in the pre-modern age in the case of genera of medium-sized mammals such as the hare, wild boar, raccoon dog, and mustelids. These negative and positive effects are likely the result of historical habitat alteration through practices such as mining (for iron ore) and over-harvesting of forest resources (for fuel), as supported by archaeological and paleoecological records.

We calculated the expected decreases and increases in the numbers of genera through past land uses (Fig. 4A, B) using our models, and we found that the numbers of mammal fauna in the Chugoku and Abukuma regions were greatly altered by pre-modern ironworking. In these regions, the diversity of forest-dwelling small mammals decreased, whereas that of medium-sized mammals that prefer the *satoyama* environment (the border habitat between foothills and flat arable lands) increased. This historical effect on fauna suggests that the diversity of medium-sized mammals could be a good benchmark of ecosystem recovery in the Abukuma region from the Fukushima nuclear power plant disaster.

Fig. 4
Distributions of changes in the numbers of mammal genera as a result of pre-modern ironworking

Decreased diversity of forest-dwelling small mammals

Increased diversity of medium-sized mammals

0   1   2   3

Number of genera lost (A) or gained (B)
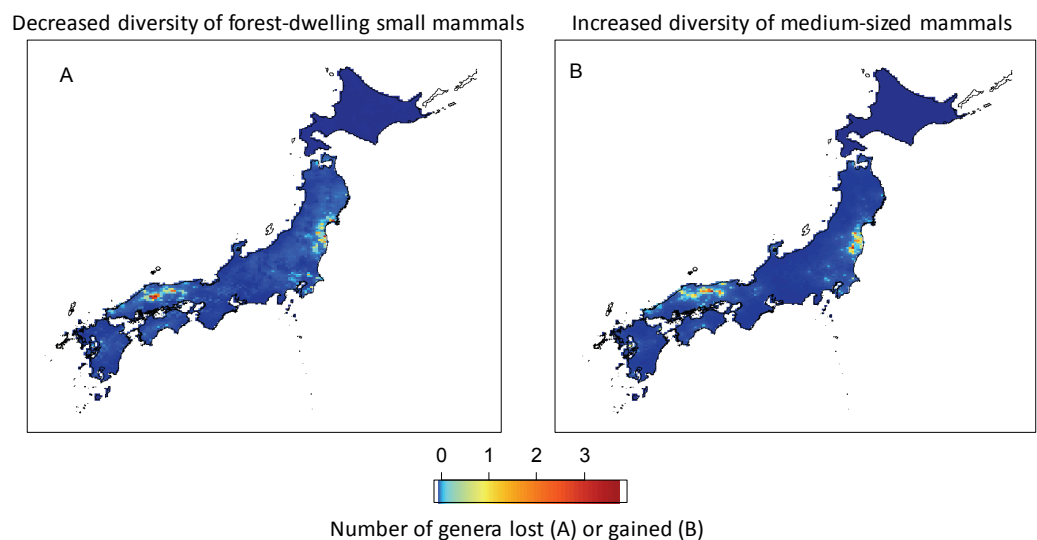
2.2 Potential distribution of newly introduced parasitoid of the giant bagworm

Many exotic natural enemies have been released to control insect pests. However, importing exotic parasitoids and predators as biological control agents can have substantial effects on native ecological communities. In the early 1990s, the parasitic fly *Nealsomyia rufella* was introduced to North China from its original population in South China to manage populations of the giant bagworm *Eumeta variegata*, which is a pest in orchards. The subsequent invasion of Japan by this

parasitic fly, which was assumed to have come from North China, is now causing serious decline of *E. variegata*. The giant bagworm has been reported to be at risk of extinction and is listed on local Red Lists of threatened species.

We conducted a sampling survey of *E. variegata* and *N. rufella* in Japan and China in 2011–2013. The survey revealed persistent distributions of *E. variegata* populations despite the high percentage of *N. rufella* parasitism in almost all populations sampled throughout Japan and China. We used distribution information from our survey and from the literature to create an ecological niche model to predict whether the parasitoid could invade the entire distribution range of *E. variegata* in Asia. The model prediction showed that *N. rufella* has already reached the northern limit of the distribution of *E. variegata*, namely the northeast part of mainland Japan and a latitude of 35°N to 36°N in China (Fig. 5). However, there are some boundary areas in which *N. rufella* was barely found. The important climate variables for the distributions of both *E. variegata* and *N. rufella* were annual mean temperature and mean temperature in the coldest season. These findings suggest that *N. rufella* will have difficulties achieving high parasitization rates in some areas because of an increase in overwinter mortality rates and a decrease in the number of generations in summer. These areas might maintain stable populations of *E. variegata*.

Fig. 5 Predicted distributions, based upon ecological niche model using environmental data, for *Eumeta variegata* (left panels, green) and its parasitic fly (right panels, red) in Asia (top panels) and Japan (bottom panels). Point location records are indicated for occurrences (circles) and absences (crosses) determined from our collection survey and the literature.
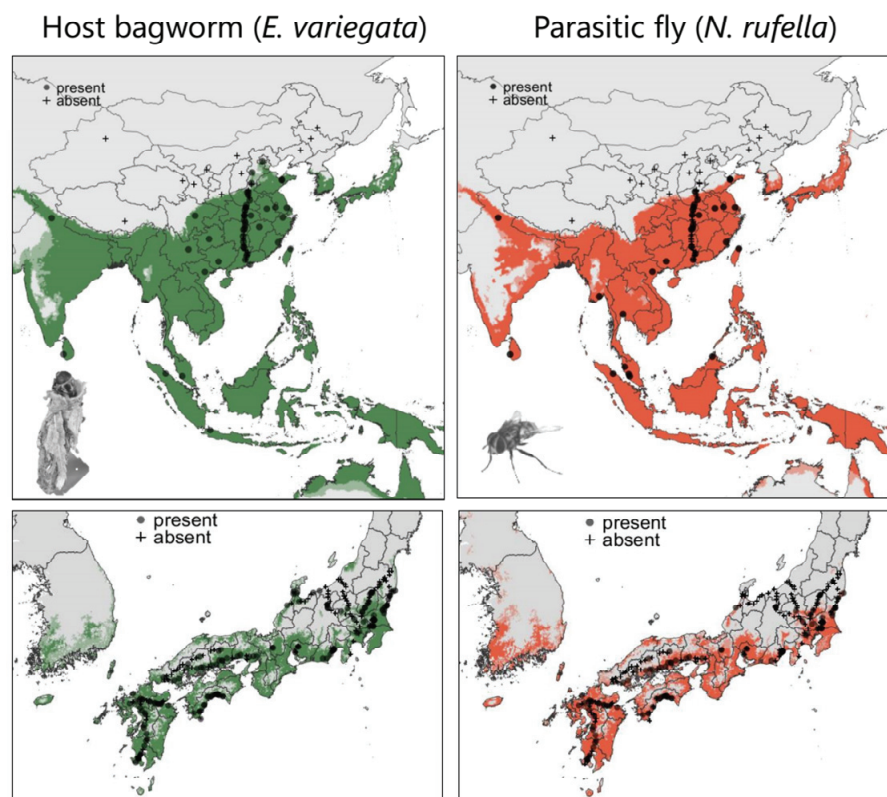
3. Platform for biodiversity databases
3.1 Land-use/cover data for biodiversity and ecosystem service estimation

By evaluating existing land-use/cover data in Japan, we prepared a new land-use cover dataset based on actual vegetation maps prepared by the Ministry of the Environment; these maps have the most detailed categories available for plant communities and vegetation naturalness. The vegetation categories and vegetation naturalness were integrated into land-use/cover categories. A systematic, hierarchical classification scheme was adopted. The spatial resolutions used are the Second-order Mesh (~10 × ~10 km) and Third-order Mesh (~1 × ~1 km) of Japan's Standard Mesh System, and the geodetic system used is WGS84. This dataset can be viewed at http://tenbou.nies.go.jp/gis/ [in Japanese]. At http://www.nies.go.jp/biology/kiban/lu/index.html we accept requests from the public for data distribution. As of March 31, 2014, 31 data requests had been made.

3.2 Satoyama Index for assessing biodiversity status in agricultural landscapes

We mapped the Satoyama Index, defined as Simpson's diversity index of land-use types within a 6-km square weighted by the proportion of agricultural land use, for every 50 × 50 m rural land-use cell in Japan (Fig. 6). Before calculating the index, we classified national land uses into the categories "wilderness land use," "rural land use," "plantation," and "urban land use" by using a new land-use/cover data set we had published (see section 3.1). The Satoyama Index was calculated only for rural land-use cells. The index should be widely applicable to large-scale assessments of biodiversity status in agricultural landscapes. The data are available at 1 × 1 km resolution at http://www.nies.go.jp/biology/kiban/SI/index.html [in Japanese]. We also provide a web GIS service for users who want to take a quick look at fine-scale maps of the index (http://tenbou.nies.go.jp/gis/indicator/).

Fig. 6 Satoyama Index values in rural land-use areas across Japan
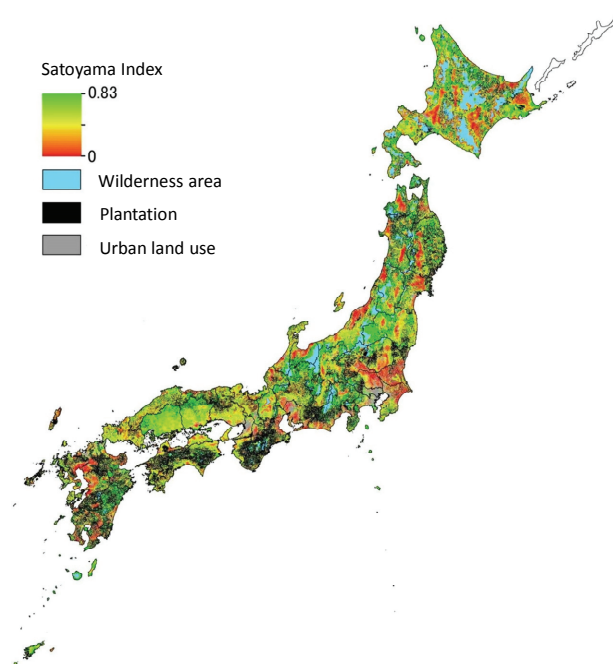
Center for Environmental Health Sciences
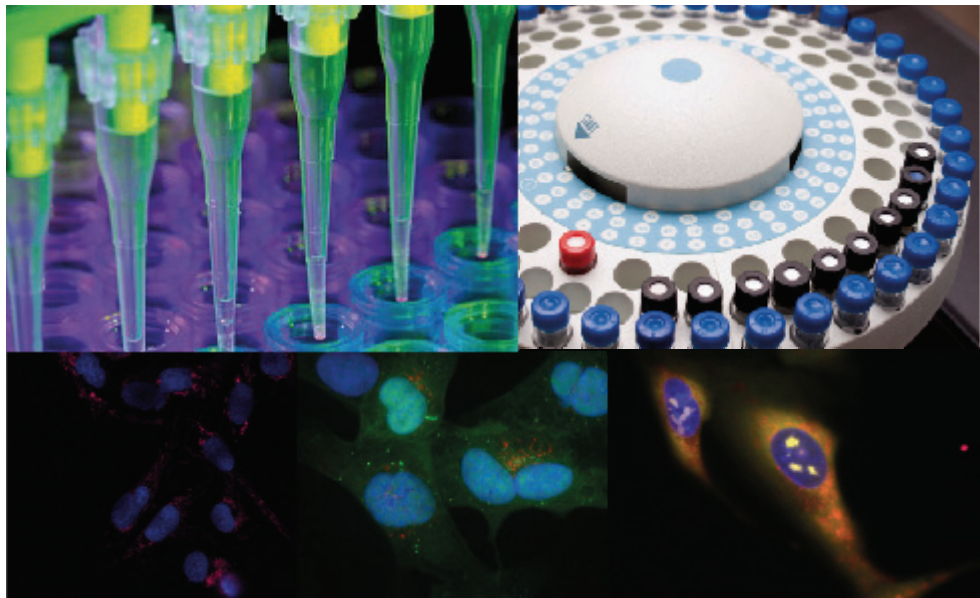
Integrated exposure and effects analysis

Integrated exposure and effects analysis (IEEA) is a scientific approach that has been proposed to meet the current chemistry and toxicology challenges posed by the ever-growing numbers of chemicals introduced into the environment. This approach combines measurements of environmental contaminants and the assessment of their potential effects on human and ecological health. The traditional methodology for evaluating the impacts of environmental pollutants is based on separated lines of evidence, namely targeted chemical analysis and acute and chronic toxicity tests in test organisms. These tests are based on classic endpoints such as mortality rates, measurement of reduced growth, and alterations in reproduction rates. A weight-of-evidence approach including chemical, toxicological, and physical lines of evidence is crucial for identifying and classifying potentially toxic chemicals in the environment. NIES has led collaborative research involving US and European researchers to develop a transferable toolbox that generates the scientifically sound information required to manage the risks posed by chemical mixtures in the environment.

The health impacts of environmental factors such as environmental pollutants have yet to be adequately clarified. To reduce or prevent such health impacts, we need to elucidate them and the mechanisms that underlie them, focusing primarily on fetuses, children, and vulnerable populations.

We therefore aim to experimentally investigate and assess the health impacts of environmental factors and their modes of action; develop a simple and fast exposure and impact assessment system; and conduct epidemiological surveys and studies to identify the impacts of the environment on health and the factors underlying them.

Specifically, we intend to assess the health impacts of environmental factors such as environmental chemicals, metals, atmospheric pollutants, and nanomaterials, and to establish, improve, and verify methods of assessing these impacts. We also intend to clarify their mechanisms of action, with a focus on genomics and epigenetics. In addition, we aim to work on the epidemiological assessment of these health impacts and to try to integrate, systematize, improve, and refine this assessment.

Finally, as the National Center for **JECS** (**the Japan Environment and Children's Study)**, we aim to plan and coordinate this study, manage the work of participating institutions, organize and manage data, and analyze and preserve materials.

The National Center for JECS conducts studies in cooperation with regional Unit Centers recruited or selected through public advertising. Regional Centers have been established by universities or research institutions at 15 locations nationwide. The Regional Centers provide local recruiting grounds and are responsible for conducting follow-up of enrolled children.

We intend to promote a pilot study program, namely the **Research Program on Environmental Health for Children and Future Generations.** This program will also be used by JECS.

A wealth of information is likely to be obtained from JECS. We will need to expand on the survey results, for example, by biologically validating the epidemiological findings. To do this, we will elucidate the health impact mechanisms or suggest target substances or impact indexes that should be epidemiologically considered from among the enormous numbers of environmental pollutants and other health impact factors.

For this reason, we aim to comprehensively investigate, assess, and elucidate the impacts of environmental factors, beginning with environmental pollutants, on children and future generations by using the epidemiological and experimental approaches described below. We aim to achieve the following:

- By developing a model for exposure assessment of environmental pollutants that takes into account various factors, and simultaneously a method for measuring the multiple components of chemical substances in human samples, we will establish a comprehensive exposure assessment system that can be applied to epidemiologic research. This will enable more efficient and accurate exposure assessment.

- We will upgrade the epidemiological health impact assessment methods and biostatistical techniques used to evaluate the growth and development of children. We will apply the knowledge we gain to real-life epidemiological research measures, such as prevention.

- We will clarify the impacts of environmental chemical exposure during the fetal period and childhood on biological functions. We will also elucidate the epigenetic changes that accompany these impacts. Furthermore, we will provide biological grounds for epidemiological research by elucidating the contributions of epigenetic changes, and their induction mechanisms, to impacts on organisms.

- With children and the future generation as the primary targets, we will elucidate the impacts of environmental pollutants on immunological and allergic diseases by using animal disease models and cell lines. In addition, by constructing an assessment system that covers both simple screening and detailed assessment, we will supplement the JECS study data and suggest target substances or biological markers that should be preferentially investigated.

Our main research outcomes in FY 2013 were as follows.

In the **Biological Impact Research Section**, we have been studying the effects of environmental pollutants on the immune system and the central nervous system.

We investigated several parameters of the immune system and central nervous system following intratracheal exposure to bisphenol A (BPA) in a murine model of allergic asthma. Combined treatment with BPA and ovalbumin (OVA) significantly enhanced airway inflammation (Fig. 1A) and Th2 cytokine/chemokine production such as interleukin (IL)-13, IL-33, keratinocyte chemoattractant, and regulated and normal T-cell expressed and secreted, compared with OVA treatment alone. In lung local lymph nodes, total cell numbers were significantly greater in the moderate-dose BPA+OVA group than in the OVA group; IL-4 production was significantly greater in the low-dose BPA+OVA group than in the OVA group (Fig. 1B and 1C). Moreover, the high-dose BPA+OVA group had poorer ability than the vehicle group to discriminate between old and new objects in a novel-object-recognition test.

These results suggest that exposure to BPA might aggravate allergic asthma.

Fig. 1 Cellular profiles in bronchoalveolar lavage fluid and lung local lymph nodes following exposure to bisphenol A (BPA) in a murine model of allergic asthma.
(A) Differential cell counts in bronchoalveolar lavage fluid. Data are means ± SE (n = 5–8; *P < 0.05, **P < 0.01 vs. vehicle group; # P < 0.05 vs. OVA group).
(B) Total cell numbers in local lymph node cells (LNC). Data are means ± SE (n = 8; **P < 0.01 vs. vehicle group; #P < 0.05 vs. OVA group).
(C) IL-4 production from local LNC after stimulation with OVA *in vitro*. Data are means ± SE (n = 3 or 4; #P < 0.05 vs. OVA group)
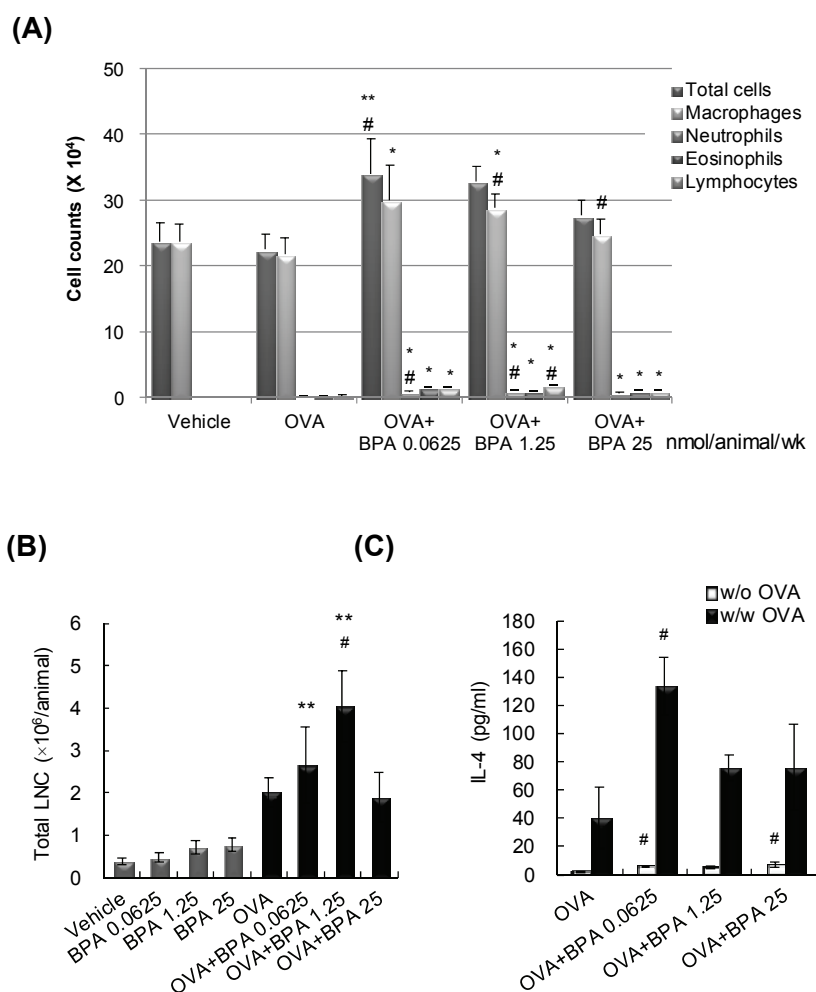
In addition, maternal exposure to benzo[a]pyrene (BaP) during the neonatal period tended to enhance allergic asthma in both male and female offspring. Although the impact of maternal exposure to BaP was weak, there might be sex differences in the response to BaP in offspring.

We investigated the effects of oral exposure to hexabromocyclododecane (HBCD) in C57BL/6J mice fed a high-fat diet (HFD) or a normal diet (ND). HBCD exposure enhanced weight gain, hyperglycemia, hyperinsulinemia, hepatic steatosis, and macrophage accumulation in adipose tissue in HFD-fed mice, but not in ND-fed mice. These results suggest that HBCD contributes to metabolic dysfunction via an interaction with diet, resulting in accelerated progression of obesity.

We also investigated the effects of inhalation exposure to diesel-exhaust-origin secondary organic aerosol (DE-SOA) on learning and maternal behavior in mice. Male BALB/c mice were exposed to clean air (control), diesel exhaust (DE), or DE-SOA for 3 months; we then examined their learning ability by using a

novel-object recognition test. Moreover, we examined maternal behavior in female mice that had been exposed to DE-SOA for 1 month before mating. Decreased novel-object recognition ability was observed in the male mice exposed to DE-SOA for 3 months (Fig. 2A). Furthermore, lower incidences of some maternal behaviors were found in DE-SOA-exposed dams than in controls (Fig. 2B). Our results indicate that exposure to DE-SOA may affect higher brain functions in mice.

Fig. 2 (A) Three months' exposure to DE-SOA impaired novel-object recognition ability. [Discrimination index (DI) = (novel-object exploration time/total exploration time) − (familiar object exploration time/total exploration time) x 100]. Each bar represents the mean ± SE ($n = 6$) (**$P < 0.01$). (B) Assessment of maternal behavior on postnatal day 5. Four parameters—nesting, licking, crouching, and retrieving offspring—were examined. Data represent percentages of mice showing maternal behaviors ($n = 6$)

(A)

(B)
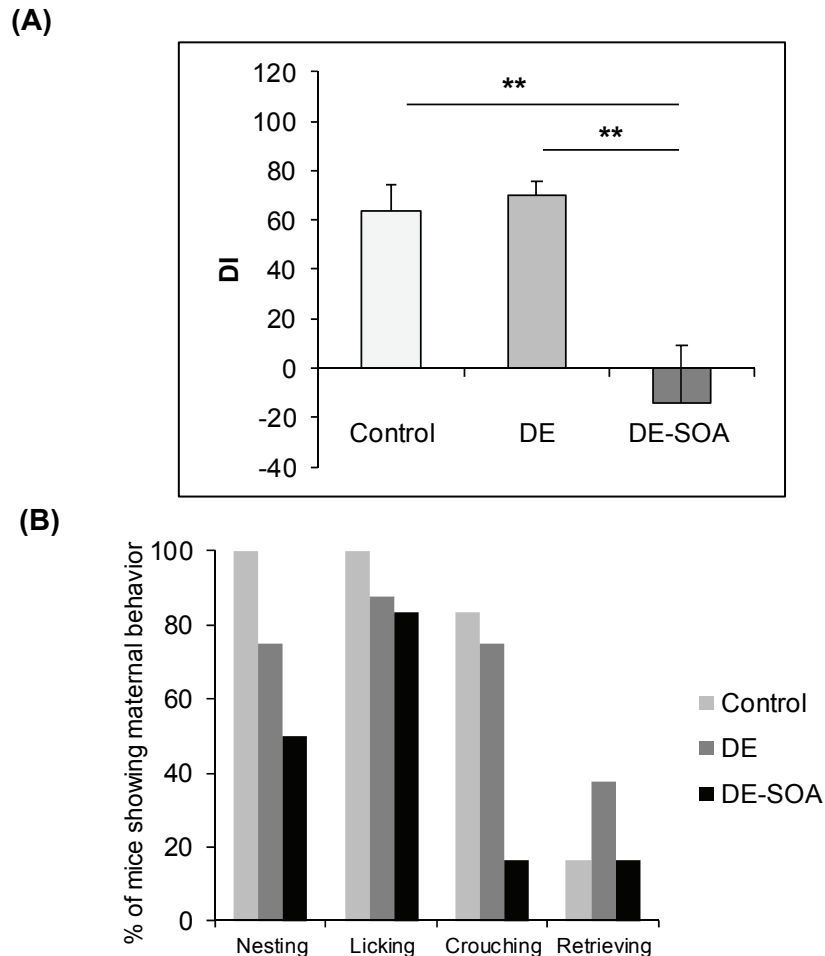
We used pluripotent stem cells such as induced pluripotent stem (iPS) cells, which can differentiate into various somatic cells, to explore the embryotoxicity of environmental chemicals by generating three germ lines under suspension culture in which the cells formed embryoid bodies. When mouse iPS cells were exposed to di(2-ethylhexyl) phthalate (DEHP), differentiation was skewed toward the generation of ectoderm and neural cells, whereas DEHP suppressed the emergence of endoderm and mesoderm (Fig. 3). Thus DEHP could affect early embryonic development via abnormal differentiation.

Fig. 3 Effects of DEHP on the differentiation of iPS cells into three germ lines

Mesoderm
Brachyury (Day 3)

Endoderm
Foxa2 (Day 3)

Ectoderm
Sox1 (Day 2)
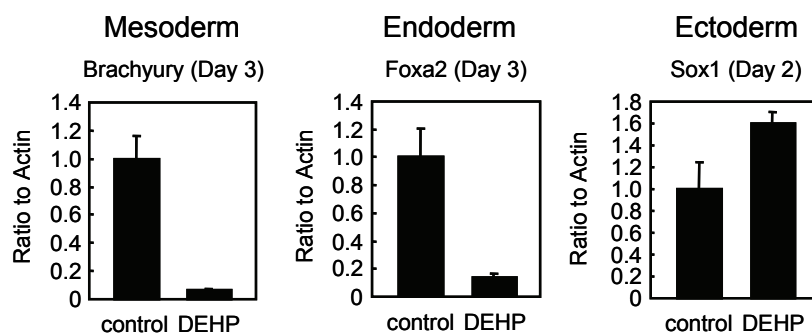
In the **Molecular Toxicology Section**, we have been studying the effects of environmental chemicals on biological and physiological functions and molecular mechanisms. Our recent particular focus has been on the effect of inorganic arsenic on cancer development and the central nervous system.

Previous studies have reported that gestational arsenite exposure of female mice (F0 generation) increases the incidence of hepatic tumors in their adult male offspring (F1). This year, we demonstrated that, surprisingly, gestational arsenite exposure of F0 females increased the incidence of hepatic tumors, even in F2 males, in adulthood. Gene expression analysis confirmed the effects of gestational arsenic exposure on the F2 liver, because expression of several genes was significantly altered in the livers of F2 male offspring of arsenite-treated F0 females compared with the livers of control F2 male offspring. The mechanism of this transgenerational effect is largely unknown and should be clarified so that we can understand and prevent the transgenerational hazardous effects of environmental chemicals.

We performed experiments to assess whether prenatal exposure to arsenic impairs the development of the central nervous system *in vivo* and *in vitro*. In our *in vivo* model, we found histologically that neurite outgrowth in the mouse cerebral cortex is suppressed by exposure to arsenic. In our *in vitro* model, we detected that the cell cycle of astrocytes during the developmental period is dysregulated by exposure to arsenic. These results suggest that arsenic has an adverse impact on both neurons and astrocytes in the brain during development.

Naturally occurring inorganic arsenic has been the cause of serious health problems, such as cancer, in many Asian countries and other areas of the world. We aimed to establish epigenetic markers to detect adverse biological effects of arsenic by analyzing the DNA methylation levels of affected genes. In FY 2013 we used pyrosequencing to establish experimental conditions for measuring DNA methylation levels in the human LINE1 (long interspersed element 1) region; these levels have been suggested to predict the adverse health effects of arsenic. We used this method to analyze DNA methylation of LINE1 in the blood DNA of people living in arsenic-endemic or non-endemic areas of Bangladesh.

Although some organoarsenicals, such as dimethylarsinic acid (DMA^V), arsenobetaine (AB), arsenocholine (AC), and trimethylarsine oxide (TMAO^V), have been studied in seafood, information on the metabolism of organoarsenicals in mammals is limited, unlike the case for inorganic arsenicals.

We investigated the distribution and excretion of arsenic compounds in the tissues, biological fluids, and feces of rats following a single oral dose of an organic arsenical (AB, AC, DMA^V, or TMAO^V) at 1.0 mg As/kg body weight. The rats were fed on arsenic-depleted rodent chow to decrease their basal tissue arsenic contents. In the DMA^V-treated group, a large amount of arsenic was accumulated in the rats' red blood cells in the form of protein-bound dimethylarsinous acid (DMA^{III}), a reportedly toxic trivalent dimethylarsenical. A toxic thio-arsenical, dimethylmonothioarsinic acid (DMMTA^V), was detected in the urine and in fecal extracts of the DMA^V-treated group. These results suggest that intake of DMA^V is a potential health hazard, given that the metabolites of DMA^V, including DMA^{III} and DMMTA^V, are known to be highly toxic.

The **Environmental Epidemiology Section** is involved in developing epidemiological methods and applications for estimating and assessing the health impacts of harmful environmental exposure. Listed below are the projects with which we have been involved, along with selected findings from our analyses.

- In a project to assess the health impacts of climate change and air pollutants, and of adaptation to climate change, we conducted an epidemiological study using heatstroke data and found that the heatstroke risk begins to increase from 21 ºC. We also estimated the number of deaths attributable to heat in the Kanto region of Japan. The results showed uncertainty related to scenario and population assumptions (Fig. 4).

Fig. 4 Combined estimates of relative risk (RR) for each degree increment in maximum 3-h apparent temperature (2-day average), assuming non-linear temperature prediction. Bars denote 95% confidence interval.
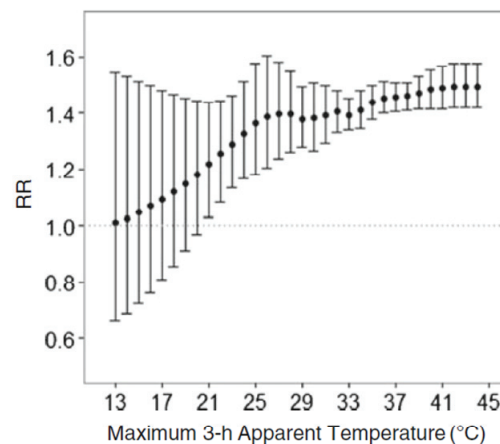
- Our current focus includes the health effects of long-range-transported air pollutants and of local air pollution. We found an increased risk of acute myocardial infarction in Fukuoka during Asian Dust events (Fig. 5).

- The health effects of short-term exposure to fine particulate matter ($PM_{2.5}$) are a focus of our research.
  1) By using data from emergency ambulance dispatches (as a proxy for acute health outcomes), we found an association between exposure to $PM_{2.5}$ and the risk of ambulance dispatches due to all-cause and respiratory diseases (Fig. 6).
  2) We prepared for a panel study to investigate the health effects (e.g. respiratory symptoms) of $PM_{2.5}$ in elementary school students. In FY 2013, we performed a pilot study and checked the feasibility of our study protocol.

Fig. 5 Association between Asian Dust and the incidence of acute myocardial infarction
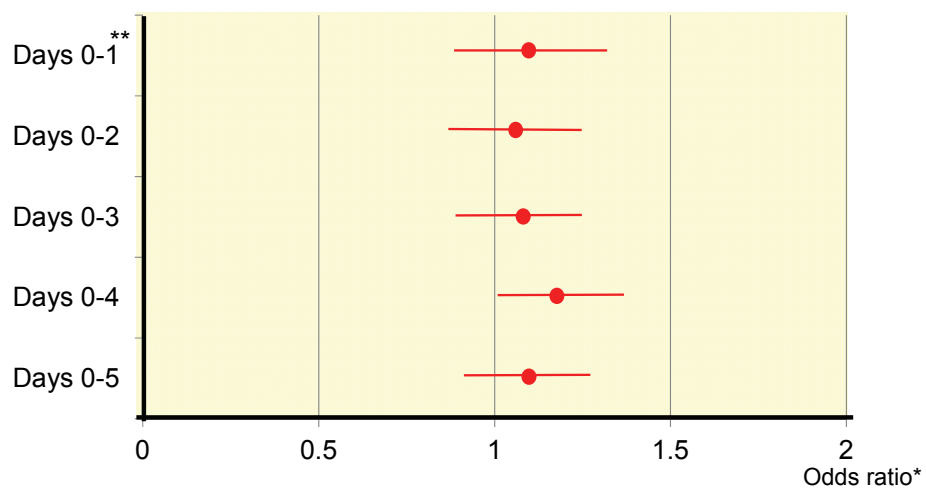
*Adjusted for temperature and relative humidity. Bars denote 95% confidence interval.
**Days 0-1 means Asian Dust events from the case day (day 0) to 1 day prior (day 1).

Fig. 6 Association between fine particulate matter ($PM_{2.5}$) concentration and emergency ambulance dispatches
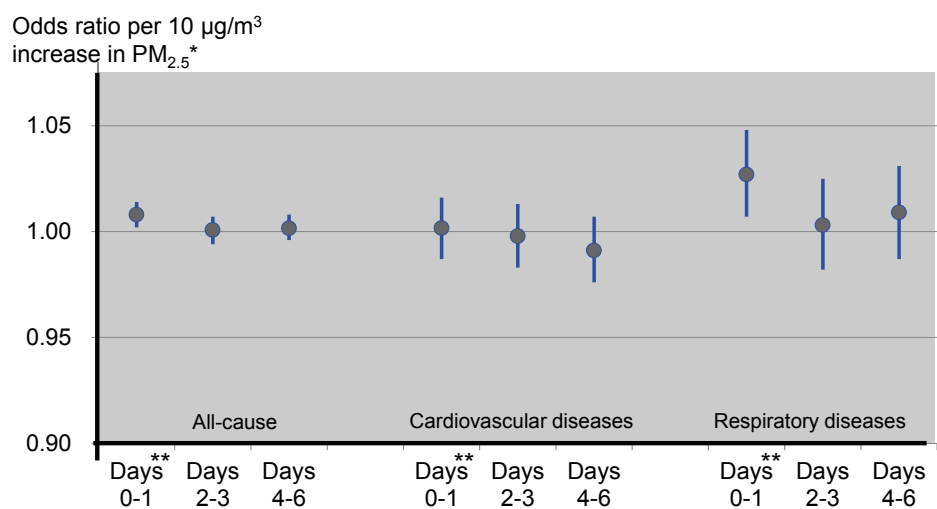
*Adjusted for temperature and relative humidity. Bars denote 95% confidence interval.
**Day2 0-1 means concentrations of $PM_{2.5}$ from the case day (day 0) to 1 day prior (day 1).

- We compiled guidelines on epidemiologic statistics for summarizing and analyzing the JECS data. We are continuing to upgrade our methods of assessing epidemiological health impacts and the biostatical methods used to evaluate the growth and development of children with continuous environmental exposures.

The **Integrated Health Risk Assessment Section** has developed high-throughput analytical methods for human biomonitoring. The methods were tailored to enable analysis for multiple compounds by using minimum amounts of biological samples in large-scale birth cohort studies. These methods are also "greener" and require minimum solvent use. To name but a few of the tests, we developed a method for analyzing elemental metals (including lead, cadmium, mercury, selenium, and manganese) by using only a dilution step followed by inductively coupled plasma mass spectrometry analysis. This eliminated the need for complex extraction procedures, saved hundreds of milliliters of solvents, and markedly shortened the analytical time. Another test we developed was for the analysis of perfluorinated compounds in drinking water. This method requires only 10 mL of sample, whereas conventional methods need at least 0.5 L.

We also developed a bioanalytical method for dioxins and dioxin-like compounds. Instrumental methods require tens of milliliters of blood samples—volumes that would unlikely be tolerated in large-scale birth cohort studies such as JECS. Our bioanalytical method can achieve optimal sensitivity using a sample volume of 1 mL or less. We analyzed house dust samples for multiple compounds so that we could prioritize target compounds in cohort studies. An exposure model that we developed for radiological dose assessment is described in the Environmental Emergency Research Section.

The **Planning and Coordination Office** and the **Data Management and Analysis Office of the Children's Environmental Health Study** play key roles in JECS. JECS is a nationwide newborn cohort study that involves the recruitment of women in early pregnancy and follow-up of their children until age 13. The goal of the study is to help us to understand the roles of various environmental factors in children's health and development. Recruitment started in 2011 and is now complete; the number of participants enrolled now exceeds 100,000. The number of biological samples collected from participants exceeds 200,000.

Center for Social and Environmental Systems Research

UN Secretary-General Ban Ki-moon delivered his keynote address to the high-level ministerial dialogue on climate finance at UNFCCC COP19 in Warsaw in November 2013

Drafting authors successfully completed the Summary for Policymakers, a contribution of the Working Group II (WGII) to the IPCC Fifth Assessment Report. It was accepted at the 10th Session of IPCC WGII and the 38th Session of IPCC in Yokohama in March 2014.

The Center for Social and Environmental Systems Research targets linkages between human activities and the natural environment in order to identify the relationships between socioeconomic systems and environmental issues. The work of the Center results in proposals for environmental policies and a sustainable society. It covers a broad area, from global environmental issues such as global warming to local issues such as recycling and lifestyles. There are five research sections:

1. The **Environmental Economics and Policy Section** studies the economic and policy aspects of environmental conservation and analyzes the economic and political effectiveness of environmental policies.
2. The **Environmental Planning Section** works on new methodologies for understanding and assessing regional environments. We are also investigating the current status of public environmental awareness and the promotion of voluntary action by individuals.
3. The **Integrated Assessment Modeling Section** develops integrated environment–economy models to assess environmental policies, such as those on global warming mitigation and adaptation, and sustainable development policies.
4. The **Sustainable Social Systems Section** studies sustainable futures for our society (i.e. a low-carbon society, LCS) and ways of achieving such a society in the long term without harming our economy.
5. The **Environmental Urban Systems Section** analyzes urban and regional environmental options such as low-carbon cities and sustainable transportation systems.

Our main research outcomes in FY 2013 were as follows.

1. Environmental Economics and Policy Section

To investigate various environmental issues, we are studying the interactions between current social and environmental systems by using approaches from social science, natural science, and systems analysis. In addition, we are analyzing the economic impacts of environmental policies such as carbon taxing and emissions trading. We are also analyzing the environmental policy decision-making processes used by various countries and investigating the possibility of international cooperation on global environmental conservation.

1.1 Qualitative analysis of various funding schemes targeting climate change adaptation

Helping developing countries to adapt to climate change is one of the key elements in a post-2020 framework on climate change. We analyzed how the Pilot Program for Climate Resilience (PPCR) and the Adaptation Fund under the Kyoto Protocol prioritize and select target countries or projects, as this has implications for future adaptation finance mechanisms. We found that the countries that were

recipients of the Adaptation Fund were not recognized as "vulnerable countries," even though the Fund aims to help developing countries that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation. The Green Climate Fund set up under the UNFCCC (United Nations Framework Convention on Climate Change) needs to include a PPCR-type funding system, as efficiency and equity in the fund need to be balanced.

1.2 Energy poverty in Japan

There is concern that a number of Japanese households live in energy or fuel poverty driven by the long-running escalation of energy prices. In this context, we considered the issue of energy poverty in Japan by using a computable general equilibrium model and anonymized microdata. The results showed that energy price hikes have severe impacts on low-income and vulnerable households. When energy prices increase by 100%, the proportion of energy-poor households in the lowest-income decile group increases to more than 40%; it increases to over 20% in mother–child households and single, aged households. We also looked at an assistance policy that would subsidize the energy costs of low-income households. The results empirically confirmed the effectiveness of the policy and revealed the budget required to offset the negative impacts of energy price escalation.

1.3 Evaluation of coral reefs as tourism resources in Okinawa

Various conservation programs are being run to save our coral reefs. The cost-efficiency of these programs needs to be evaluated, as the budget is limited. We used a questionnaire to survey tourists at Naha and Ishigaki airports in Okinawa. Our aim was to use the travel cost method to measure the effect of coral reefs on the tourists' choice of sites to visit. The results showed that the marginal willingness of each tourist to pay for coral reefs was about 15,000 yen/km^2 for each visit to Okinawa. The deteriorations in the coral reef at Yaeyama had the largest impact on the tourists' site choice.

2. Environmental Planning Section

We are studying the development and assessment of regional plans and basic environmental plans for environmental conservation. We are also investigating new methodologies for understanding and assessing regional environments. Moreover, we are investigating the current status of public environmental awareness and the promotion of voluntary action by individuals.

2.1 Theory and effects of voluntary environmental actions taken by individuals and enterprises

We calculated the amount of electricity saved by baseball spectators during game

time in the summer season by using data collected through a questionnaire survey conducted before a baseball game at a stadium. The answers to the questionnaire revealed the total number of spectators who attended baseball games with the whole family and whether they had taken standby-energy-saving measures before leaving for the game. We found that: 1) The amount of energy saved by spectators who attended baseball games (both on weekdays and weekends) with their entire families exceeded the average energy consumption at the game in 2010 of 13,500 kWh/game (6.5 h) during night games. 2) As a result of the campaign to save energy, the number of spectators who took measures to save energy increased by 7% to 8%. 3) The amount of energy that can be saved during a baseball game in summer at home exceeds the average amount of energy consumed during that game if the number of spectators is above 17,000.

2.2 Study of national trends in public interest in environmental issues

We conduct ongoing monthly public opinion surveys to evaluate the levels of public support for environmental policies. These surveys have included perceptions of the 2011 Great East Japan (Higashi-Nihon) Earthquake disaster in the Tohoku region. Our questionnaires cover "the world's most important issues" and "Japan's most important issues." Our sample populations consist of 4000 men and women who are drawn from across the nation and are 20 years and older. Respondents are randomly selected every month, and in each month we usually obtain more than 1000 responses.

Figure 1 shows the results of a survey of the world's most important issues from June 2005 to December 2013. The environment was considered to be the most important global issue from early 2007 to mid-2008, and since then it has stayed in the top three to five issues. The environment issue made a comeback in summer 2009, and after summer 2013 it made another comeback, this time as the second most important global issue.

The likely reasons for the rise in 2013 are as follows. 1) Mass media coverage of climate change increased, and people are now very much aware of "extreme weather events" such as storms, snowfalls, and stronger typhoons. 2) Mass media coverage also increased because the IPCC released new reports (WG1 in September 2013 and WG2 in March 2014). 3) News coverage of levels of PM2.5 (fine particulate matter) from China received a great deal of public attention, and in late 2013, there was intensive media coverage of China's atmospheric pollution issues.

People often pointed out that environmental issues were becoming less popular in the Japanese political and social arena, but according to our survey results, environmental issues are still receiving much public attention.

**Fig. 1** Changes in public perceptions of global and national issues from June 2005 to December 2013
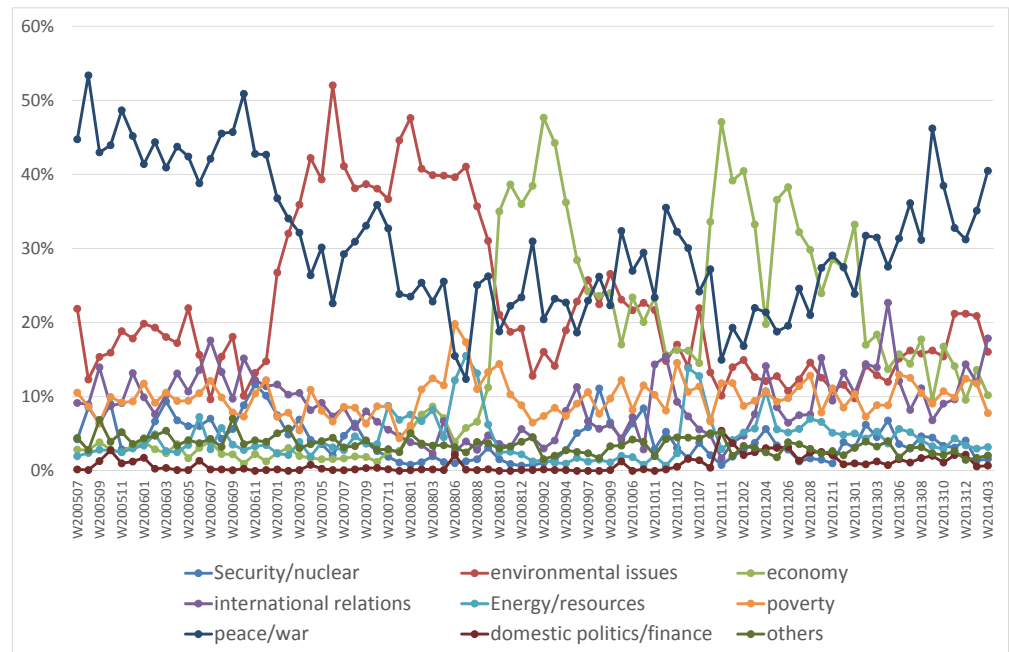
2.3 Wind tunnel investigations of the effects of building materials on flow fields under heating conditions

We are using scale models to characterize the thermo-physical properties of different insulating materials. We are also determining how different building materials influence outdoor thermal environments and flow fields; working out how fluctuating solar radiation influences building materials and eventually influences outdoor thermal environments; and obtaining optimum height-to-width ratios for the spaces between buildings with different surface materials. The results of these investigations will guide the future application of building technologies to urban design and planning for low-carbon cities.

Solar radiation heats walls and the urban canopy surface and generates a strong buoyancy flow. The long-wave radiation emitted from urban surfaces also heats air and generates buoyancy. The impact of this buoyancy is more obvious at low wind velocities. Flow patterns depend mainly on the wind velocity at rooftop level, as well as on the exposure of walls to radiation and the canyon aspect ratio H/W (the ratio of building height to street width). We therefore conducted experiments on the mutual influence of wind velocity and the surface temperatures of asphalt and steel heated by four halogen lamps (representing solar radiation) in a wind tunnel (Fig. 2), and we performed numerical simulations for the same conditions to determine the flow field distribution. Wind velocity above rooftop level and roof surface temperature were measured. When the wind speed was 1 m/s, the difference in velocity between heated and unheated conditions was barely observable. Wind flowed through the roof before it was influenced by the buoyancy flow generated by the heated roof. When the wind speed was 0.5 m/s,

the velocity under heated conditions was generally higher than that with no heating. A vortex was formed near the windward edge. Our calculations revealed that the energy maintaining the vortex was derived from the turbulent effect at the windward edge and from momentum transport.

Fig. 2 Wind-tunnel experiment to measure the thermal effect of roof material and shape on the indoor–outdoor environment and flow patterns by using visualization and a laser beam. "Position" on the x-axis means distance from the windward edge of the roof.
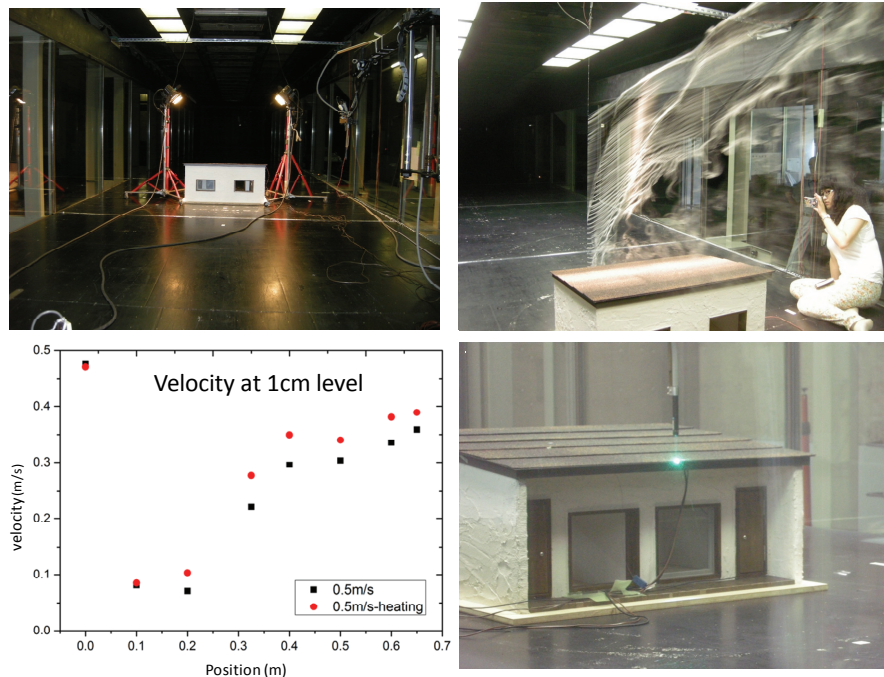
3. Integrated Assessment Modeling Section

"Integrated assessment" is a framework for linking the policymaking process with scientific knowledge from a wide range of disciplines. The core tool in integrated assessment is a model that evaluates policy options for solving various environmental problems. We have developed and modified the Asia-Pacific Integrated Model (AIM) to assess climate and other environmental policies. The spatial coverage in the models we have developed ranges from the local scale to the global scale. We are expanding the AIM to include not only climate problems, but also the assessment of sustainable development issues. The following topics were our main activities in 2013.

3.1 Development of a regional model for China and Korea

It is important to consider the regional characteristics of Asia when analyzing global GHG emission pathways consistent with a global temperature change limit of 2 °C from the pre-industrial level and discussing transitions towards a low-carbon society. We have been developing the AIM/Enduse model, with a detailed mitigation technology database, for China and Korea at the regional scale

(31 provinces in China and 6 districts in Korea). In FY 2013, we focused on regional analysis in the residential sector in China and Korea. First, we analyzed regional socioeconomic characteristics. Then we developed a service-demand estimation model and evaluated technology selection and GHG emissions by using the AIM/Enduse model. The characteristics of GHG mitigation potentials and major mitigation technologies differ between urban and rural regions and among different climate zones, but the common trend is that, in China, at a low-carbon price there are many mitigation potentials compared with the reference case.

3.2 Assessment of GHG emission-reduction targets for 2020–2030 in Japan

After the Great East Japan Earthquake and the Fukushima Dai-ichi Nuclear Power Plant Accident, Japan's climate and energy policies changed dramatically. The new Japanese mitigation target of 3.8% reduction in 2020 as compared with the 2005 level (which corresponds to a 3.1% increase from the 1990 level) was assessed by using the revised computable general equilibrium (CGE) model for Japan. The revised model was coupled with a technology selection module in the conventional CGE model. According to the results of the revised CGE model, introducing advanced energy-saving technologies to achieve the abovementioned new target could bring a net benefit in the long run. However, introducing the energy-saving technologies would result in a large economic loss in the short term, because these technologies are expensive to purchase and install. As a result, it is very hard to select them while keeping in mind short-term objectives.

3.3 Development of impact functions for analyzing the impact of climate change on global crop yields

We developed "impact functions" for global maize, wheat, and paddy-rice yields in order to assess the impacts of climate change in an integrated assessment model. An impact function is a look-up table of the country-averaged impacts on a certain sector under arbitrary conditions of climate change. To develop impact functions for crop yield, we conducted a sensitivity analysis using a full-scale impact model, named M-GAEZ model, with varying levels of temperature and precipitation. We averaged the crop yield for each country to obtain the impact functions. The results revealed that the sensitivity of crop yield to temperature and precipitation differs among both crops and countries. The maize and wheat yields in the United States and China, which are among the top-producing countries, would increase with increasing precipitation and decrease with increasing temperature. Wheat yield in these countries is more sensitive to increasing temperature than is maize yield. Maize yields in Brazil and paddy-rice yields in Indonesia would decrease in most cases of change in temperature and precipitation. In India, the wheat yield would decrease to about 30% of a present level if the temperature were to increase by 4 °C; that is, wheat would barely grow under such conditions (Fig. 3).

Fig. 3 Changes in crop yields estimated by impact functions in association with changes in temperature and precipitation in the top-three producing countries. These results are based on statistics from 1991 to 2010 for each crop. The base period ($\Delta T = 0$ °C, $\Delta P = 100\%$) is the 30 years from 1961 to 1990.
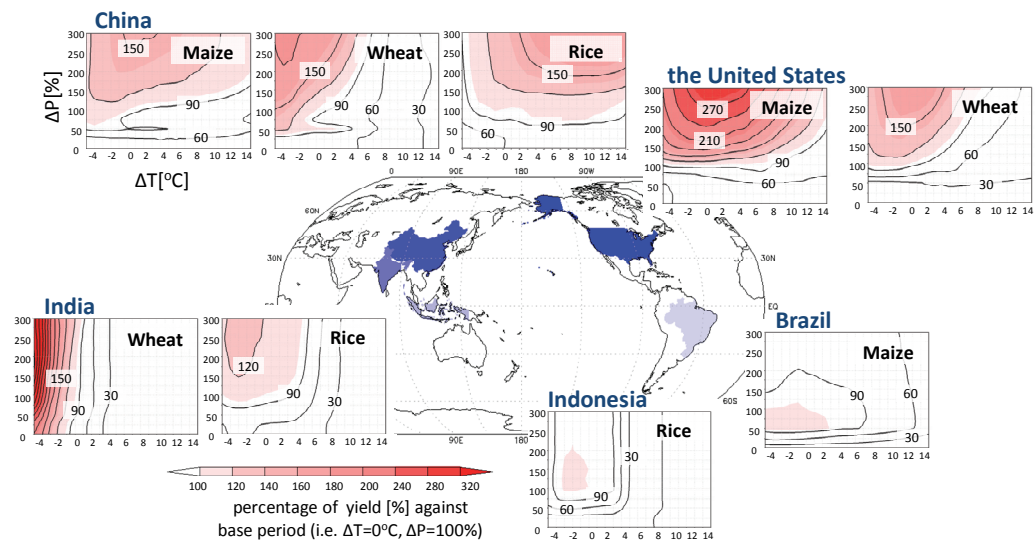
4. Sustainable Social Systems Section

We mainly lead research projects related to climate change. While doing so, our intention is not only to deal with climate change per se, but also with other ecological and economic values so that the outputs of our studies are directed toward a sustainable future for our society. How can we achieve a low-carbon society (LCS) in the long term without harming our economy? What are the ways we can integrate LCS strategies and development policies in countries in Asia? What kind of adverse impacts of climate change are likely to occur without mitigation efforts? How far can we adapt to the new climate? How can we arrive at a multilateral agreement to alleviate the adverse effects of climate change? These are some of the research questions we address.

4.1 Creation of LCS scenarios for Asian countries

Together with local researchers, we have developed Asian country-wise and city-wise LCS scenarios. These scenarios become inputs for local stakeholder dialogues, Asia-wide network meetings (such as LoCARNet, Low-Carbon Asia Research Network), and global conferences (such as COP19) aimed at understanding how we can achieve an LCS both qualitatively and quantitatively. Low-Carbon Action Plans and Roadmaps have been approved by the authority of the Iskander Malaysia region on the basis of our research output. One of our major action plans is a low-carbon education program: 23 primary schools joined the "Iskandar Malaysia Eco-Life Challenge" program.

4.2 Assessment of an electricity-saving plan at NIES

Although no legally binding directives for electricity use were set for summer 2013, NIES continued its voluntary efforts to save electricity, for several reasons,

including a rise in electricity prices, the replacement of our supercomputer system, and the initiation of a new research program for the Fukushima area (Environmental Emergency Research). Our research in this area consisted of two parts: (1) planning an electricity-saving strategy for NIES on the basis of historical data; and (2) monitoring the strategy's progress through continuous data collection.

During summer (from July to September), warnings against exceeding the upper limit of electricity consumption at NIES were announced twice, on 10 July and 10 August. Almost 10% of our electricity consumption was cut immediately after the warning, although it was found later from electricity consumption data that some facilities had re-started before the warning was cancelled. Regardless of the announcement of these two unexpected warnings, and with the cooperation of all NIES staff, we managed to limit our electricity consumption by up to 95.8% of the voluntary target (5000 kW) in July, by 92.2% in August, and by 89.8% in September.

4.3 Research on climate change impact and adaptation

Our project on "Comprehensive Study on Impact Assessment and Adaptation for Climate Change" consisted of systematic impact projections for Japan, based on new Representative Concentration Pathway (RCP) scenarios. It established common scenarios for the national impacts of GHG concentration pathways and climate scenarios in order to project impacts in the mid-21st century (2031–2050) and late 21st century (2081–2100). The consequences for Japan across a broad range of global warming impacts throughout the 21st century were reaffirmed. These include escalating impacts on 1) public health and safety; 2) quality of life and economic activity; and 3) ecosystems and other environmental fields. These impacts stem from the detrimental effects of meteorological disasters, heat stress, and other relevant factors on health, water resources, and agriculture.

4.4 International institutions beyond 2020

In this study we aimed to explore a plausible international agreement under the United Nations Framework Convention on Climate Change (UNFCCC) that could be achieved by the year 2015. On the basis of our research results in FY 2012, we held a side event, the "Dialogue on the Agreed Outcomes by 2015 under the Durban Platform Process," during COP19 of UNFCCC, held in Warsaw in November 2013. The side event invited established experts on international institutions and included discussions with the audience on the key elements and legal form of the agreement.

4.5 Development of sustainability indicators

Our aim in this study was to investigate sustainable development indicators, both

for Japan and at an international level. We conducted a thorough survey to determine the criteria required to construct a variety of existing "sustainability indicators" for such items as food, industry, and education. The survey revealed that the indicators tended to include criteria on social issues such as basic human needs the most, and that some of them tended to neglect the sustainable use of natural resources in the long term. We also conducted another online survey to investigate how Japanese people in general perceived happiness and the values they wanted to sustain into the future in Japan. The "values" were categorized into social, environmental, and economic ones. The results showed that many Japanese people considered social issues such as pension funds and healthcare to be the most important for their happiness.

5. Environmental Urban Systems Section

Our section pursues studies on the environmental and economic sustainability of cities, with a focus on local energy systems, regional resource circulation, transportation systems, and land-use-control management systems. The target of our section is to develop an integrative urban environment simulation system for regional carbon resources, waste circulation, local energy supply and demand networks, urban and regional transportation, and population migration patterns, and to integrate a combination of these systems.

5.1 Study of China's provincial air pollutant emissions and cost-effective mitigation technologies

China has been suffering substantial environmental problems—particularly the notorious heavy haze in north China in recent years—with increasing large-scale industrialization, urbanization, and the number of motor vehicles. Our research projected China's air pollutant emissions and their reduction potentials by choosing different mitigation technologies, with the aim of finding the most cost-effective technology combinations and regions. We studied 30 Chinese regions (22 provinces, 4 province-level mega cities, and 4 autonomous regions) and three air pollutants (SO_2, NO_x, PM) by applying the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies)–China model. We found that, by 2030, with the implementation of air mitigation technologies, China's SO_2, NO_x, and PM emissions would be reduced by 56.2%, 46.3%, and 44.4%, respectively from no mitigation technology case. Further analysis revealed regional disparities in terms of reduction potential, unit abatement cost, and economic impact. The most cost-effective regions were generally the less well developed western regions such as Ningxia, Gansu, Sichuan, Chongqing, Guangxi, and Inner Mongolia. In contrast, the least cost-effective regions were mostly the developed eastern regions such as Shanghai, Heilongjiang, Jiangsu, Guangdong, Beijing, and Hebei.

5.2 Integrative environmental policy and technology simulation system

Promoting recycling is important for resource saving, reducing carbon dioxide emissions, and reducing the amounts of wastes going to landfill. At the same time, recycling systems need to be cost effective if the effects of recycling are to increase. Changes in external factors will affect the cost-effectiveness of a recycling system: for instance, Japan and most other developed counties are facing population declines, which will lead to decreasing waste generation. A recycling system should be robust enough to cope with such changes. We therefore structured a framework for a robust recycling system. The system would be realized by considering the quality of resources and energy, making use of existing facilities such as furnaces used in materials industries, producing high-demand recycled products, and keeping a balance in the diversity of waste-treatment facilities with different functions. We used the framework to design a recycling system that promotes the use of a part of waste plastics and papers that are of a quality unsuitable for materials recycling as substitutes for fossil resources in industry. We then conducted a simulation to compare the cost-effectiveness of such a recycling system in a case study area in the Tokyo Metropolitan Region with that of a conventional system. We found that the recycling system could not only reduce carbon dioxide emissions but also lower the overall costs of recycling and appropriate waste treatment. Also, we found that the unit cost of the system was relatively stable in the face of changes in the amount of waste because of its lower fixed costs for facilities.

5.3 Implementation of a community network system for low-carbon rebuilding

We are helping to rebuild several areas damaged by the tsunami disaster and the Tohoku earthquake. One of the targeted cities is the town of Shinchi, which has a population of about 8000 and is located on the north-east coast in Fukushima Prefecture. Although this town was hugely damaged by the disaster, several strategies, such as local accumulation of energy industries, redevelopment of the damaged area, and a policy of attracting industrial development that is symbiotic with the local community, could help the town to recover through appropriate energy and urban planning. Our section has proposed an energy demand and supply optimization system. The demand side would be controlled by an energy-monitoring system that uses tablets in houses and offices. Gas and heat from energy industries would be supplied to industry, agriculture, and urban areas.

We have also developed a Community Network System (CNS) to control regional energy and help with community activities, and this system has been applied to Shinchi. In the CNS, we have built an information center to feed back the needs of residents and businesses by using a combination of basic statistics, map information, and simulation information. Moreover, we have installed smart

meters in residential, commercial, and public facilities for real-time visualization of CO_2 emissions and energy-consumption characteristics. Power saving in response to energy-saving messages can be measured on the basis of these kinds of information and analyses. We intend to establish a system for sharing environmental information and community information that has been weakened by the earthquake. The system will help to reconstruct bonds in the region through the sharing of information on the network.

Fig. 4 The community network system (CNS)
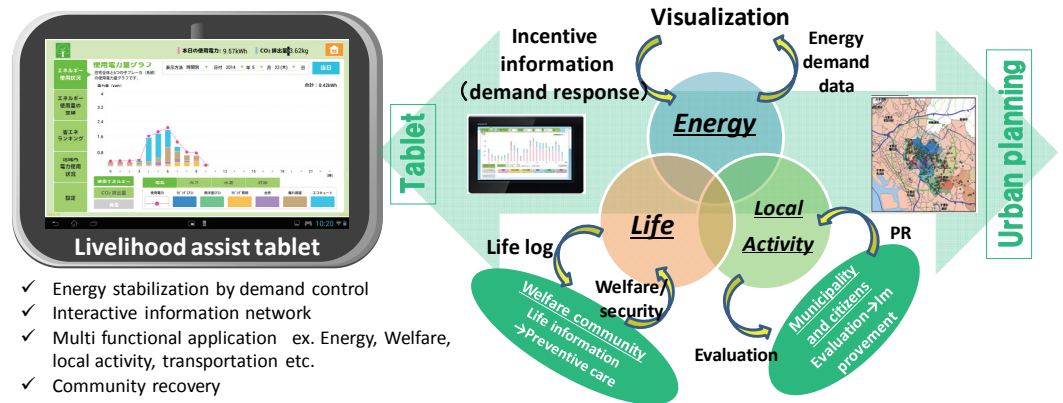
- ✓ Energy stabilization by demand control
- ✓ Interactive information network
- ✓ Multi functional application   ex. Energy, Welfare, local activity, transportation etc.
- ✓ Community recovery

Center for Environmental Measurement and Analysis
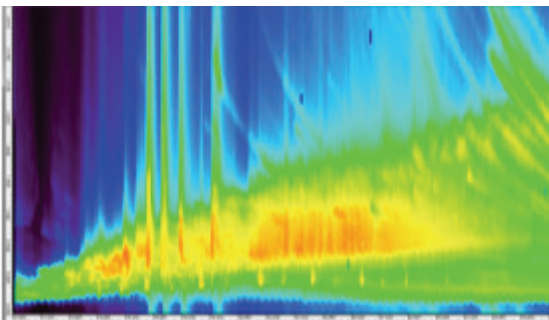
Original total ion chromatogram data from an indoor air sample not subjected to manual cleanup in the laboratory. Sample was assessed by GC×GC–HRTOFMS.

Twenty-nine organochlorines were found after a library search. Dioxins and PCBs were not detected.
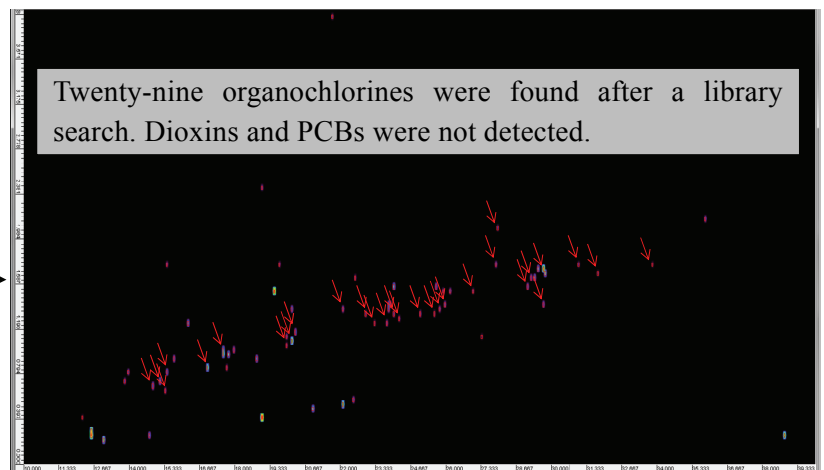
Organochlorines were selectively extracted by processing their high-resolution mass spectra with our newly developed software.
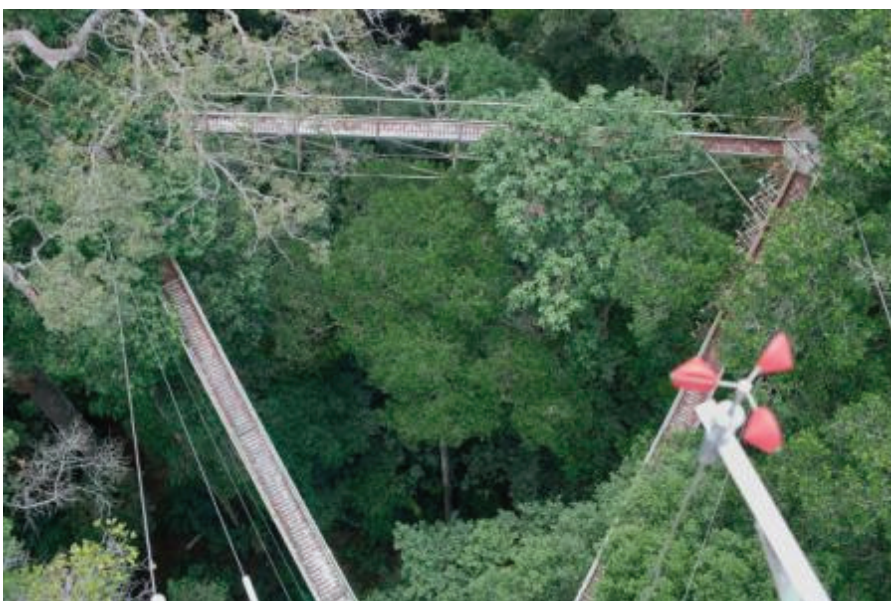
Triangular canopy corridor 31 m high at the Pasoh Forest Reserve in Negeri Sembilan, Malaysia. Field work has been conducted in the tropical rainforest to study the exchange of methyl halides between plants and the atmosphere.

The goals of the **Center for Environmental Measurement and Analysis** are to contribute to the quality assurance and quality control (QA/QC) of chemical analyses of environmental samples, develop better scientific methodologies to improve our understanding of environmental issues, and demonstrate the effectiveness and advantages of these new or improved methodologies.

To achieve these goals, the seven sections of the Center have been conducting a variety of studies. The Fundamental Chemical Analysis Section has been developing environmental Certified Reference Materials (CRMs) and studying their analytical application to QA/QC. The Advanced Organic Analysis Section has been developing techniques for comprehensive analysis of organic pollutants. The Isotope and Inorganic Analysis Section has been investigating precise measurement of the abundance of stable isotopes of heavy metals and sensitive measurement of radiocarbon (^{14}C) in a variety of environmental samples. As part of Radioactive Materials and Environmental Disaster Research Activities at NIES, this section has also been studying the dynamics of radioactive materials emitted by the accident at the Fukushima Daiichi Nuclear Power Plant. The Environmental Chemodynamics Section has been investigating the chemodynamics of natural and anthropogenic volatile organic compounds, as well as carbon cycles in the ocean. The Biological Imaging and Analysis Section has been pursuing the development of techniques for detecting and analyzing the *in vivo* responses of biological systems to various environmental factors. The Advanced Remote Sensing Section has been developing advanced techniques for remote sensing, such as lidar (laser radar), and the Environmental Information Analysis Section has been devising new methods of analyzing the large quantities of data gathered by using space- and ground-based remote-sensing techniques.

Following are brief accounts of some of the important results of our research in FY 2013.

Preparation of certified reference material for Kosa Dust (NIES CRM no. 30)

Surface soil was collected from four locations in the southern Gobi Desert in Mongolia and the pooled material was subjected to coarse sieving, classification by treatment with a cyclone classification, refinement, and homogenization, yielding 1.2 kg of a fine dust with a particle diameter below 10 μm. For certification, elemental analyses were performed by 13 independent laboratories; after statistical assessment of the data, 11 elements (Na, Mg, Al, K, Ca, Ti, Fe, Mn, Zn, Sr, and Ba) were certified. The certified values are listed in Table 1. A further 11 elements (Si, P, Sc, Cr, Co, Ni, Cu, La, Pb, Th, and U) were given reference-only values. This CRM has been designated NIES no. 30 "Gobi Kosa Dust." (*Kosa*, meaning "yellow sand," is the Japanese term for mineral dust blown in from the Asian continent.) We estimated the median aerodynamic diameter of the dust to be about 4 μm, which is within the range of median

diameters (3 to 5 µm) of the *kosa* carried to Japan by the wind. The mineral composition of the dust, as determined by the ratios of the concentrations of each element to that of Al, is very similar to those of 11 *kosa* samples collected in Japan (Table 2). This new CRM also contains clay minerals and calcite, which are characteristic of *kosa*. Carbonate carbon, derived from calcite, was estimated to account for about 50% of the total carbon content (2.16%) of the material. The amount of calcium extracted by a 5% acetic acid solution represented about 90% of the total Ca content of the CRM. Assuming that the Ca was all in the form of calcium carbonate, the carbonate carbon content was calculated to be 1.1%. This value was in good agreement with the results of a direct analysis.

NIES no. 30 is a useful material for quality control and for verifying the results of experiments on the environmental behavior of Asian mineral dust.

Table 1 Certified values for NIES CRM no. 30

Table 1

	Mass fraction		
Element	Unit	Certified value
Na	%	0.939 ± 0.071
Mg	%	1.51 ± 0.13
Al	%	7.58 ± 0.42
K	%	2.13 ± 0.11
Ca	%	4.25 ± 0.35
Ti	%	0.426 ± 0.040
Fe	%	3.84 ± 0.35
Mn	mg/kg	768 ± 83
Zn	mg/kg	93.1 ± 8.5
Sr	mg/kg	250 ± 20
Ba	mg/kg	535 ± 31

Table 2 Ratios of the concentrations of each element to that of Al (mass basis) in NIES no. 30, CJ-2, and 11 representative kosa samples collected in remote areas on the western (upwind) side of Japan over the period 2000 to 2011

Table 2

			Typical kosa dust in Japan (n=11)		
Element	NIES No.30	CJ-2	Range	Average	RSD (%)
Na	0.124	0.235	0.116-0.455	0.257	40
Mg	0.199	0.267	0.203-0.347	0.264	14
K	0.281	0.289	0.298-0.350	0.322	6.0
Ca	0.561	0.906	0.326-0.926	0.527	33
Ti	0.0562	0.0782	0.0469-0.083	0.0596	17
Fe	0.507	0.514	0.514-0.585	0.557	4.1
Mn	0.0101	0.0109	0.0125-0.0150	0.0137	4.8
Zn	0.0012	0.00134	0.0018-0.00977	0.0053	59
Sr	0.00330	0.00415	0.00260-0.00588	0.00369	24
Ba	0.00706	0.00798	0.00637-0.00917	0.00777	9.9

Software for detection of halogenated compounds using data obtained by GC×GC–HRTOFMS of environmental and biological samples

We developed a method that selectively extracts a subset from comprehensive 2D gas chromatography (GC×GC) and high-resolution time-of-flight mass spectrometry (HRTOFMS) data in order to detect and identify trace levels of organohalogens.

The data were obtained by measuring several environmental and biological samples, namely fly ash, soil, sediment, the atmosphere, and human urine, without any sample purification, because in this global analysis we searched for as many pollutants as possible. Samples were measured with a series 6890 gas chromatograph (Agilent Technologies, Palo Alto, CA, USA) with a KT2004 GC×GC system (Zoex, Houston, TX, USA) coupled with a JMS-T100GC (JEOL, Tokyo, Japan) HRTOFMS system.

By using original software that finds isotopic clusters of chlorine in mass spectra, we achieved selective extraction of the mass spectra of organochlorines from the huge amounts of data obtained from the samples by GC×GC–HRTOFMS. For accurate data extraction, high mass resolution and mass accuracy were essential.

The use of mass defect (the difference between the nominal and exact masses of an element) was very effective in isolating the mass spectra of hydrocarbons. Figure 1 gives three examples obtained by applying a mass defect filter (MDF) to the original data from the indoor air, sediment, and human urine samples. If the sample (e.g. an air sample) contained a lot of hydrocarbons and the mass spectra of their fragments overlapped with those of the target, then the MDF was very effective in removing these spectra. (Compare (a) and (b) in Figure 1.) However, the mass spectra of molecular sulfur in the sediment sample or in metabolites or biological derivatives in human urine samples could not be removed with the MDF (see (b) and (c) in Fig. 1). This is because the hydrogen in hydrocarbons has a mass sufficiency and the sulfur, oxygen, and heavier elements, which are commonly found in metabolites, have a mass deficiency. Direct measurement and data extraction by using new software were therefore effective for non-target analysis. However, deconvolution of the peaks and mass spectra is required to improve data extraction performance, because many compounds are co-eluted even when GC×GC is used, depending on the sample matrix. Further development and improvement of the hardware and software for GC×GC–HRTOFMS will make it possible to qualify and quantify many compounds simultaneously.

Fig. 1 Comparison of the results of pre-screening of samples with a mass defect filter.
Notes:
MDF, mass defect filter; TIC, total ion current
1 Retention times on the first and second gas chromatograms are shown in minutes and seconds, respectively.
2 Mass spectra with mass deficiencies within the range of 0 to −0.2 were left in the data; other spectra were removed.
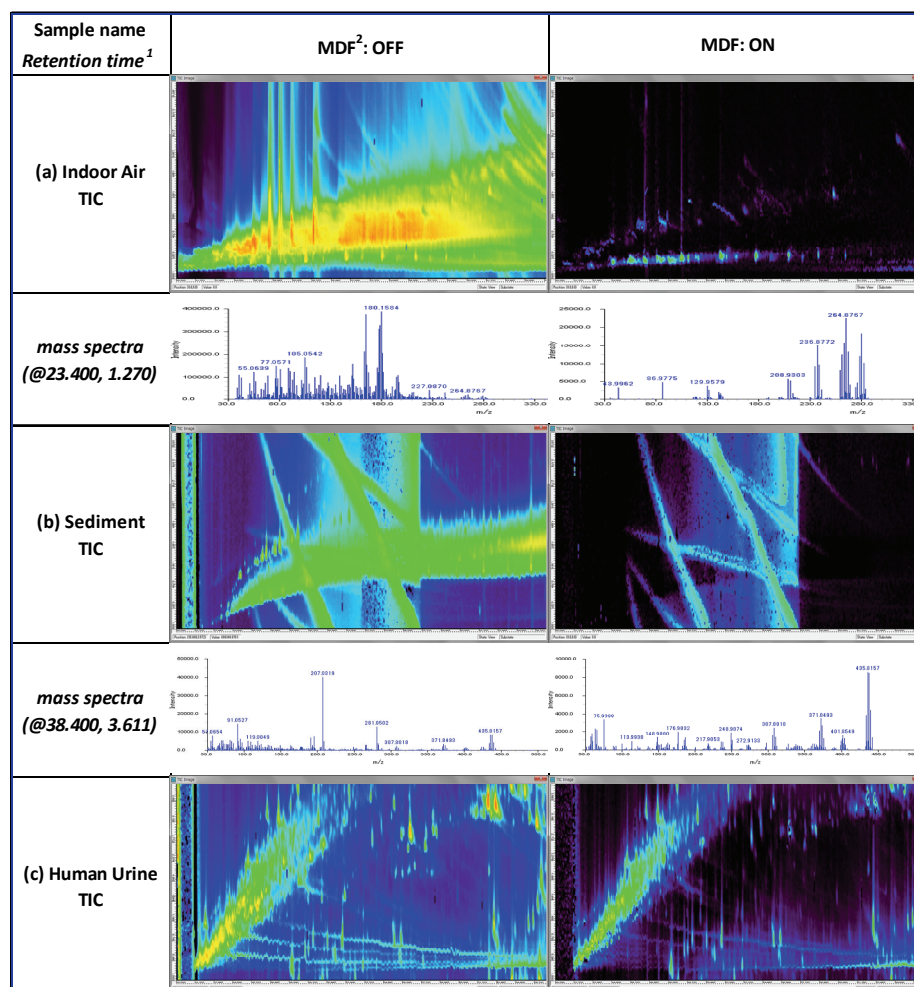
Bidirectional exchange of methyl halides between tropical plants and the atmosphere

Tropical plants play an important role in stratospheric chemistry by emitting methyl chloride and methyl bromide, which carry ozone-depleting halogens to the stratosphere. However, the factors affecting the emission of methyl halides are not well known. Here, using a stable isotope tracer technique, we studied the exchange of methyl chloride (CH_3Cl) and methyl bromide (CH_3Br) between plants and the atmosphere in a tropical rainforest in Malaysia. Most plant species examined showed not only production but also consumption of CH_3Cl, with a large net emission overall (Figure 2, top). In contrast, CH_3Br consumption was comparable to its production, so the net emission was small (Figure 2, bottom). The rates of CH_3Cl and CH_3Br consumption were highly correlated with each other, and their ratio was consistent with the values reported in other terrestrial ecosystems, where microorganisms have been found to be responsible for this consumption. Such microorganisms might also participate in the consumption we observed in this tropical ecosystem, as consumption rates were faster in saplings (the leaves of which were generally covered with epiphytic microorganisms) than in healthy looking leaves on mature trees.

Fig. 2 Rates of gross production (gray bars) and gross consumption (white bars) of (top) CH_3Cl and (bottom) CH_3Br by tropical plants at the Pasoh Forest Reserve in Peninsular Malaysia. Error bars indicate standard deviations for single species.
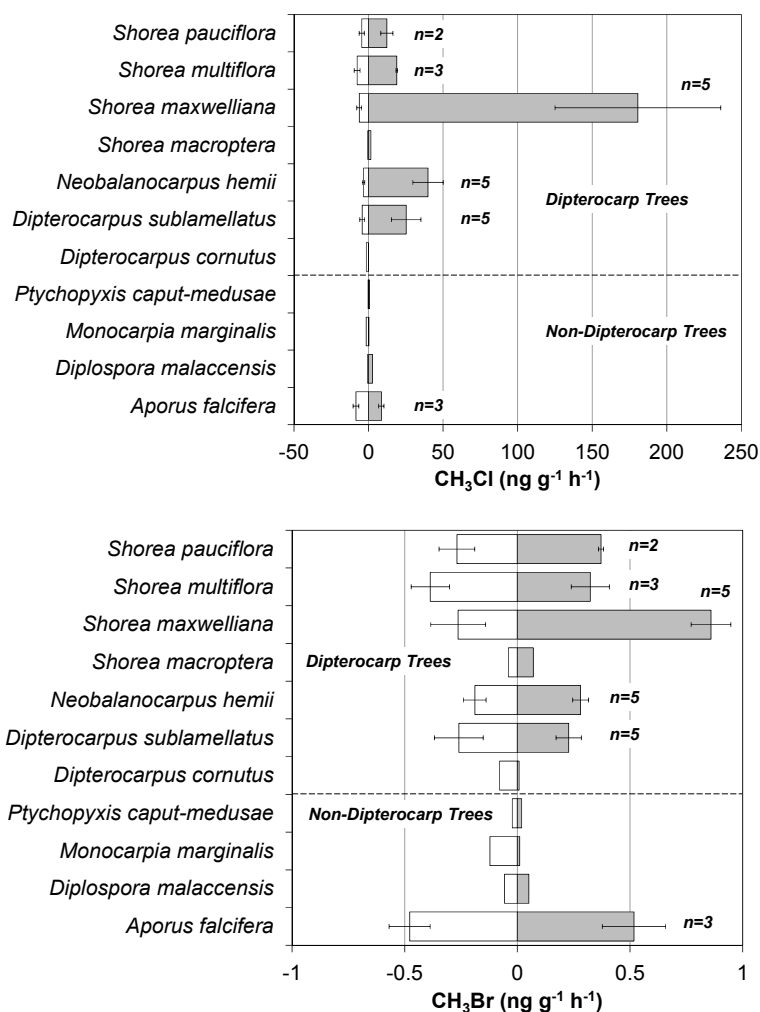
Absolute quantitation of glutamate, GABA, and glutamine by using *in vivo* localized 2D constant-time correlation spectroscopy

Glutamate (Glu) and γ- amino butyric acid (GABA) are major neurotransmitters in the human brain. Glutamine (Gln) is a precursor and storage form of Glu that is synthesized predominantly in astrocytes and plays an important role in the Glu-Gln cycle in the human brain. Therefore, measuring the concentrations of Glu, GABA, and Gln *in vivo* may give us useful information on human health. Although these metabolites can be detected by magnetic resonance spectroscopy, in conventional ^{1}H spectra of the human brain, their peaks overlap because of strongly coupled spin systems. We therefore proposed an absolute quantitation method for these metabolites that uses localized 2D constant-time correlation spectroscopy (CT-COSY). We collected several CT-COSY spectra with a variety of constant-time delays from a localized voxel in the human brain (Figure 3a). For quantitation, we developed a T_2 correction, a curve-fitting to determine the peak volume (Figure 3b), and a calibration using an internal water reference from the same voxel (Fig. 3c). To validate this method, we performed experiments with a 10-mM glutamate solution; we also measured Glu, GABA, and Gln in a human brain. The measured glutamate concentration of the phantom solution was 9.4 mM. The concentrations of glutamate, GABA, and glutamine in the parieto-occipital lobe of a human brain were 9.5, 0.61, and 3.6 mM, respectively; these values were in good agreement with those previously reported. In conclusion, the concentrations of metabolites in the presence of strongly coupled spin systems can be measured by using our proposed absolute quantitation method on 2D CT-COSY spectra.

Fig. 3 In our absolute quantitation protocol, CT-COSY spectra are obtained from a voxel in the human brain (a). The region around the diagonal peak of glutamate is extracted for curve-fitting (b). The water signal in the same voxel is also obtained for use in calibrating the concentration of glutamate (c).
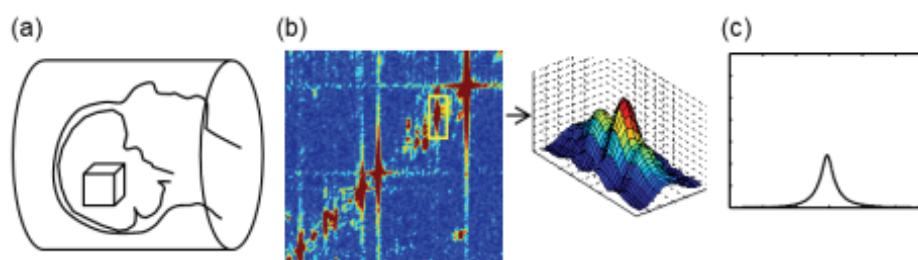

Three-dimensional transport of Asian dust revealed by AD-Net observations and CFORS assimilation

We studied Asian dust events as part of Japan-Korea-China Joint Research on Dust and Sandstorms under the Tripartite Environment Ministers Meeting (TEMM WG1). We used the AD-Net lidar network (the Asian Dust and Aerosol Lidar Observation Network, coordinated by NIES), CFORS (the Chemical Weather Forecasting System), and shared surface observation data. Transport of Asian dust and mixing with air pollution aerosols were analyzed in four Asian dust events, in 2008 (24 May to 4 June) and 2009 (12 to 25 March, 13 to 26 October, and 15 to 28 December).

The event of 24 May to 4 June 2008 was important in that it was unusually late in the spring dust season. The dust event of 12 to 25 March 2009 was an interesting example of an elevated dust layer, and transport of dust from the elevated dust layer to the ground by boundary layer activity was observed by the lidar and surface observations. The dust events in October and December 2009 were examples of dust events in autumn and winter, respectively. The online mode of CFORS reproduced the observation data generally well, except in the case of the event from 24 May to 4 June 2008. Four-dimensional variational assimilation of the lidar network data reproduced the dust concentrations in Korea and Japan during that event reasonably well (Figure 4).

The concentration of air pollution aerosols was generally high at the beginning of the dust events in Seoul, except during the October 2009 event. During the dust elevation event in March 2009, the air pollution aerosol concentration remained relatively high. Our results showed that the vertical structure, as well as the transport path, was important in the mixing of dust and air pollution. They also suggested that understanding the state of mixing of dust and air pollution aerosols was indispensable in studying the effects of Asian dust on the environment and human health. We recently introduced an in-situ-polarization optical particle counter that measures the size and non-sphericity of each particle. We have started simultaneous observations with lidar in Seoul to study the optical characteristics of internally mixed polluted Asian dust.
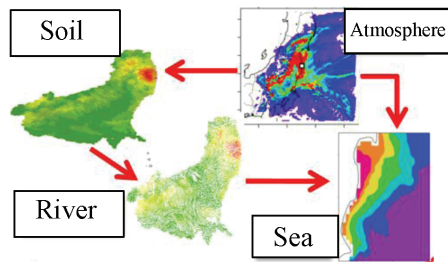
Fig. 4 Time–height indications of the dust extinction coefficient during the dust event of 24 May to 4 June 2008, as (a) observed with the lidar network and (b) calculated with the assimilated model
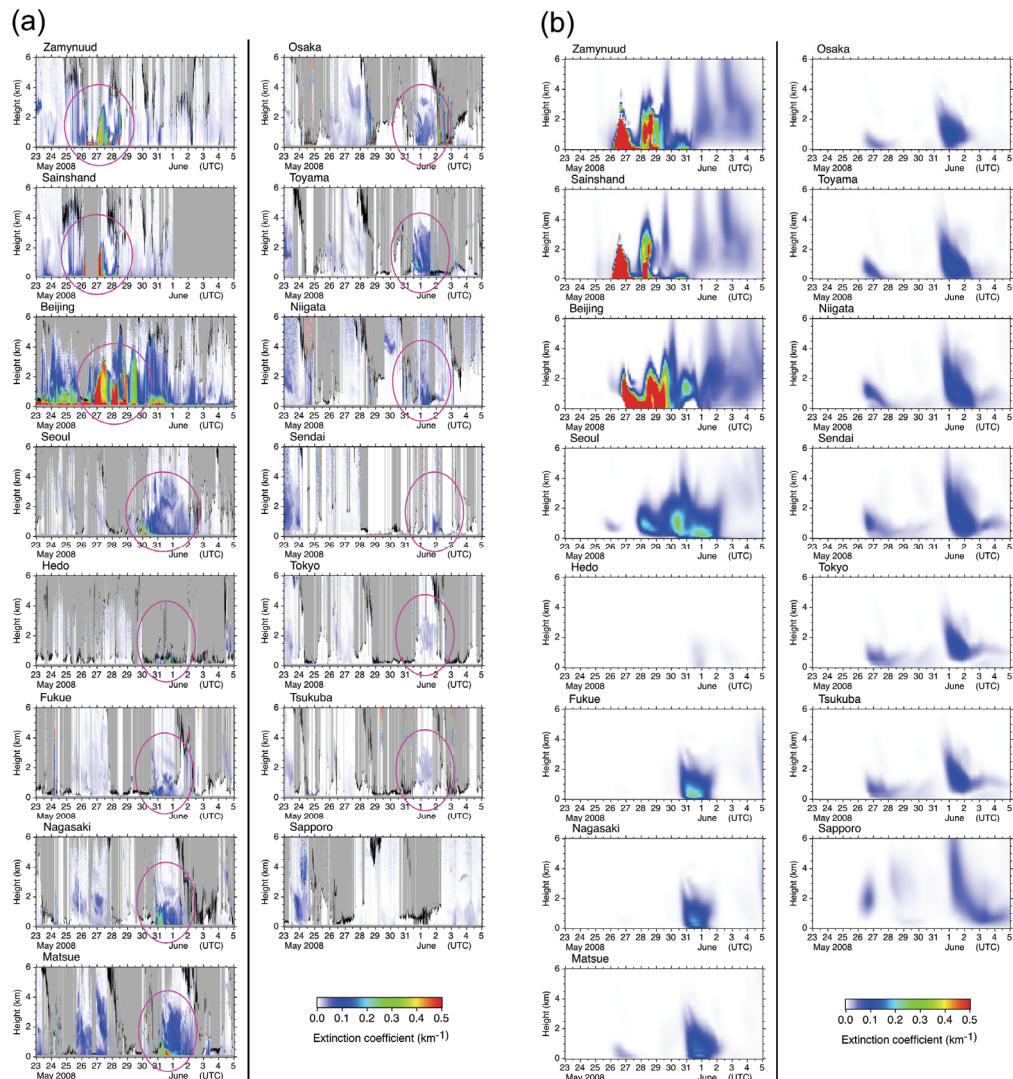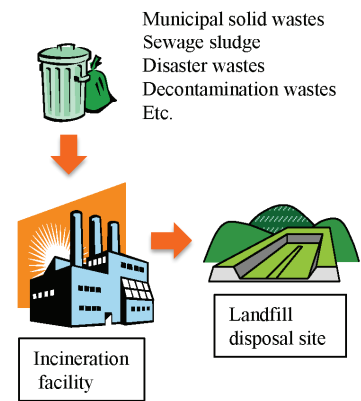
Environmental Emergency Research
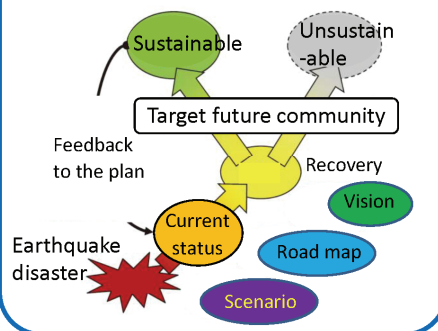

Environmental Recovery Research Program

- Radioactively contaminated waste management

Soil

Atmosphere

River

Sea

Municipal solid wastes
Sewage sludge
Disaster wastes
Decontamination wastes
Etc.

Incineration facility

Landfill disposal site

- Radioactive substances behavior
- Research into impacts on organisms and ecosystems

Environmental Renovation Research Program

Sustainable

Unsustain-able

Target future community

Feedback to the plan

Recovery

Vision

Current status

Road map

Earthquake disaster

Scenario

Environmental Emergency Management Research Program

- Capacity development

- Quantitative estimation of disaster debris

0   5   10   15
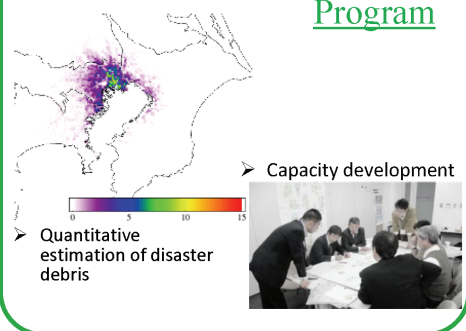
1. Establishment of technologies and systems for managing disaster wastes and radioactively contaminated wastes

Large amounts of disaster waste were generated as a result of the Great East Japan Earthquake in March 2011. Moreover, the Fukushima Daiichi Nuclear Power Plant accident resulted in the grave problem of solid waste contaminated by radioactive substances. We are performing various types of urgent research on behalf of central and local governments into the appropriate management of these wastes to contribute to the solving of these problems in as expedient a manner as possible.

Our research is reflected in various measures, including technical guidelines from the Ministry of the Environment (MOE), discussions by an MOE panel, and the passing of the *Act on Special Measures Concerning the Handling of Pollution by Radioactive Substances*. With the help of these measures, we expect to make a real contribution to the establishment of techniques for managing radioactively contaminated waste.

Below is a summary of our main research findings.

1.1 Clarification of fundamental properties and behavior mechanisms of radioactive substances

1) Distribution of cesium to ash during incineration of contaminated biomass
We investigated the distribution of radioactive cesium (Cs) to ash during the combustion of various types of contaminated waste biomass at different temperatures (Fig. 1). The distribution behavior differed significantly among the different types of biomass, and it also depended on the combustion temperature. In addition, we conducted a leaching test of the ash residues. The leaching ratios of radioactive Cs differed among the different types of biomass. The differences in the distribution and leaching behaviors were explained by the transformation of radioactive Cs compounds during biomass combustion, as predicted by our equilibrium calculation method. We used this method to develop various types of multizonal equilibrium models for predicting the transformation of radioactive Cs compounds in facilities for the incineration of contaminated municipal solid waste.

Fig. 1 Distribution of radioactive cesium (r-Cs) to ash during combustion of various waste biomass samples
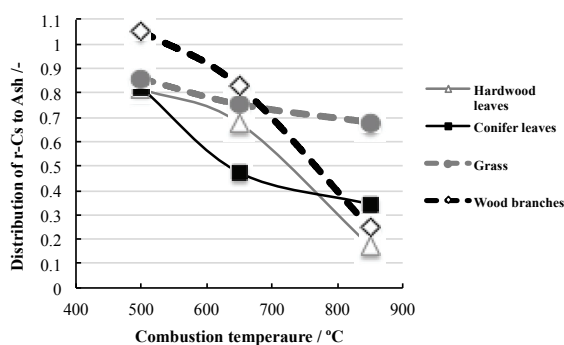
2) Leaching characteristics of radioactive Cs from soils and plants

We performed long-term leaching tests on a radioactive Cs-polluted decomposed granite soil and a radioactive Cs-polluted zeolite. The percentage of leached radioactive Cs was lowest in pure water, moderate in seawater, and highest in landfill leachate. When landfill leachate was used, the rate of radioactive Cs leaching from decomposed granite soil was about 15%; the rate of leaching from zeolite was 4%. The lower leachability in zeolite is likely related to the crystal structure of this medium. Further investigation is needed to determine whether the chemical form of absorbed radioactive Cs changes with time.

Sequential extraction testing revealed that the amount of radioactive Cs in the water-soluble fraction approximately doubled when a organic soil was a mixed with 20% plant material. However, the amounts of radioactive Cs in the ion exchange fraction and carbonate fraction did not change.

Percolation testing revealed that the radioactive Cs concentration decreased gradually when plant materials were incorporated into the soil at various concentrations; this effect decreased as the L/S increased (Fig. 2).

Fig. 2 Changes in ^{137}Cs concentration in an upflow percolation test of soil–plant mixed samples
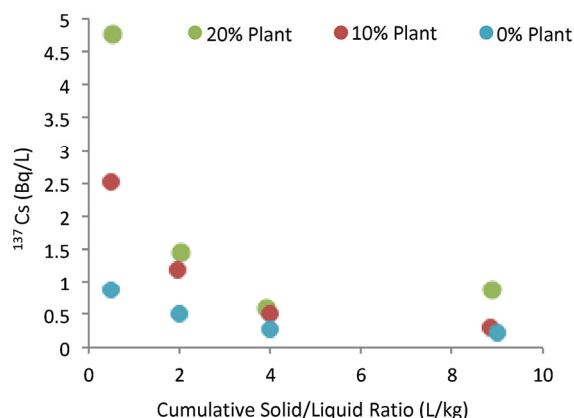
3) Landfill soil adsorption ability

It is important to install a soil layer under radioactively contaminated waste that is disposed of into landfills. Although it is well known that soil can adsorb radioactive Cs, this ability is poor if the landfill leachate is highly saline. We performed batch-type adsorption tests by using leachate from contaminated fly ash samples as a solvent because this leachate was more saline than seawater. The adsorption capability declines with the use of saline leachate because the leachate contains thousands of ppm of potassium and calcium. The distribution coefficients obtained for radioactive Cs in various soils when we used solvent with its electrical conductivity adjusted to 4000 mS/m are shown in Figure 3. A distribution coefficient of the zeolite is hundreds mL/g even if it is tens of thousands mL/g when a pure water is used as a solvent.

Fig. 3 Distribution coefficients of radioactive Cs in soil layers under landfill
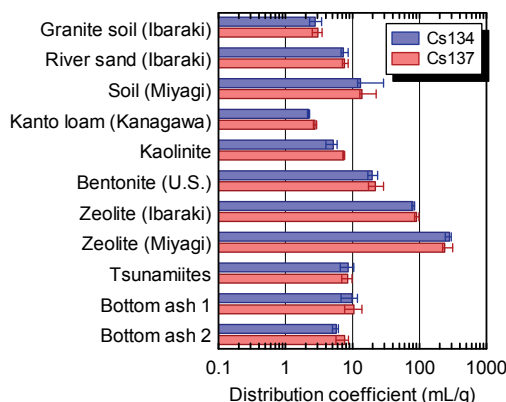
## 1.2 Development, optimization, and assessment of treatment, disposal, and recycling technologies

1) Waste volume reduction by using thermal technology and fate assessment of Cs in incineration processes and in refractory brick

We measured the concentrations of r-Cs and other elements in solid samples from a stoker furnace with an ash-melting system for municipal waste and from a temporary incineration plant for disaster waste. We concluded that controlling the ratio of CaO to SiO_2 effectively controls the distribution of radioactive Cs between fly ash and bottom ash and also between slag and melting fly ash.

We developed a melting decontamination technology for radioactive ash from biomass incineration and sewage sludge. A large-scale experiment (3 t/day) using a surface-melt furnace gave high levels of decontamination, with a Cs removal ratio of more than 99%.

We surveyed the accumulation of radioactive Cs in refractory brick samples from waste incineration facilities (Fig. 4). We analyzed the concentrations of both dioxins and radioactive Cs in the refractories and on the materials deposited on an inner wall of the incinerator. Furthermore, we measured the air dose outside and inside the incinerator and before and after repair of refractory materials due to their deterioration. Data on the relationship between the measured dioxin concentration and radioactive Cs activity and on the air-dose reduction effect of refractory repair or replacement were of fundamental use for maintenance and demolition of the waste incinerator in a safe manner.

Fig. 4 Profile of radioactive Cs activity in refractory brick, plotted against refractory depth
Left side: inner wall of incinerator, right side: outer wall of incinerator
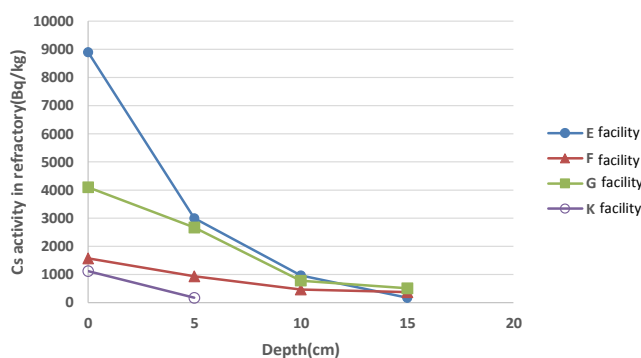
2) Development of washing and treatment technologies for r-Cs-contaminated ash and leachate

Almost 20,000 t of ash contaminated with $^{134/137}$Cs at an activity concentration of more than 8000 Bq/kg was produced by municipal solid waste incineration in FY 2013. As of 31 March 2014 a total of 100,000 t of contaminated ash was being stored on site.

Normally, the percentage of Cs leached from fly ash by water is very high, but some samples have poor leaching efficiencies. Adsorption tests using fly ash leachate revealed that the activated clay used for exhaust-gas treatment adsorbs Cs moderately well; we assumed that activated clay is therefore an important factor in Cs leaching efficiency.

An average of 90% of r-Cs was removed from fly ash in a bench test of washing followed by Cs adsorption. Repetitive washing of fly ash decreased the radioactive Cs concentration of the washed ash. Radioactivity in leaching tests was also decreased by repeated washing (Fig. 5). Radioactive Cs in the leachate was removed with zeolite, and the radioactivity of the effluent water was less than 10 Bq/L. The radioactivity of the used adsorbent can be controlled to below 100,000 Bq/kg by using an appropriate mixture of zeolite and other minerals; the adsorbent can then be disposed of at a national final disposal site in Fukushima. During the bench testing we were able to control the radiation dose rate to below the standard of the Ministerial Ordinance on Prevention of Ionizing Radiation Hazards; the fly-ash washing process can therefore be done safely.

Fig. 5 Relationship between radioactivity in leaching tests and number of washings
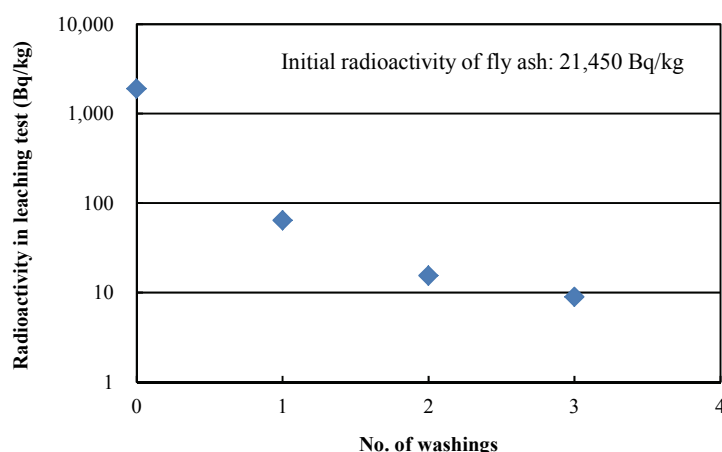
3) Application of concrete technologies

NIES has organized ten technical meetings of specialists from various technical fields such as concrete materials, concrete structures, construction technology, waste management, radioactive wastes management, and swelling soil and is preparing a technical report on the application of concrete technology in final disposal facilities for municipal solid waste incinerator (MSWI) ash contaminated with radionuclides. MSWI fly ash contains substantial amounts of $CaCl_2$, alkali chlorides, and $Ca(OH)_2$. The concrete pits used in final disposal facilities are

isolated carefully from water by the use of multiple barriers. However, if accidental water incursion occurs then the concrete can degrade (Table 1). To avoid serious damage, despite the fact that the possibility of such unusual accidents is extremely low, we plan to enhance the durability of the concrete by using fly ash from coal-fired power plants in order to obtain adequate time to prepare suitable action against such a problem.

Table. 1 Problems with final disposal of radioactive Cs–containing MSWI fly ash in reinforced concrete facilities (gothic indicates very rare case accidents) samples

Component	Possible issues	Countermeasures
Soluble radioactive Cs	Release of water into facilities may leach out soluble radioactive Cs and create radiation hotspots.	Protection from water intrusion; ensuring system isolation; immobilization of Cs
Stable Cs in the order of 0.1–10 ppm	The absolute quantities of radioactive Cs released from the Fukushima accident are extremely limited compared with the amounts of stable Cs present in MSWI fly ash at concentrations on the order of 0.1 to 10 ppm; both types of Cs contamination need to be considered.	Use absorbent with adequate ability to immobilize Cs.
KCl in the order of %	Zeolite, bentonite, and soil can adsorb Cs, but their performance is seriously degraded by K at high concentrations.	Consider the coexisting effects of ions on Cs adsorption when designing adsorbents.
$CaCl_2$ on the order of 5% to 30%	Drying shrinkage of concrete as a result of deliquescence of $CaCl_2$.	Use an expansive agent or shrinkage-reducing agent
	Generation of concentrated chloride solution as a result of moisture absorption and deliquescence of $CaCl_2$.	Estimates indicate that this would take 100 years. And therefore is not an immediate problem
	Once concentrated chloride solution is generated, the corrosive effect on steel reinforcement by the chloride will be severe.	Decrease Cl diffusion in the concrete and use coated or stainless-steel reinforcement.
	Once concentrated Ca chloride solution reaches the concrete, the concrete can be degraded by the generation of expansive minerals.	Add pozzolanic materials containing reactive siliceous phase such as fly ash from coal-fired plant, blast furnace slag, silica fume, meta-kaolin, etc.
Alkali chloride at high concentration	Once concentrated alkali chloride solution reaches the concrete, alkali-silica reaction can induce cracks in the concrete.	Evaluate the suppressing effect of pozzolanic materials and use them appropriately.

4) Landfill and storage technology for contaminated wastes and soil
With the aim of exploring ways of stably and temporarily storing biodegradable decontamination wastes, we demonstrated the structural stability and safety of press-packed baling. By using press-packed bales we were able to more than halve the required storage area, and no heat accumulation or risk of spontaneous combustion was observed.

To check for use of the appropriate landfill methods, we patrolled landfill sites where radioactively contaminated wastes had been disposed of. The fate of radioactive Cs at each landfill site was simultaneously simulated by using the

finite element simulation code COMSOL.

Rainwater infiltration has to be controlled for the appropriate operation of landfills used for the disposal of radioactively contaminated wastes. Infiltration rate becomes an important factor in the design of final cover systems for landfills. We have constructed a demonstration site to simulate infiltration rates and have started monitoring the water balance.


Fig. 6 Site for demonstration of final cover systems for landfills

1.3 Establishment of monitoring technologies for radioactivity, and their application to waste management

Ways of measuring Cs radioactivity in bulky waste urgently need to be developed so that we can rapidly and accurately evaluate the disaster wastes that need to be treated or disposed of in the disaster zone or evacuation areas. We developed a new plastic scintillation detector for large-scale measurement and applied it to 13 flexible waste-container bags stored at one site in Fukushima Prefecture (Fig. 7). Within 70 s, Cs radioactivity in the whole 1-m^3 flexible bag can be measured by rotating the bag and directing its entire surface toward the detector. For comparison, nine increment samples (with a volume of approximately 10 L) were taken from the bags. The samples were further crushed or cut and the radioactivity of their homogenized portions (volume 1 L) was measured with a NaI(Tl) scintillation detector or LaBr$_3$(Ce) scintillation detector. The plastic

Fig. 7 Comparison of results of measurement of radioactive Cs concentrations in disaster wastes in 13 flexible waste-container bags (values obtained by plastic scintillation detector, NaI(Tl) scintillation detector, and LaBr3(Ce) scintillation detector)
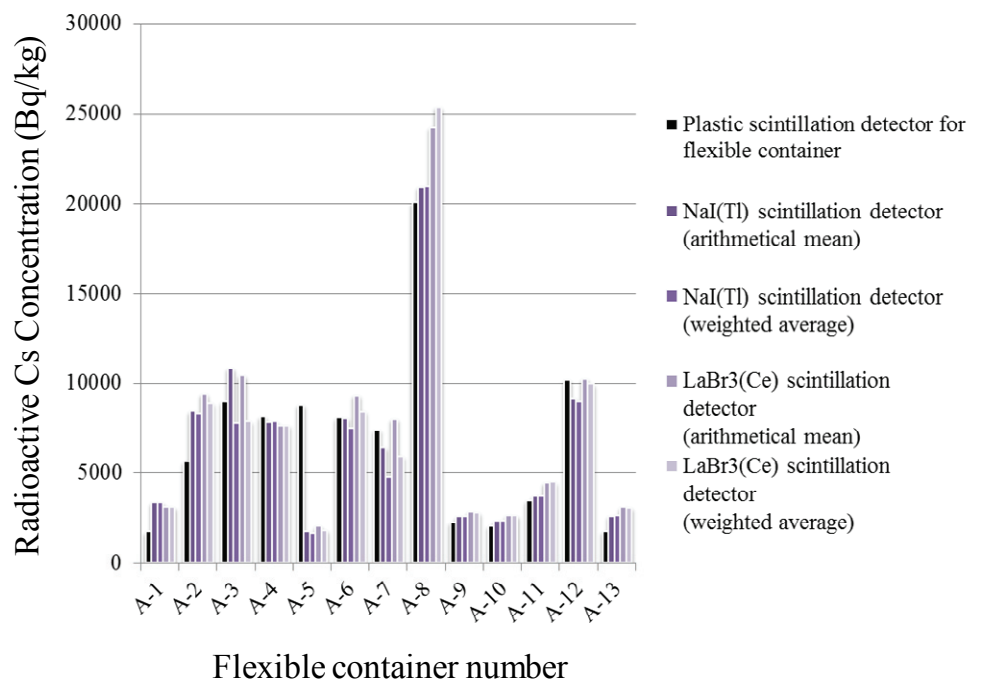
scintillation detector was able to measure radioactivity in the waste bags over a range of about 300 to 20,000 Bq/kg. Its measurement repeatability for the bag (>1000 Bq/kg) was confirmed to be less than 5%, as assessed by using the coefficient of variation. The bulk measurement results obtained with the plastic scintillation detector were also in good agreement with the increment measurement results (calculated as arithmetical means or weighted averages) obtained with the conventional small-scale detectors. The newly developed apparatus should be a powerful tool for screening for radioactivity at thresholds as far-ranging as 8000 or 100,000 Bq/kg before subsequent waste treatment such as incineration or landfilling.

1.4 Elucidating radioactive Cs flows in the anthroposphere to optimize management systems for Cs-contaminated waste

We estimated radioactive Cs concentrations in municipal solid waste (MSW) in eastern Japan by using data on MSW incineration ash and then analyzed their regional and temporal trends (Fig. 8). The radioactive Cs of MSW has decreased over the past 3 years with seasonal variation. When the decrease by radioactive decay and the seasonal variation were eliminated, the radioactive Cs concentration of the MSW has exponentially decreased at the rate of 43% per year. We succeeded in describing the temporal changes in radioactive Cs concentration in MSW incineration ash by using three factors: decreasing trend of input, seasonal variation of input, and radioactive decay. We have conducted a similar analysis of sewage sludge.

Fig. 8 Describing the temporal changes in radioactive Cs concentration of MSW incineration ash in eastern Japan by three factors

*Dotted lines from Nov. 2013 onward are predicted values.
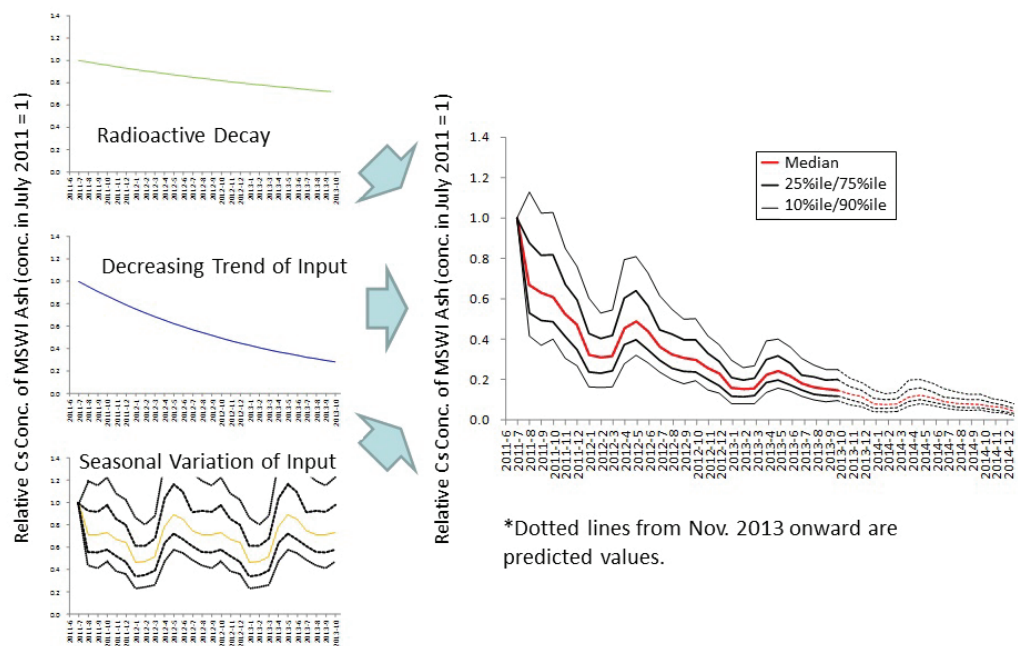
1.5 Risk communication

1) Web questionnaire
We conducted a web questionnaire on "risk uneasiness and information needs" and reported part of the results. In the questionnaire, we studied the respondents' levels of recognition, trust, and information sources in regard to 10 popular scientific misconceptions of the health effects of radioactivity. We collected 1.467 samples covering five age groups (<20, 30s, 40s, 50s, 60s and older) and five areas of Japan (four in the Kanto region and one in Kyushu). Although not everyone (only 30% or less) had heard of these misconceptions, we found that the majority of those who had heard them (65% at most) believed them.

Having an everyday interest in natural science and a degree of scientific literacy were factors that were largely related to the subjects' believing such misconceptions. It is conspicuous in particular in themes that are often associated with radioactivity, such as deformity in animals and plants.

We also found that 6 months to a year after the Fukushima Daiichi nuclear power plant accident more people had changed their minds from distrust of scientific misconceptions to trust than vice versa. The most popular information sources were television and the internet. We investigated the reasons behind this change to trusting scientific misconceptions despite the provision of scientifically correct information via many channels.

2) Selection of landfill sites in Miyagi, Ibaraki, Tochigi, Gunma, and Chiba prefectures for wastes contaminated with radioactive substances
Since March 2013, meetings of the *Yushikisya Kaigi* council of advisers and the *Shicho-Soncho Kaigi* conference of city mayors have been held to select landfill sites for wastes contaminated with radioactive substances. We used a content analysis to analyze the proceedings of the *Shicho-Soncho Kaigi* conference and thus determine whether the city mayors had achieved consensus on how to select landfill sites. We found that they had not reached sufficient agreement.

1.6 Quantitative and qualitative disaster-debris management systems

After the 2011 Tohoku Disaster, it was clearly recognized that for recovery and reconstruction of catastrophically devastated areas in such an emergency we need to dispose of disaster debris appropriately. For unhindered disaster debris disposal, we need to understand the status of the damaged areas and have a quantitative and qualitative understanding of disaster debris, which can be generated by earthquakes, tsunamis, or other events.

In FY 2013, we collected damage and hazard information and established a database of the amounts of disaster debris observed after the 2011 Tohoku Disaster. The amount of disaster debris from this disaster was correlated directly

with the number of completely collapsed, damaged houses (r_s = 0.947, n = 31, P < 0.01). We used multivariate linear regression modeling controlling for the number of damaged dwellings to estimate the per-unit generation of disaster debris. The per-unit generation of complete collapses was estimated to be 116.9 t/house.

1.7 Establishment of a disaster waste management technology and system

1) Evaluation of intermediate treatment technology for disaster waste
We surveyed the status of disaster waste management in all municipalities and at temporary treatment sites in Miyagi and Iwate prefectures, and we analyzed the factors affecting the performance and cost of this work. Rates of incineration and disposal of disaster waste were affected by the quality and quantity of the tsunami sediment included in the waste. We also conducted experiments to find factors affecting performance in the mechanical and manual sorting of real and simulated disaster wastes. In the manual sorting of expanded yard waste, increasing the number of waste items sorted and the amount of work space per person would reduce the efficiency of sorting.

2) Studies of the proper management of asbestos in disaster waste treatment
We examined methods of rapid screening for asbestos in disaster wastes and proposed a screening method that uses a polarized light microscope. We then validated the method by applying it to disaster debris. We found that improved reliability of identification was required for samples containing asbestos at low levels (less than 3%).

As part of a study of the visual identification of asbestos-containing building materials (ACBMs) in damaged buildings, we prepared a manual for visual identification and trained demolition workers and inhabitants to use the manual. We confirmed that the trained persons could accurately identify ACBMs such as slate boards and ceramic sidings more than 90% of the time.

We proposed a procedure for estimating the amounts of asbestos-containing wastes (ACWs) generated in the Great East Japan Earthquake, and we used the procedure to estimate ACWs generated in the city of Sendai. The estimated amounts of board-type ACWs in Sendai mostly agreed with the amounts of board-type ACWs actually treated in that city.

In a study of asbestos emission during disaster waste treatment, we investigated a disaster waste treatment site equipped with sorting machines. We confirmed that no notable scattering of asbestos fibers had occurred. In a study of the scattering of asbestos fibers from ACW-containing soils, we confirmed that the content of friable asbestos components in soils containing disaster debris did not exceed that associated with a 10^{-6} risk level. Scattering of asbestos fibers could be controlled by moistening.

3) Development of recycling technologies and a strategy for disaster waste and by products

We investigated the amounts of materials generated as waste by the Great East Japan Earthquake and Tsunami Disaster and the amounts and requirements for construction works related to recovery from the disaster. We also performed a numerical comparison of the environmental loads of newly excavated soil and of recycling materials recovered from tsunami deposits and industrial byproducts. We concluded that use of tsunami deposits and byproducts should take priority over the use of new soil so as to reduce environmental loads. We proved that tsunami deposits could be used sufficiently well as banking materials from the perspective of physical, dynamic, and environmental safety.

4) Establishment of a disaster reduction–oriented decentralized johkasou system

The Great East Japan Earthquake caused enormous damage to wastewater treatment facilities. The purpose of this research is to help make Japan's wastewater systems more robust by using the *johkasou* decentralized wastewater treatment technology.

We have started to develop and standardize earthquake-resistant construction and installation techniques for *johkasou*. Characterization of data on the damage to 22 types of *johkasou* revealed that the damage to some types had distinctive features. *Johkasou* model experiments revealed that appropriate compaction of soil and the use of various other installation techniques would make *johkasou* more earthquake resistant. In addition, we designed and developed an energy- and water-independent *johkasou* system for a shelter. A mathematical model was developed and applied to demonstrate the best way of transporting human waste and *johkasou* sludge in emergencies. We concluded that wastewater treatment facilities should be re-evaluated from the perspective of disaster response and the costs of recovery.

1.8 Disaster waste management methods

We studied methods for managing disaster waste in terms of preparedness planning and organizational functions. For preparedness planning, we established principles and criteria for effective disaster waste management (DWM) planning on the basis of interview surveys and the literature on emergency planning. One example of such a principle is the following: "DMW Planning should put emphasis on the continuing process, including educational and training perspectives". We tested these principles through ex-post evaluation of a DWM practice in Japan. The results suggested that our proposed principles and criteria were useful as evaluation tools and that the pro-forma-based DWM planning currently undertaken in Japan had some weaknesses.

In our examination of organizational functions, by structuralizing actual DWM operations observed in the case of the Great East Japan Earthquake, we identified

the fundamental emergency-support functions needed for DWM. Data were collected through a series of interviews and literature surveys and then structuralized by using a hypothetical DWM support function framework based on the five principal functions (incident command, operations, logistics, finance/administration, and planning) of emergency response adopted by the US Incident Command System. Our analysis showed that the hypothetical framework matched actual DWM practice well, and we have now identified a set of emergency support functions for DWM.

1.9 Networking of disaster and environmental emergency research

It is important for future disaster resilience in our environment that our experience of the 2011 Tohoku Disaster is transferred to the next generation. Also, it is important that we share our practical knowledge of environmental emergencies with the whole world. NIES has worked hard to establish a new field of research, namely "Environmental Emergency Management Research." Establishment of an intelligence network for environmental emergency management research is a crucial practical element of Environmental Emergency Management Research.

In FY 2013 we conducted a questionnaire survey on disaster waste management; it revealed that there was a demand for sharing knowledge, information, and expertise on this issue. We developed an intelligent platform for disaster waste management and planning; the aim of the platform is to disseminate comprehensive information on disaster waste disposal and treatment based on the 2011 Tohoku Disaster and other past natural disasters.

Disaster reduction and prevention in environmental emergencies requires not only an exchange and networking platform system but also the development of capacity in environmental emergency management. One of the objectives of this research project is to develop a training program for local government practitioners who play leading roles in disaster waste management. First, we identified the competencies required for those administrators who have responsibility for disaster waste management in an emergency. We then held a 2-day workshop in which participants with various types of experience in disaster waste management and planning discussed the issues and their solutions. At the workshop we also identified the competencies required for these solutions. The output has been analyzed according to our KSA (knowledge, skill, and attitude) framework, which we developed from the leadership literature and training evaluation studies. We found that administrators of disaster waste management require technical skills, human skills, and conceptual skills based on practical knowledge of both waste management and disaster management.

2. Study of the dynamics of radioactive materials in multimedia environments

A nuclear accident at the Fukushima Daiichi Nuclear Power Plant (FDNPP) accompanied the Great East Japan Earthquake and Tsunami on 11 March 2011. As a result, enormous amounts of radioactive materials were emitted into the atmosphere and the ocean. Radioactive materials adversely affect human health through the contamination of air, water, soil, and food. It is therefore of great important to understand the current status of radioactive contamination and the dynamics of radioactive materials in multimedia environments.

From this perspective, to gain a better understanding of the impacts of radioactive contamination on wildlife and ecosystem health, we implemented a study of the dynamics of radioactive materials in multimedia environments by using field measurements and multimedia fate modeling. The main results are summarized below.

2.1 Contamination of marine organisms in the inshore waters of Fukushima by radionuclides from the nuclear disaster and possible adverse effects

Since October 2012, we have been investigating contamination of the inshore waters of Fukushima Prefecture by radionuclides released from the accident at the FDNPP. We have been examining the marine environment and looking for adverse effects in marine organisms. In mid-October 2012, we used a Smith-McIntyre bottom sampler to collect bottom sediment samples from 66 sites to determine the geographic/horizontal distributions of radionuclides in Fukushima inshore waters. On board the survey ship, we obtained sub-core samples from the bottom samples. In the laboratory the sub-core samples were cut to a thickness of 2 cm and then roughly dried. The radionuclide content of each of the 2-cm-thick sub-core samples was determined by using a gamma spectrometer with a germanium semiconductor detector. The concentrations of radioactive Cs (the sum of ^{134}Cs and ^{137}Cs) in the surface layer sediment (the 0- to 2-cm layer of the sub-core samples) appeared to be higher in the southern waters than in the northern waters. The highest concentration of radioactive Cs in the surface layer sediments was 1650 Bq/kg, at site S50-A-1 (Fig. 9). The vertical distributions of radioactive Cs in the sub-core samples differed among sites: the surface layer had higher concentrations than the other layers at some sites, whereas at other sites all of the layers had similar concentrations.

Additionally, since October 2012 we have periodically conducted comprehensive sampling surveys (of seawater, bottom sediments, phyto- and zooplankton, and meio-, macro- and megabenthos) in the northern, central, and southern waters of Fukushima. Radionuclides in these environmental samples have also been quantified by gamma spectrometry with germanium semiconductor detection. Concentrations of radioactive Cs in surface seawater varied within the survey

period, and their temporal trends were unclear. In contrast, radioactive Cs concentrations in the bottom seawater seemed to rise gradually within the survey period. Although concentrations in the bottom sediment did not change greatly during the survey period, scattered areas of high concentration were present. Tissue concentrations of radioactive Cs in megabenthos (e.g. fishes, crustaceans, bivalves, cephalopods, and echinoderms), as well as the percentage detection of radioactive Cs, were higher in specimens from the central and southern waters than in those from the northern waters. There was a large intraspecies variation in tissue radioactive Cs concentrations, but concentrations above 100 Bq/kg (a tentative guideline limit for food contamination set by the Japanese government) were often observed in rays and flounders. Moreover, in the northern, central, and southern waters of Fukushima there were many biological specimens in which the estimated concentration factors (the ratio of the radioactive Cs concentration in the tissue to that in seawater) were much higher than 10^2 (a known concentration factor of ^{137}Cs in the literature). Further mechanistic studies of the concentration, magnification, and excretion of radioactive Cs in megabenthos are needed, as are continued comprehensive sampling surveys in the inshore waters of Fukushima.

Fig. 9 Geographic/horizontal distributions of radioactive Cs (the sum of ^{134}Cs and ^{137}Cs) in surface layer sediments (the 0- to 2-cm layer of sub-core samples) in Fukushima inshore waters, October 2012. 1F: Fukushima Dai-ichi Nuclear Power Plant
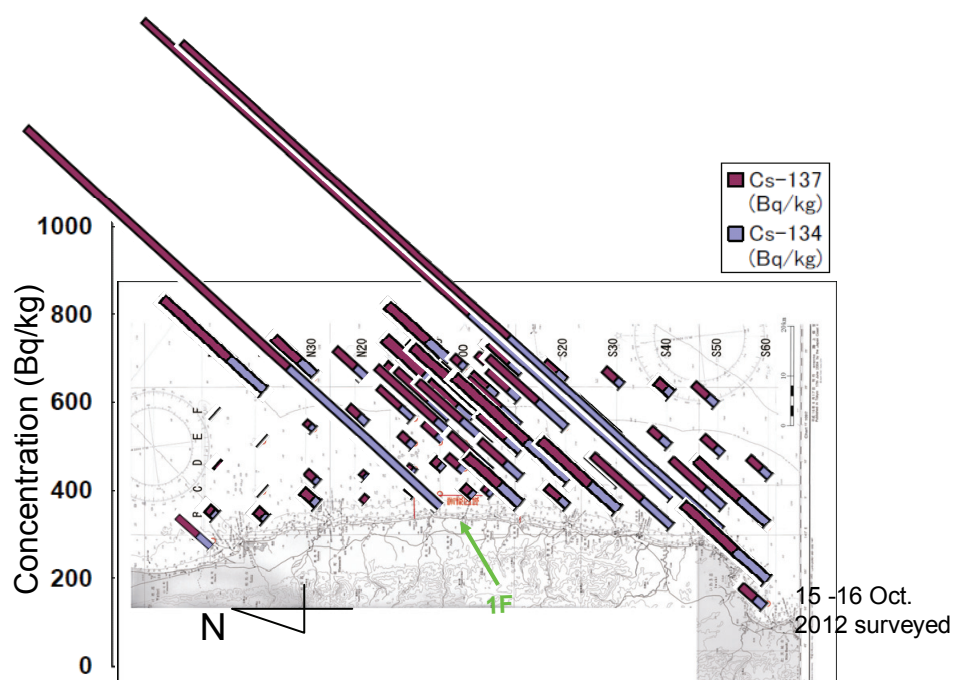
2.2 Multimedia fate modeling

We have been developing a multimedia fate model for radioactive substances by coupling models for atmospheric, oceanic, and terrestrial environments. Development of the models for the atmosphere and ocean was based on an atmospheric transport and deposition model and a coastal sea model, respectively; both models were developed at the Center for Regional Environmental Research. Development of the model for the terrestrial environment was based on the
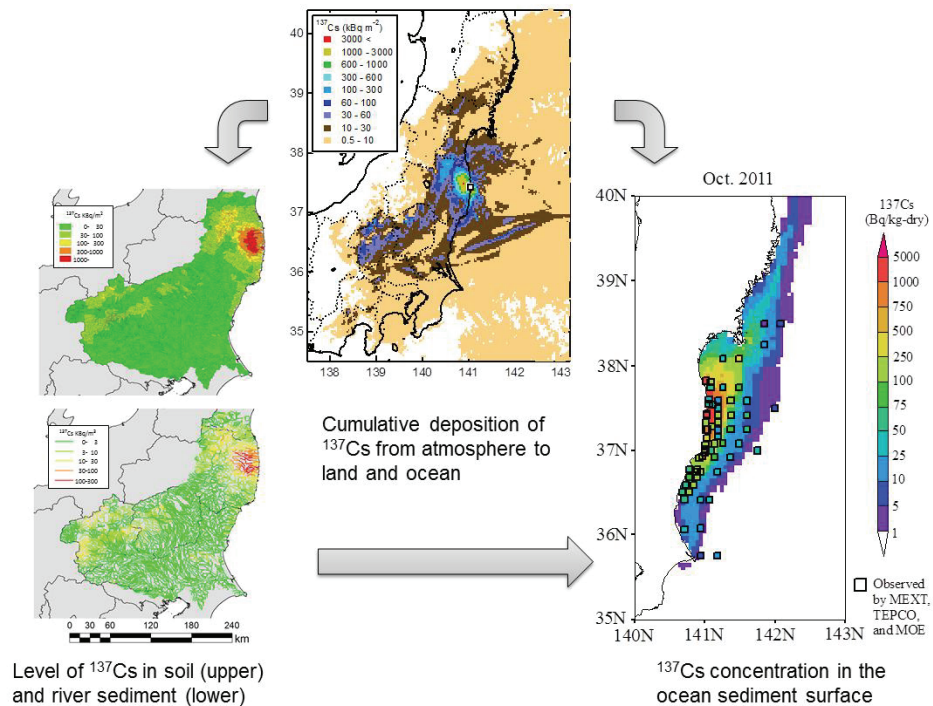
multimedia fate model G-CIEMS (Grid-Catchment Integrated Environmental Modeling System) developed at the Center for Environmental Risk Research. By combining the three models for atmospheric, oceanic, and terrestrial environments, we aimed to simulate the multimedia fate of radioactive substances at grid-based and appropriate geographic resolutions. In FY 2013 year we studied the fate modeling of radioactive Cs surrounding the Fukushima region.

From the atmospheric modeling, we estimated the amount of ^{137}Cs emitted from the FDNPP by combining an atmospheric model, an a priori source term, and observed deposition data. To our knowledge, this is the first use of airborne survey data on ^{137}Cs deposition (more than 16,000 data points) as observational constraints in inverse modeling. As compared to the simulation using the a priori source term, the model simulation driven by the a posteriori source term achieved better agreement with the ^{137}Cs depositions measured by aircraft survey and at measuring stations over eastern Japan. In addition, an ^{131}I deposition map created from an airborne monitoring survey was used to evaluate the model performance in terms of ^{131}I deposition patterns. The observed ^{131}I/^{137}Cs deposition ratio was higher in areas southwest of the FDNPP than northwest of the FDNPP; this behavior was reproduced by the atmospheric model if we assumed that more of the released ^{131}I was in the gas phase than as particles.

In our terrestrial multimedia modeling, we continued our long-term simulation of terrestrial fate processes in the region (Fig. 10). In FY 2013 we observed agreement between the model and our observations of average concentrations of ^{137}Cs in river sediments in Fukushima Prefecture. To improve the model, we investigated differences in trends in the spatial distribution of air dose rates, as calculated from a map created by a vehicle-borne survey and a distribution map of radiation doses sampled at one location per 2×2 km mesh in an 80-km radius around the FDNPP. We advanced our incorporation of the universal soil loss equation into surface soil runoff calculations and the development of relevant datasets.

For our ocean modeling, our model was modified to consider three important processes of ^{137}Cs migration: adsorption onto suspended matter, sedimentation, and resuspension from the seabed. We conducted numerical simulations and assessed the performance of the modified model. The model improvements resulted in better reproducibility of the spatial ^{137}Cs distribution in the surface sediments from May to December 2011. The simulation results indicated that substantial adsorption–sedimentation of ^{137}Cs occurred during a strong wind event, because a large amount of suspended matter was transported into the upward layer by resuspension from the seabed and strong vertical mixing.

Fig. 10 Trial simulation of the fate of ^{137}Cs in and around Fukushima Prefecture, using combined atmospheric transport and deposition, terrestrial fate, and coastal sea models

Cumulative deposition of ^{137}Cs from atmosphere to land and ocean

Level of ^{137}Cs in soil (upper) and river sediment (lower)

^{137}Cs concentration in the ocean sediment surface

2.3 Measurement of environmental concentrations of radionuclei, and model estimation of radiation dose

To estimate radiation doses from the Fukushima incident and the exposure sources, we measured radioactive Cs concentrations in the environment and also used numerical modeling. We also developed analytical methods for ^{129}I, ^{89}Sr, and ^{90}Sr.

1) Cs concentrations in soil, indoor dust, air, and foodstuffs

We measured radioactive Cs concentrations in soil, indoor dust, and foodstuffs collected from Iitate in Fukushima Prefecture, as well as from an area where we had observed relatively high radiation levels (i.e. a "hotspot"). We then estimated the radiation exposure from each source. Ambient air and indoor dust samples were also, continuously collected and analyzed for radioactive Cs. The majority of the ambient air samples from two sites in Iitate from March 2012 to the present (Fig. 11a) did not exceed 0.001 Bq m^{-3}; from this, we estimated the inhalation dose to be less than 0.001 mSv year^{-1}. The radioactive Cs concentration in indoor dust collected from the "hotspot" area decreased gradually from soon after the accident to the present (Fig. 11b). However, Cs was still detected at several hundreds of Bq kg^{-1} in indoor dust 3 years after the accident.

Fig. 11 Temporal changes in radioactive Cs concentrations in ambient air (a) and in indoor dust collected from residences in a "hotspot" area (b).

(a)

(b)
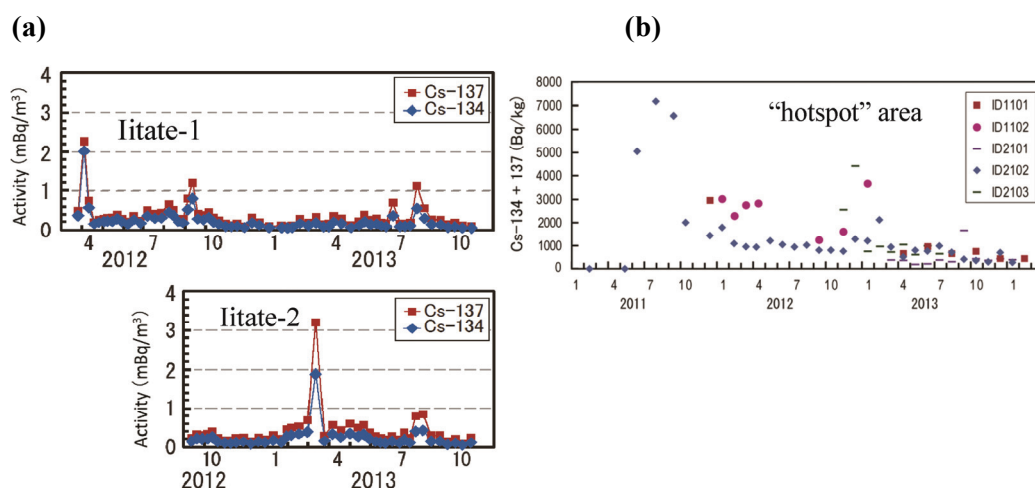
2) Estimates of long-term radiation exposure

We used a numerical exposure model to estimate long-term radiation doses. The model was built by using a set of data that we collected, as well as data provided by other institutions. We collected house dust samples from Iitate in Fukushima Prefecture and from an area where we had observed relatively high radiation levels (i.e. a "hotspot"). We compared the radiation in bulk house dusts and soils with that in samples after 250-µm sieving to calculate enrichment factors to estimate the ingestible portion of radiation. Comparison of the model outputs with personal monitoring data also collected in the hotspot area revealed reasonable agreement. External exposure of all age groups accounted for >90% of total exposure, whereas diet accounted for <10%. Exposure from other sources was estimated to be minor.

3) Development of a method for measuring ^{129}I, ^{89}Sr, and ^{90}Sr

To estimate exposure to radioactive iodine we needed to assess the distribution of ^{131}I from the FDNPP. However, ^{131}I is considered to have disappeared relatively soon after the incident because of its fast decay constant. We therefore developed a method for analyzing ^{129}I, which has a long half-life (15.7 million years), by using accelerator mass spectrometry. We assessed 10 gaseous radioactive iodine samples collected on an activated charcoal filter during the first 2 weeks after the accident. The ratio of ^{129}I to ^{131}I was about 22—twice as high as that of particles collected on a quartz filter. We need more sample analyses and data validations.

Radioactive Sr is also important and can affect human and other organisms' health. We established a sample preparation method for Sr by using crown ether (Sr Resin, Eichrom, Lisle, IL) and applied it to seawater samples and bivalves collected after the nuclear accident. Figure 12 shows the space–time distribution of radioactive Sr from FDNPP.

Fig. 12 (a) Map of sampling points. (★:FDNPP) (b) Concentrations of ^{90}Sr in seawater and bivalves *(Septifer virgatus)* collected in 2011 and 2012.
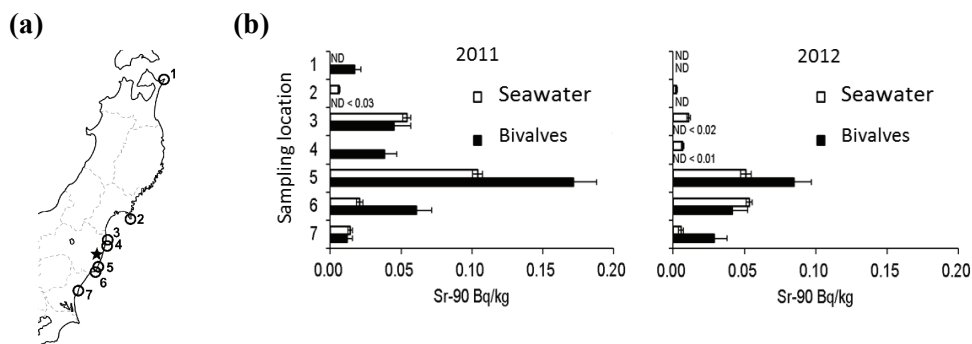

2.4 Effects of low-level gamma-irradiation on wild animals and higher plants

A few reports have shown that low-level gamma-radiation has had some impacts on wild organisms or wild populations in Fukushima Prefecture. However, no report has yet demonstrated the effects of nuclear radiation from contaminated soil in the prefecture on organisms at a molecular level. Consequently, we performed the following experiments to clarify the impact of low-level gamma-radiation from polluted soil on wild organisms in Fukushima Prefecture: (1) we evaluated the genetic variation in wild rodents living in a forested area in Fukushima; and (2) we used transgenic plants to detect the repair of radiation-damaged DNA in order to evaluate recovery from DNA damage caused by gamma-radiation. Our findings are described below in more detail.

1) Evaluation of genetic variation in field mice

Wild Japanese field mice (*Apodemus speciosus*) were captured in a high-gamma-dose area in Fukushima Prefecture and in low-gamma-dose areas (Aomori and Toyama prefectures). To compare the genetic variations in the wild mice populations in these different places, we performed a sequence analysis of a regulation region (D-loop) or a cytochrome b region (Cytb) of mitochondria. Genomic DNA was isolated from the liver and was used to amplify the D-loop or Cytb by polymerase chain reaction (PCR). Nucleotide sequences of the PCR products were determined with direct sequencing, and the DNA sequences obtained were compared in the wild mice captured in the different places. There were no significant differences in D-loop and Cytb nucleotide sequence diversity among the wild mice from the different areas. Furthermore, we compared the average diversity at eight microsatellite loci. There were no significant differences in average gene diversity among the wild mice from the different places (Fig. 13). These findings indicate that there are no significant traces of DNA mutations from gamma-irradiation in *A. speciosus*.

Fig. 13 Average gene diversity of *Apodemus speciosus* at each study site, as determined by using eight microsatellite markers. Values are expressed as means ± standard deviation.
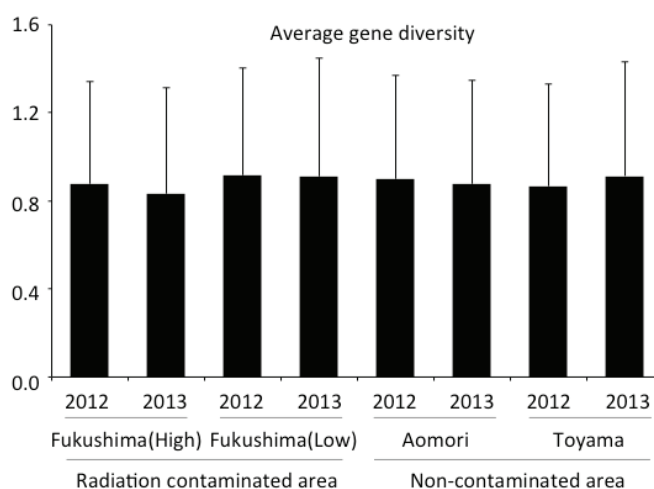
2) Evaluation of DNA damage in transgenic plants

To evaluate DNA repair following DNA damage caused by gamma-irradiation from contaminated soils in Fukushima Prefecture, we previously established a transgenic *Arabidopsis thaliana* into which we introduced a GU-US construct. (A gene encoding beta-glucuronidase [GUS] was separated into two parts with a 600-bp overlap.) This plant can detect homologous recombination activity induced by double-strand breaks of DNA. The transgenic plants were grown for 30 days on contaminated soil collected from three different air-dose sites in Fukushima Prefecture (final doses of irradiation were 261, 1340, and 2840 μSv). Plants were also grown on uncontaminated soil for 30 days (final dose of irradiation was 57.6 μSv). Thereafter, GUS staining analysis was performed to estimate the frequency of DNA repair in the plants. The DNA repair frequency increased with increasing dose of irradiation (Fig. 14a), suggesting that DNA damage caused by gamma-radiation in Fukushima Prefecture was remediated immediately by endogenous DNA repair systems. In addition, the DNA repair frequency in plants grown on contaminated soil did not differ from that in plants irradiated with gamma-radiation (Fig. 14b). This indicated that the DNA damage caused by the contaminated soil could have occurred from external exposure to gamma-radiation rather than internal exposure.

Fig. 14 (a) DNA repair frequency in plants grown on soils contaminated with different level of radioactive Cs. Values are means ± standard deviation.
(b) Comparison of DNA repair frequencies in plants grown on contaminated soil (left) or under irradiation with gamma-rays (right). Values are expressed as means ± standard deviation.
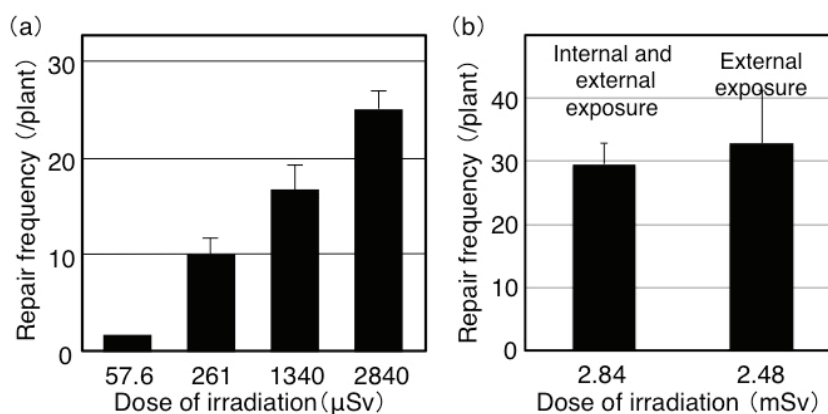
3. Promotion of surveys and research toward restoration or creation of post-disaster regional environments

Our environmental renovation research program aims to predict future needs for promoting surveys and research that will restore or create post-disaster regional environments.

3.1 Development of regional information systems for environmental renovation

Japan is facing the twin challenges of energy conservation and climate change in the post-Fukushima era. Industrial and power plant–sourced waste heat is an important potential resource for nearby sinks. However, because industrial facilities are not usually operated optimally for waste heat utilization, most of the potentially recoverable heat is emitted to the surrounding environment. In this study, we developed a basic power-generation process model and inventory database for waste heat utilization.

We developed a standard coal thermal power plant model to evaluate the additional costs and environmental loads of heat energy extraction from the power generation process. The overall system flow of a coal thermal plant was evaluated quantitatively. Three different potential heat energy sources were considered. The first source was heat wasted by emission to the sea through the condenser. A second possibility was to use gas exhausted from the stack. The last source was heat energy extracted from the steam turbines. By using this source database we were able to evaluate heat energy utilization from the condenser, or the stack, without maximum potential electricity loss.

3.2 Development of a regional scenario analysis model for environmental renovation

1)Feasibility assessment of the use of power plant–sourced waste heat for heating vegetable greenhouses, taking into account spatial configurations
To achieve future targets for an efficient network providing energy to the coastal regions of Fukushima that were devastated by the tsunami, in this study we developed a simulation process model integrating spatial analysis, technology systems, and land-use controls to maximize the utilization of waste heat from coal-fired thermal power plants by nearby factories.

We established a process analysis–based urban energy model to evaluate an energy-exchange system that took into account spatial configurations. Figure 15 outlines the model framework and system boundary. By developing an urban energy analytical model combined with spatial analysis, we assessed the technical and economic feasibility of power plant–sourced waste heat transfer to commercial vegetable greenhouses. This is a key part of our proposed regional

energy symbiosis-planning in the areas of Fukushima being reconstructed following the nuclear power plant and tsunami disaster.

From the location pattern of current facilities in the case study area, we concluded that a heat exchange system could reduce CO_2 emissions by more than 50%. Energy supply costs would increase because of the need to install pipelines. By using a sensitivity analysis, we identified the radius within which excess power-plant heat energy could be supplied more cheaply than with existing individual heating systems. The feasibility assessment emphasized the point that to improve eco-efficiency (environmental benefit at a lower economic cost) the relocation of heat sources and sinks on the basis of a spatial analysis is important.

Fig. 15 Structure of the regional energy analytical model and system boundaries
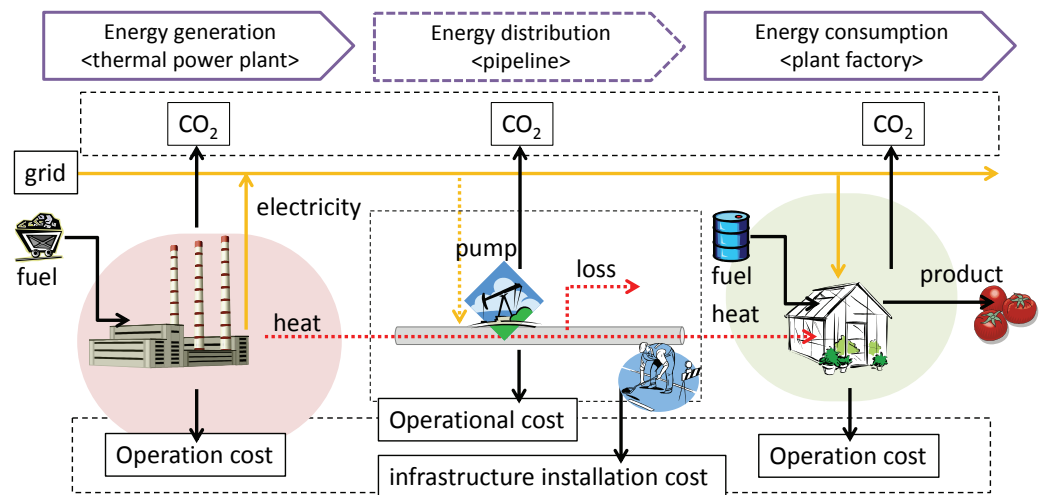
2) Preliminary evaluation of regional woody biomass production
To evaluate recovery planning in the Tohoku region, we assessed Japan's forestry process, from the plantation stage to wood biomass production, by using an ecological and forestry cost-calculation model. Four forest-management scenarios in central Japan were evaluated for preliminary calculations on a community scale. They were business as usual (BAU); forestry management as recommended by local government to enhance and improve forest management to include woody biomass production (FM1: modified practices; and FM2: extended practices); and CNV: converting part of a plantation into secondary forest under the FM2 scenario but taking into account forest biodiversity. The results of a long-term simulation revealed that current forestry management (BAU and FM1) was not efficient in producing woody biomass from the viewpoint of economic cost. The FM2 scenario (modified from the FM1 scenario) and CNV scenario would produce ecological and economic improvements, but there would be an increase in carbon emissions and labor requirement as a result of the enhanced forest practices. We also showed that woody biomass production needs to be supported by carbon offsetting, such as endeavoring towards a reduction in coal combustion in thermal power plants.

3) Localization of AIMs (Asia-pacific Integrated Models) into the Fukushima region and its cities

We have established a framework for applying several types of AIM (Asia-pacific Integrated Model) at a local scale. Because the primary objective of AIM is the assessment of climate change, it has been applied mainly at the global and national scales. It is therefore necessary to define spatial layers, boundary conditions between layers, and algorithms to find optimal local solutions. In addition, the models need to be extended to specifically consider recovery from disaster. The following AIM family models will be modified for this purpose: AIM/Enduse, a bottom-up technology-selection model that finds the combination of energy technologies that will minimize system costs; AIM/CGE, a computable general equilibrium model that assesses the economic impact of a particular energy and environmental policy; AIM/ESM, an energy system model used to find optimal energy systems, taking into account energy demand at a fine time scale and the availability of local renewable energy; and ExSS (extended snapshot tool), an accounting-type model used to give a consistent vision of society and the contribution of the options to the target. In FY 2014 these models will be modified and localized for application to Fukushima Prefecture.

3.3 Multi-stakeholder participation approach to community renovation

Three years have passed since the Great East Japan Earthquake. Many municipalities have come up with restoration plans that take a short-term view. However, a long-range view is important to meet various future challenges such as population aging and global warming. To this end, residents themselves need to discuss their visions for the future. Encouraging active participation of the younger generation in such a process is particularly important for actualizing those visions.

In this context we held a workshop titled "Let's talk about the town of Shinchi in 2050!" The participants were 88 students in first grade at Shoei Junior High School in the town of Shinchi. They were allocated to 15 groups to debate the 2050 vision of their town. The workshop revealed that these students had thought carefully about their town's future. For example, some students said that they should conserve nature in the region, and others felt that Shinchi could regain its vitality if the train service were restarted. Many of the students also emphasized the need for earthquake disaster reconstruction. These children will be mature members of the community in 2050, so we should respect their opinions.

4. Research into the impacts of various environmental changes caused by the earthquake and tsunami disaster
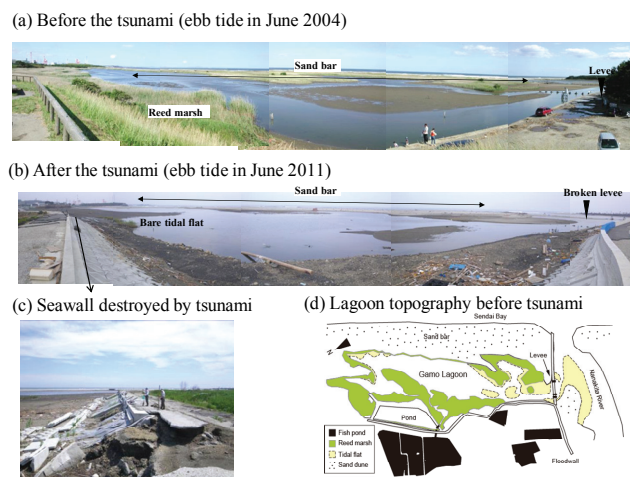
The tsunami that followed the Great East Japan Earthquake caused topographic changes and modified the living environments of the area's inhabitants, as well as

its natural coastal habitats. NIES has investigated and evaluated the influence of the various environmental changes caused by the disaster on the environment, human health, and ecosystems. We describe some of our main results below.

Impact of the tsunami on a wetland ecosystem and its recovery

Gamo Lagoon is a bag-shaped lagoon in the mouth of the Nanakita River, which flows through the northern part of the city of Sendai in Miyagi Prefecture (Fig. 16). It is a brackish lagoon with a depth of approximately 800 m and a width of about 250 m. At the time of the Great East Japan Earthquake of 11 March 2011, the coast of Sendai was inundated by a tsunami more than 7 m high. The seawall (approximately 4 m high) in place on the western side of the lagoon was penetrated and collapsed in several places. The seaside sandbar of Gamo Lagoon was almost washed away by the tsunami, but littoral drift resulted in the deposition of drift sand along the coast in the 2 months following the earthquake. This resulted in re-formation of the bag-like terrain by June 2011. Nevertheless, the area that had previously been exclusively lagoon was filled with drift sand and thus became land. In addition, most of the previously dense area of reeds around the lagoon was swept away, and this area became a barren tidal flat. Reeds that escaped being washed away remained, but the plant density and height were reduced.

Fig. 16 Geographic changes in Gamo Lagoon

(a) Before the tsunami (ebb tide in June 2004)

(b) After the tsunami (ebb tide in June 2011)

(c) Seawall destroyed by tsunami

(d) Lagoon topography before tsunami

The tsunami has changed the lagoon environment and associated biota. Organic pollution was already an issue in Gamo Lagoon before the tsunami, and thick viscous matter (sludge) had been deposited over a wide area from the center to the interior of the lagoon. However, because this matter was carried away by the tsunami and drift sand was transported and deposited from the sea, the sediment composition throughout the lagoon became markedly sandy.

Surveys we conducted of benthos from April to August 2011 confirmed that 47 of

the 79 species that have been identified since 2004 were in a state approaching extinction. On the other hand, some amphipods and polychaetes had significantly increased their population densities throughout the lagoon (Fig. 17a). These colonized, and rapidly recovered their populations in, the barren areas that had resulted from the tsunami and where no other benthos had previously been found. One of the probable factors that prompted the explosive growth of these species was the washing-away of muddy sediment, which does not constitute an appropriate habitat for most benthic animals, by the tsunami and the resulting substantial improvement in the sediment environment. In spring 2012, the fresh presence of many bivalve spats was confirmed. The source population likely had remained in the adjacent areas and supplied planktonic larvae to the lagoon. The tsunami also disturbed the vegetated areas in Gamo Lagoon, which are important habitats for several macrozoobenthic taxa. For instance, the areas of marsh, pine trees, and sand dune vegetation respectively decreased by 85%, 52%, and 98% (Fig. 17b).

Fig. 17 (a) Changes in species number and density of macrozoobenthos (b) Changes in vegetated areas
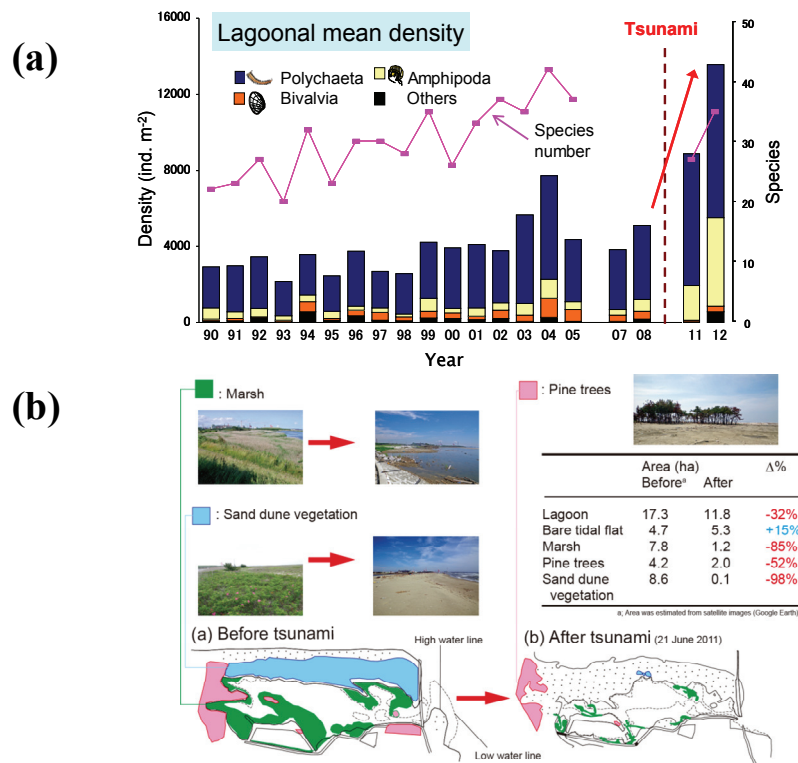
Gamo Lagoon is currently in the process of ecosystem recovery, and we expect that the populations and numbers of species of benthic animals will gradually recover as time goes on. To facilitate this process, the quality of the habitats and environment of Gamo Lagoon must be maintained over the long term. However, the underlying geographical features have changed many times as a result of complex natural and anthropogenic processes. During the years 2011 to 2013, the lagoon underwent various topographical modifications. These included disappearance of the sand bar; redeposition of the drift sand; recovery of the sand

bar; river-mouth closure; channelization; and reconstruction of the levee. Since 2013 the geographic features of Gamo Lagoon appear to have achieved relative stability. However, environmental modifications resulting from human activity, as well as the effects of natural disturbance, have the potential to lead to major disturbances that would exceed even those caused by the tsunami. Accordingly, we need to meticulously monitor the successions in progress in both the landscape and the wetland ecosystem.

Environmental
Information Department

The Environmental Information Department provides the public with various kinds of environmental information through websites.

The Environmental Information Department provides information technology (IT) support for research and related activities at NIES; runs public relations activities for NIES (including publishing NIES research reports); and performs miscellaneous other activities, including collecting and processing environmental information and disseminating it to the general public and performing tasks commissioned by the Ministry of the Environment (MOE). These tasks are described in detail below.

1. IT support for research and related activities at NIES

The Department manages and operates the computers and related systems at NIES, uses IT to improve the work efficiency of NIES, and runs a library service.

1.1 Management and operation of computers and related systems

New computer system began operation in June 2013. The UNIX-based computing environment consists of a supercomputer system and various subsystems, including a scalar-computing server, a front-end server, and storage devices. Our vector supercomputer (NEC SX-9/A(ECO); Fig. 1), which is equipped with a FORTRAN compiler with high-level debugging capability and high-efficiency optimization, executes the large-scale programs needed to model global environmental problems.

A local-area network called NIESNET was established at NIES in 1992. NIESNET was upgraded in March 2013. Registered users outside NIES can use the supercomputer system through the Tsukuba wide-area network via the SINET (Science Information Network) connection to the Internet.

Fig. 1 The NEC SX-9/A(ECO) supercomputer

1.2 Use of IT to improve work efficiency at NIES

The Department gives IT support to the management sector of NIES with the aim of increasing work efficiency. It also provides NIES researchers with processed research data and helps them to disseminate their data through the NIES website. In FY 2013, the Department supported:

- development of an electronic application and registration system at NIES
- operation of a thin-client PC management system for the administrative section
- development of the NIES research information database
- modification and operation of a database of basic information on each member of staff at the Institute.

1.3 Library service

As of March 2014, the NIES library held 53,265 books, 326 journals (including electronic resources), 122,268 microfiches, and various other technical reports and reference materials. These materials can be searched by using OPAC (Online Public Access Catalog) via the Intranet.

In addition to these materials, researchers at NIES can use abstracts and full-text articles through scientific and technical information databases such as ISI Web of Knowledge (including Web of Science, Medline, and Journal Citation Reports), JDreamII, G-Search, and CiNii.

Library facilities include separate rooms for reading books, journals, reports, and microfiches.

Fig. 2 The NIES library

2. NIES public relations activities

The Department manages the NIES website. It also edits and publishes NIES reports such as research reports and this *Annual Report*.

2.1 Management of the NIES Website

NIES began to provide public information on its research activities and results via the Internet (http://www.nies.go.jp/; Fig. 3) in March 1996. The website was completely renewed and improved in accordance with the restructuring of NIES in April 2001 as an independent administrative institution. Because NIES started the third stage of its medium-term plan in April 2011, a newly designed website was prepared in accordance with the new organization and activities. The new site also provides information on NIES initiatives related to the Great East Japan Earthquake.

Fig. 3   The NIES website

2.2 Editing and publication of NIES reports

Reports on NIES research activities and results, such as the NIES *Annual Report* and research reports, official newsletters (*NIES News*, in Japanese), and NIES

research booklets (*Kankyo-gi*, in Japanese), are edited, published, and distributed by the Department.

3. Other activities

3.1 Collection, processing, and dissemination of environmental information

One of the major tasks at NIES is: "the collection, processing, and dissemination of environmental information". The Department provides various kinds of environmental information to the public through websites; processes and manages environmental information databases; and provides environmental information via GIS (Geographic Information System).

Environmental Observatory (Information Platform for Environmental Outlook)
The Environmental Observatory (Information Platform for Environmental Outlook) is a multimedia site providing integrated environmental information to promote wider involvement in environmental conservation. It gives users broad access to a range of systematically organized environmental information aimed at creating a sustainable society. The site offers a quick search facility, domestic and global news updates, descriptions of key environmental technologies, information on policies and laws in environmental fields, environmental information via GIS, and other content helpful for environmental learning.

Processing and management of environmental information databases
Various environmental data are needed for research, policy decisions, and policy enforcement. We compile and process air quality and water quality data collected by local governments and reported to the MOE. These processed data can be accessed through the database on the NIES website. Duplication and lending services are also available.

Provision of environmental information via GIS
The Department, with the cooperation of the MOE, has been using GIS to develop an environmental data provision system. This system helps users to easily understand the status of the environment by showing data on environmental quality and other information on maps. The system has been publicly available through the Internet since September 2002 and was revised in March 2011.

3.2 Tasks commissioned by the Ministry of the Environment

In FY 2013 the Department performed the following two tasks commissioned by the Ministry of the Environment:
• maintenance and support of a data entry system for living environment data, including data on noise, vibration, and offensive odors
• conversion of hourly values of regular air monitoring data to standard format.

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