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NIES Annual Report 2020

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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 2019 (FY2019: April 2019 to March 2020) which marks the fourth year of our 4th NIES Five-Year Plan (4th FYP; FY2016-FY2020).

During the 4th FYP, several new research bases have been established. Fukushima Branch established in 2016 is located in Miharu Town, Fukushima Pref. and serves as a collaboration hub to conduct environmental emergency research; Lake Biwa Branch Office established in 2017 sits by Lake Biwa in Shiga Pref. and conducts research on lake environment and its ecosystems. These two facilities are supported by and in close collaboration with the local governments and communities. Furthermore, Center for Climate Change Adaptation (CCCA) was established in late 2018 in response to Climate Change Adaptation Act to faciliate planning and implementation of adapatation actions by local governments and other agencies. These newly joined research bases have strong ties with the seven Research Centers in our Tsukuba Headquarters located in Ibaraki Pref., each of which are focusing on various aspects of environmental issues in the current world, ranging from local to global scale, integrating the approaches of natural and social sciences.

Our research activities are categolized into several types. *Research Programs* are carried out under 5-year plan pursuing specific goals and carried out by the collaboration of researchers with various backgrounds. Research Programs have two clusters: *Issue-Oriented Research Programs* consisting of five programs each aiming at low carbon society, sustainable material cycles, harmonization with nature, health and environmental safety, and environment-economy-society integration; *Environmental Emergency Research Programs* consisting of three programs, each focusing on recovery, renovation, and emergency management on the aftermath of the Great East Japan Earthquake.

Research Projects -what we call- is aiming at the full use of our research outcomes and carried out with outside institutes and agents. To name a few, GOSAT project is observation of earth-level GHGs by Greenhouse Gases Observing Satellite (GOSAT) and its successor GOSAT-2; and JECS project is a nation-wide birth cohort study to explore the relationship between perinatal exposure to numerous chemicals and child's growth/development.

Another catetogy of our activities is *providing infrastructures* for environmental research in/outside NIES by archiving and providing various types of research tools and data/samples such as various monitoring data, greenhouse gas emissions inventory, environmental as well as biological specimen banking, reference laboratory functions, and various environmental databases.

All of these activities are supported by our *basic/elemental research* which are conducted in the laboratories of our research units, centers and basis, some of which requires incessant efforts, some are in the phase of sprouting, and some will be developed as a core of a Research Program.

Since we are nearing the end of our 4th FYP, we started discussing the activity plans for the upcoming 5th FYP beginning from FY2021. As the first step, we invited stakeholders from various (non-academic)

community to find out what expectations the society has on NIES and also held the Spring Open Campus online which successfully attracted 30,000 audience participation. Internal discussions on how to communicate on major issues such as climate change and biodiversity loss as a group of researchers in environmental research is also ongoing. While focusing on our primary mission as a research institute, NIES will also strive to focus on activities that emphasize being in touch with the society and holding social dialogues.

NIES furthers advance and research networks domestically and globally, having research agreements with more than 50 foreign institutes and universities, and 12 research projects conducted under the Science and Technology Cooperation Agreements between the governments. Furthermore, NIES contributes to various kinds of global initiatives including The Intergovernmental Panel on Climate Change (IPCC), The Global Climate and Health Alliance (GCHA), and Future Earth. To promote research collaborations in Asia, NIES together with National Institute of Environmental Research (NIER; Korea) and Chinese Research Academy of Environmental Sciences (CRAES; China) participated in the 16th Tripartite Presidents Meeting in Hangzhou, China and exchanged views for future collaborations. NIES also held the 5th NIES International Forum to discuss current environmental issues with Asian research communities in Yangon, Myanmar.

We hope that this report will help facilitate a greater understanding of our institute's activities, and we invite your full and frank feedback and opinion about these activities.

Watanabe, Chiho
President
November, 2020

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.

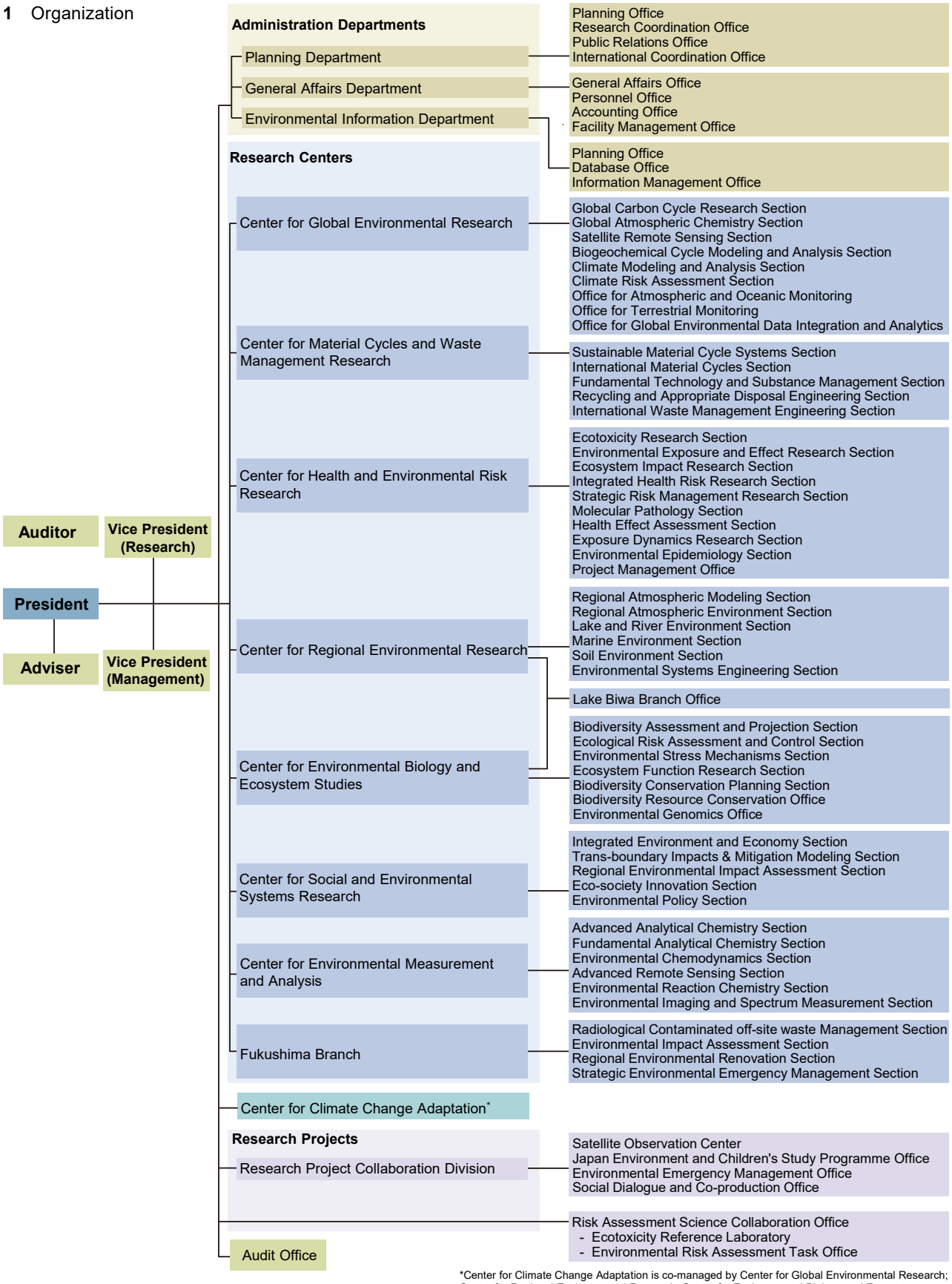
During the two decades following the establishment of NIES, rapid technological progress, structural changes in industry, and lifestyle changes, created additional issues for environmental science to confront. Moreover, global environmental problems such as climate change; depletion of the stratospheric ozone layer; acid deposition; destruction of tropical rain forests; desertification; and decreasing biodiversity, 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. During the third five-year plan, research was carried out under eight fundamental fields of environmental research. Research activities to respond to and recover from the Great East Japan Earthquake have also been ongoing since the direct aftermath of the disaster. In March 2013, the five-year plan was revised following a directive of the Minister of the Environment and NIES relaunched as a National Research and Development Agency from April 2015.

April 2016 marked the beginning of the forth medium-and-long-term plan (2016–2020). NIES established five issue-oriented research programs for this plan's term, and will pursue them in an integrated manner that transcends individual fields. NIES has established Fukushima Branch, where it is running Environmental Emergency Research Programs. Also in April 2017, Lake Biwa Branch Office was established

Fig. 1 Organization



*Center for Climate Change Adaptation is co-managed by Center for Global Environmental Research; Center for Regional Environmental Research; Center for Environmental Biology and Ecosystem Studies; and Center for Social and Environmental Systems Research.

located in Lake Biwa Environmental Research Institute where developed research for water environmental protection is jointly conducted. In December 2018, we established the Center for Climate Change Adaptation (CCCA) in line with the enactment and enforcement of the Climate Change Adaptation Act to research and promote adaptation to climate change. Furthermore, to produce scientific findings on environmental protection, NIES will carry out research projects that include consolidating the institute's research foundation through basic research, data acquisition and analysis, preservation and provision of environmental samples, and other efforts.

NIES plays a central role in research networks too, for example, GOSAT/GOSAT-2 satellite observations and the Japan Environment and Children's Study (a large-scale environmental epidemiology survey). Also important among our tasks is actively disseminating environmental information in easy-to-understand formats, including the outcomes of our research efforts and projects.

As of April 1, 2020, there are 302 NIES permanent staff and 679 contract staff (Table 1; Figs. 2 to 5). The total budget for FY2019 was 20,544 million yen (Table 2).

Table 1
Numbers of permanent staff

Administration Departments	61
Research Centers	236
Executives and Advisers	5
Total	302

(As of April 1, 2020)

Table 2
Budget for the fourth five-year plan

(Unit: million yen)

	Category	2016–2020 Budget (5 years)	Fiscal Year 2019 Budget
Revenue	Grants for Operating Costs	62,665	16,659
	Subsidies for Facilities	1,710	328
	Commissioned Work	17,786	3,557
	Total	82,162	20,544
Expenditure	Project Costs	44,399	12,839
	Facility Improvements	1,710	328
	Expenses for Commissioned Work	17,786	3,557
	Personnel Expenses	16,112	3,337
	General Administrative Expenses	2,154	483
	Total	82,162	20,544

Note: The budget for each annual work plan will be requested and decided for each fiscal year, based on the medium-and-long-term plan.

Administration Departments	:	61	
Research Centers	:	236	(6)
Executives and Advisers	:	5	
Total		302	(6)

Notes:
1. Data is as of April 1, 2020.

2. Figures in parentheses indicate number of non-Japanese.

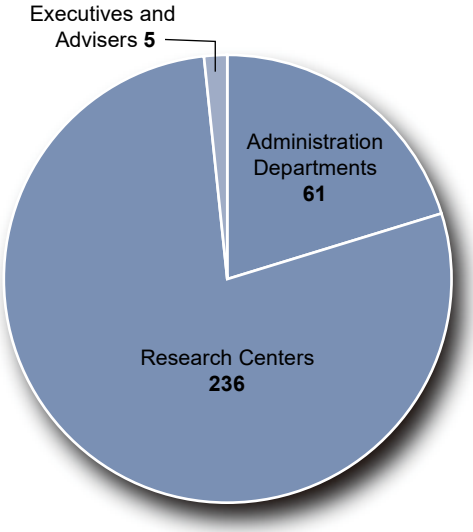


Fig. 2 Permanent staff breakdown

Basic Sciences (Physics, Chemistry, Biology)	:	83	39.15%
Engineering	:	68	32.08%
Agricultural Sciences	:	33	15.57%
Sciences	:	10	4.72%
Medical Sciences	:	9	4.25%
Economics	:	3	1.41%
Pharmaceutical Sciences	:	3	1.41%
Fisheries Sciences	:	1	0.47%
Law	:	1	0.47%
Veterinary Medicine	:	1	0.47%
Total		212	

Notes: Data is as of April 1, 2020.

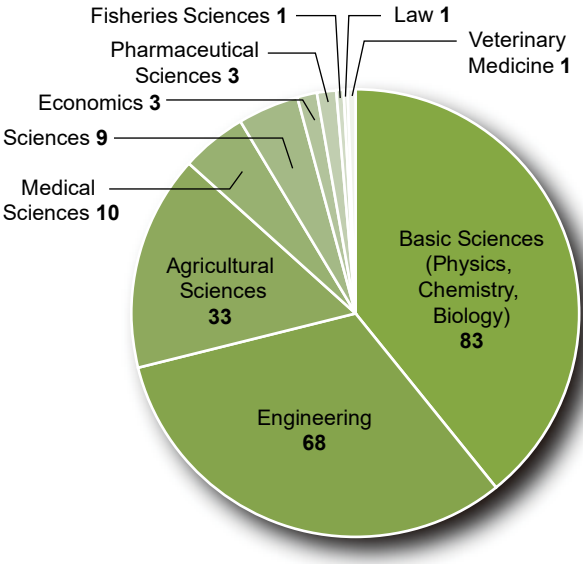


Fig. 3 Fields of expertise (Researchers holding doctorates (95.9%))

Senior Fellow	:	1	
Fellow	:	7	
Research Associate	:	96	(39)
Junior Research Associate	:	13	(4)
Research Assistant	:	31	(11)
Specialist	:	231	(7)
Assistant Staff	:	284	
Senior Staff	:	7	
Senior Research Associate	:	9	
Total		679	(61)

Notes:
1. Data is as of April 1, 2020.

2. Figures in parentheses indicate number of non-Japanese.

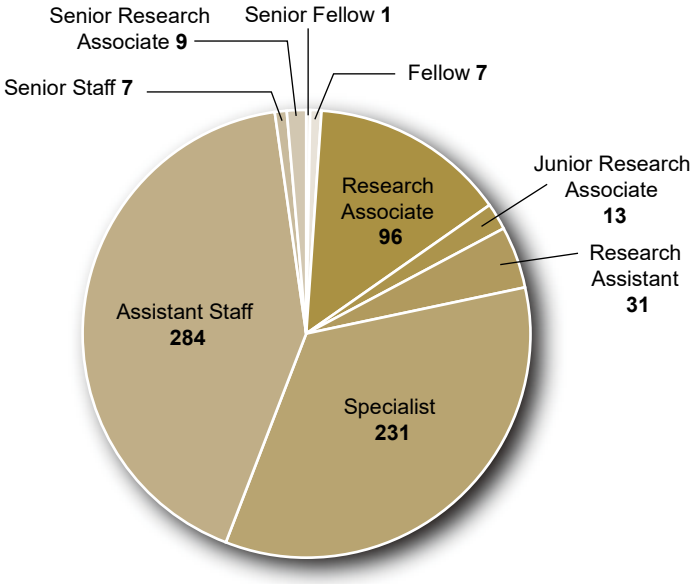


Fig. 4 Contract Staff Breakdown

Visiting Researcher	209	(11)
Research Student	42	(18)
Collaborative Researcher	80	(19)
Interns	10	(4)
Total	341	(52)

Notes:

1. Data is the total number accepted in FY2019.

2. Figures in parentheses indicate number of non-Japanese.

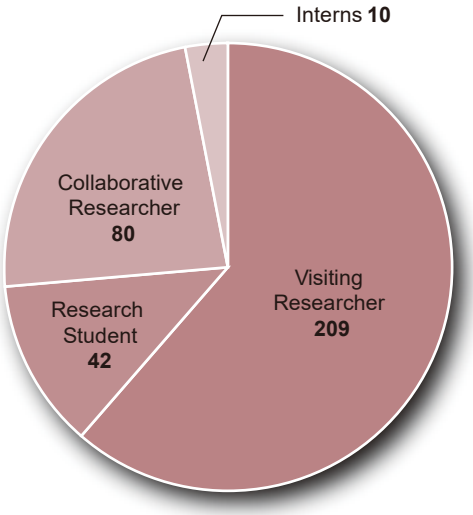


Fig. 5 Visiting and Collaborative Researchers, Research Students, and Interns

Issue - Oriented Research Programs

Low-Carbon Research Program

The concept behind this program is to build a scientific foundation that society can use to tackle the goal of keeping the global mean surface temperature increase well below 2 °C, and preferably below 1.5 °C, relative to pre-industrial levels. In the program we will conduct observations, mainly in the Asia-Pacific region, to assess the balances of the greenhouse gases (GHGs) that cause global warming, as well as climate change impacts and control measures. To accomplish this, we will use surface and aerial observations, and data from observation satellites launched in 2009 and 2018, to develop a highly reliable three-dimensional global-scale GHG monitoring system. Furthermore, we will combine climate change projection models, impact assessment models, and integrated socioeconomic assessment models and use them to discuss the need for, and feasibility of, building a sustainable, low-carbon society along the path indicated by this comprehensive research program.

The program consists of three research projects: (1) Study of a multi-scale system for observing and evaluating GHG variation and mitigation; (2) Global-scale climate risk research based on integrated assessment of climate projections, impacts, and response options; and (3) Policy assessment research toward a global low-carbon society (Fig. 1). Each project and its research highlights are described below.

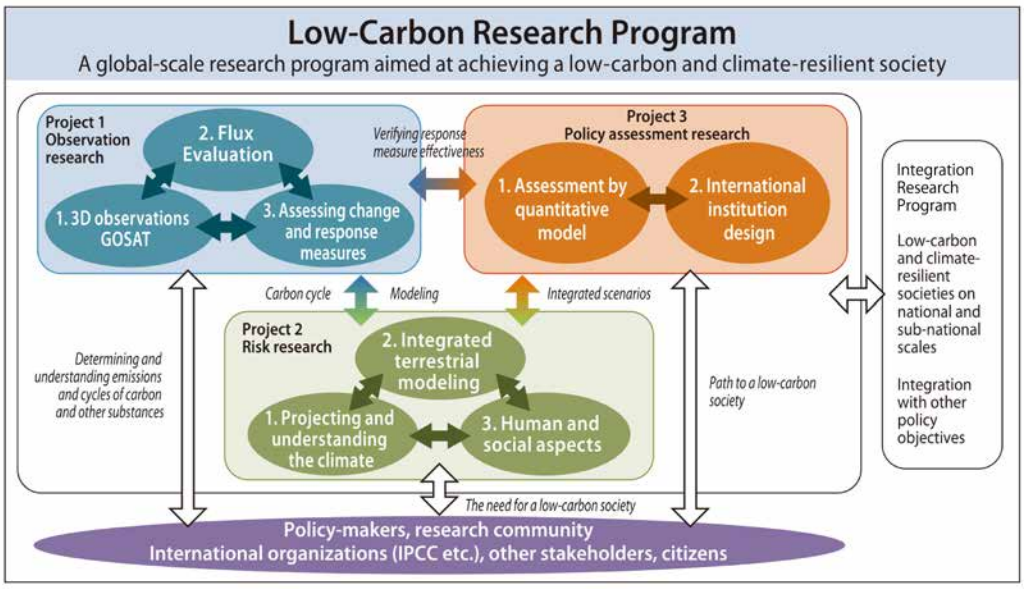


Fig. 1 Structure of the Low-Carbon Research Program. The three projects interact with each other and with society.

Project 1. Study of a multi-scale system for observing and evaluating GHG variation and mitigation

This project aims to develop a multi-scale observation and analysis system for estimating spatial and temporal variations in the atmospheric concentrations of GHGs and their surface fluxes, including those from anthropogenic and natural sources and sinks. The system is essential for analyzing a variety of climate change mitigation and adaptation policies and evaluating their effectiveness. The project comprises three sub-themes: (1) Evaluation of GHG budgets at different spatial scales, from global to local; (2) Estimation of oceanic and terrestrial GHG budgets and their upscaling; and (3) Assessment of climate change mitigation and impacts at different spatial scales.

In FY 2019, sub-theme 1 estimated interannual variations in the net ocean and land fluxes of CO_2 globally by using individual analyses based on (1) atmospheric potential oxygen (APO); and (2) the stable carbon isotope ratio in CO_2 (^{13}C). The interannual changes in land CO_2 flux estimated by using APO agreed well with those estimated by using ^{13}C, with weak absorption in 2002–2004, then intense absorption around 2008–2011, followed by a modest sink in 2013–2017 (Fig. 2). The estimated ocean CO_2 fluxes based on the APO and ^{13}C methods indicated a gradual increase in absorption from the early 2000s to 2015. The ocean fluxes obtained by using the GCP models were weaker and changed more steadily than our observation-based fluxes, especially from 2010–2015. Because the fluxes obtained by the GCP model plus imbalance were almost consistent with our observation-based fluxes, we considered that the imbalances in the GCP budget in 2006–2015 were caused by bias in the ocean models. In contrast, the imbalance in about 1998 may have been related to bias in the land biosphere flux simulation.

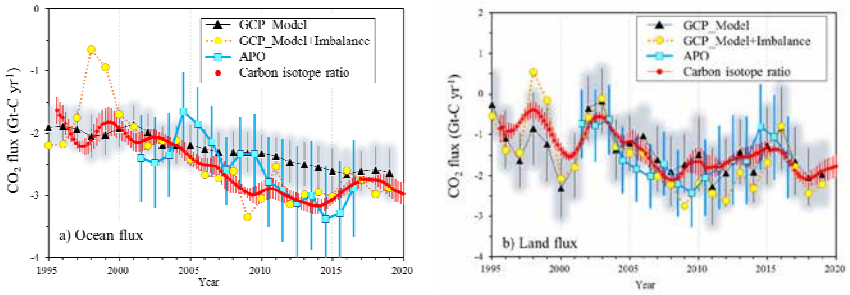


Fig. 2 Interannual variations in carbon flux for ocean (a) and land (b), as estimated by observation of atmospheric potential oxygen (APO) and carbon isotope ratio, together with estimations obtained by using Global Carbon Project (GCP) models

To examine the temporal and spatial distribution of ocean sinks more in detail, under sub-theme 2 we produced monthly maps of the ocean-surface partial pressure of CO_2 (pCO_2) and air–sea CO_2 flux in the Global Ocean (60ºS–70ºN) from 2001 to 2014 on the basis of observations recorded in the international pCO_2 database (Surface Ocean CO_2 Atlas; SOCAT). We plotted the trend distribution of air–sea CO_2 flux during the period and confirmed that the distribution was reasonably well estimated. The results clearly suggested that strengthening of

CO_2 uptake by the ocean occurred especially in the North Pacific, the North Atlantic, and the Southern Ocean (south of 30ºS), whereas the exchange was relatively stable in the Indian Ocean and the South Atlantic. Now we are trying to expand the estimation period up to 2019 and will investigate the mechanism of increasing CO_2 uptake in each region.

Methane (CH_4) is the second most potent anthropogenic GHG, and East Asia has a number of strong CH_4 sources. Under sub-theme 3, we adopted a bottom-up approach to evaluate the CH_4 budget of East Asia by using an anthropogenic emission inventory (Emission Database for Global Atmospheric Research; EDGAR), biomass burning data (Global Fire Emissions Database; GFED), land-use data (Land Use Harmonization; LUH), and a process-based biogeochemical model (Vegetation Integrative SImulator for Trace gases; VISIT). The regional CH_4 budget of East Asia in 2000–2012 was estimated at a net source of 67.3 Tg CH_4 $year^{-1}$, of which 88% was from anthropogenic sources. Fossil fuel extraction (e.g., by coal mines) was the largest source and was responsible mainly for the emission increase after 2002. These results are useful for implementing climate change mitigation by reducing CH_4 emissions. The emission maps are useful for interpreting observational data and improving inverse estimations under sub-themes 1 and 2, as well as for facilitating future assessments in collaboration with Project 2.

Project 2. Global-scale climate risk research based on integrated assessment of climate projections, impacts, and response options

In this project, we are developing a comprehensive modeling approach in which models for climate projections, impact assessments, and assessments of response options at a global scale are used in an integrative manner. With this approach, we aim to describe synthetic scenarios of climate change risk. This project consists of three sub-themes: (1) Projection and interpretation of climate change; (2) Synthetic assessment of low-carbon scenarios based on an integrated terrestrial model; and (3) Assessment of climate impacts, adaptation, and mitigation from the human and social perspectives.

Sub-theme 1 contributes to the development of climate change risk scenarios by projecting the future climate and understanding past climate changes. This fiscal year, we analyzed simulation data produced by multiple climate models to better understand the uncertainty—namely inter-model differences—in future projections. We found that some climate models show overly active deep convection in the tropical atmosphere compared with observations. Interestingly, such models tend to project a smaller amount of future warming compared with other models, suggesting that, to reduce uncertainty, we might be able to put a constraint on future projections based on observations. We also investigated factors contributing to the record low sunshine duration over Japan during August 2017. We found that human-induced warming and a decaying El Nino contributed

to an increase in the probability of this occurrence.

Under sub-theme 2, we helped to develop the Integrated Terrestrial Model (ITM). In particular, we developed a terrestrial ecosystem model to assess ecosystem service impacts on the basis of land-use scenarios (Shared Socioeconomic Pathway–Representative Concentration Pathways; SSP-RCPs), and we used the VISIT process-based terrestrial ecosystem model to investigate the impacts of climate change and the deployment of countermeasures. We showed that global warming under RCP8.5 (the pathway with the highest GHG emissions) would substantially affect terrestrial productivity and carbon stocks, and that even under RCP2.6 (the most ambitous mitigation scenario) it would also affect several vulnerable ecosystems, such as those in the Arctic. Deployment of countermeasures, such as the expansion of biofuel crop cultivation and climate engineering, was estimated to considerably affect terrestrial ecosystems. This has important implications for planning the optimal management of land systems.

In sub-theme 3, we emphasized integrated economic analyses of climate change impacts on sensitive sectors at the global scale. There are great uncertainties in the projected economic impacts of climate change. There are three main uncertainties: in the climate response, the climate change mitigation pathway, and the socioeconomic development pathway. Although the relative contributions of these uncertainties are important for climate-change-related decision-making, they are poorly understood. We therefore aimed to show the extent to which the projected economic impacts of climate change could be attributed to these three uncertainties. Our modeling framework, consisting of global, multisectoral-impact models coupled with an integrated assessment model, enables us to estimate the global total economic impacts of climate change while incorporating these uncertainty sources (Fig. 3). Whereas the most pessimistic pathway, without mitigation, would result in a net economic impact equivalent to 6.6% (3.9% to 8.6%) of global gross domestic product at the end of this century, the pathways with stringent mitigation would limit the impact to about, or less than, 1%. Although all of the uncertainties are great, the climate change mitigation pathway is the dominant one, but socioeconomic developments can also help to alleviate the impacts of climate change.

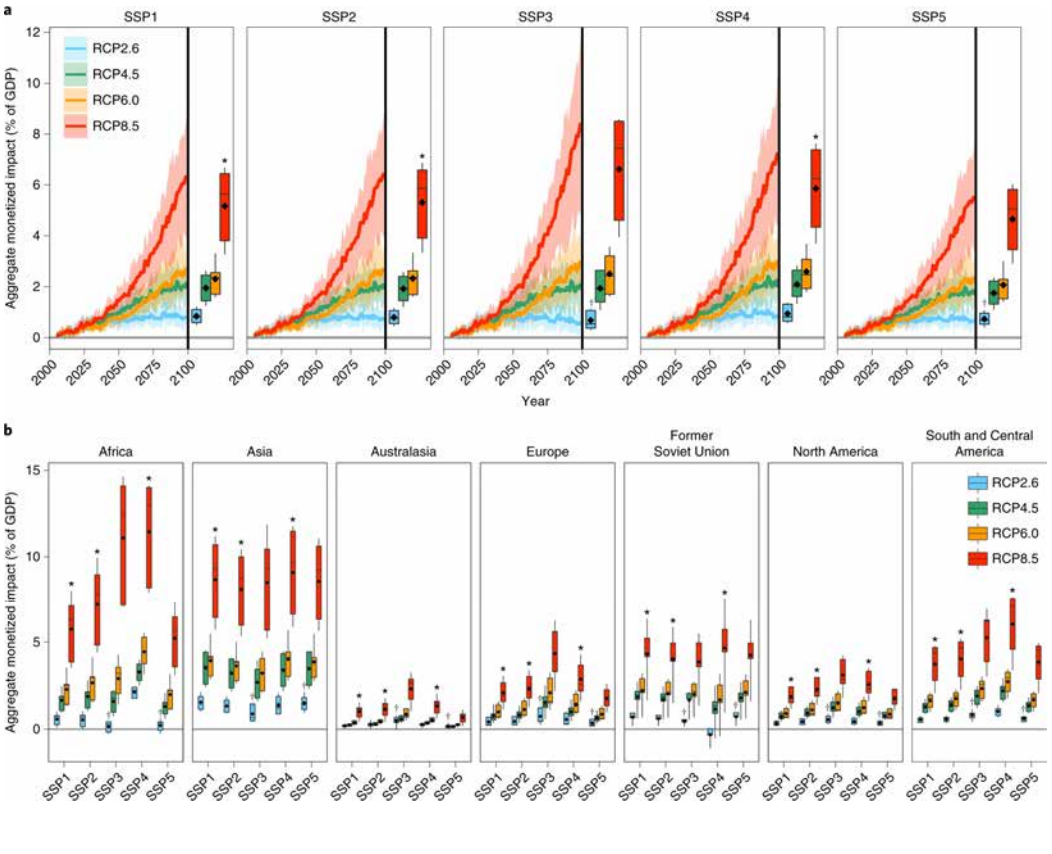


Fig. 3 (a) Time series of aggregate monetized impacts and the mean impact for 2080–2099. (b) Regional impacts. In a, the mean (line) and uncertainty range (shaded area) of each of the five general circulation models (GCMs) are shown. For the boxplots in a and b, the mean impacts for 2080–2099 are shown and the ranges are the uncertainty ranges for the five GCMs. Center line: median; dot: mean; box limits: upper and lower quartiles; whiskers: range.

(Takakura, J., Fujimori, S., Hanasaki, N. et al. (2019) Dependence of economic impacts of climate change on anthropogenically directed pathways. *Nat. Clim. Change* 9, 737–741)

Project 3. Policy assessment research toward a global low-carbon society

The aim of Project 3 is to provide scientific knowledge from the perspectives of modeling and analysis, scenario development, and negotiation processes, to achieve a global low-carbon society. National- and local-scale analyses toward a low-carbon society are being implemented in the Integration Research Program. Project 3 of the Low-Carbon Research Program consists of two sub-themes: (1) Assessment by using quantitative models, and (2) International institution design. The following are the main results obtained in FY 2019 in each sub-theme.

In sub-theme 1, we analyzed emission projections of long-lived GHGs such as CO_2 and N_2O, short-lived climate pollutants (SLCPs) such as black carbon and CH_4, and air pollutants such as SO_2, NO_x, $PM_{2.5}$, PM_{10}, CO, and NMVOCs (non-methane volatile organic compounds) in global regions by using the AIM/Enduse [Global] model. Our aim was to investigate the emission gaps between the emission reduction targets of the Nationally Determined Contributions (NDCs) reported in major countries and the CO_2 emission reduction required to achieve the global 2°C target as is described in the Paris Agreement. We analyzed effective technological countermeasures to reduce the gaps, and we have been promoting better understanding of the synergies and trade-offs of various combinations of low-carbon measures and air pollutant control measures. We found that future emissions in Asian regions would account for a large proportion of global emissions, and that the NDC targets were almost

in line with the reference scenario shown in Figure 4. Countermeasures to narrow the gaps of CO_2 emission between NDCs and the 2°C target can contribute for reducing air pollutants largely, except for CH_4 emission. Major emission sources of CH_4 are different from those of CO_2 (i.e. non-energy related sectors such as agriculture, waste and mining sectors). ASEAN countries are major emitters next to China and India in Asia due to rapid economic development. Figure 4 shows sectoral mitigation potentials to narrow the gaps between reference and 2°C target scenarios. CH_4 is the major SLCP that is expected to achieve early-stage drastic reduction for contributing to the 2°C target, but it is not easy to reduce CH_4 drastically in following decades, especially in India and ASEAN countries where the agriculture sector accounts for a large proportion of CH_4 emission.

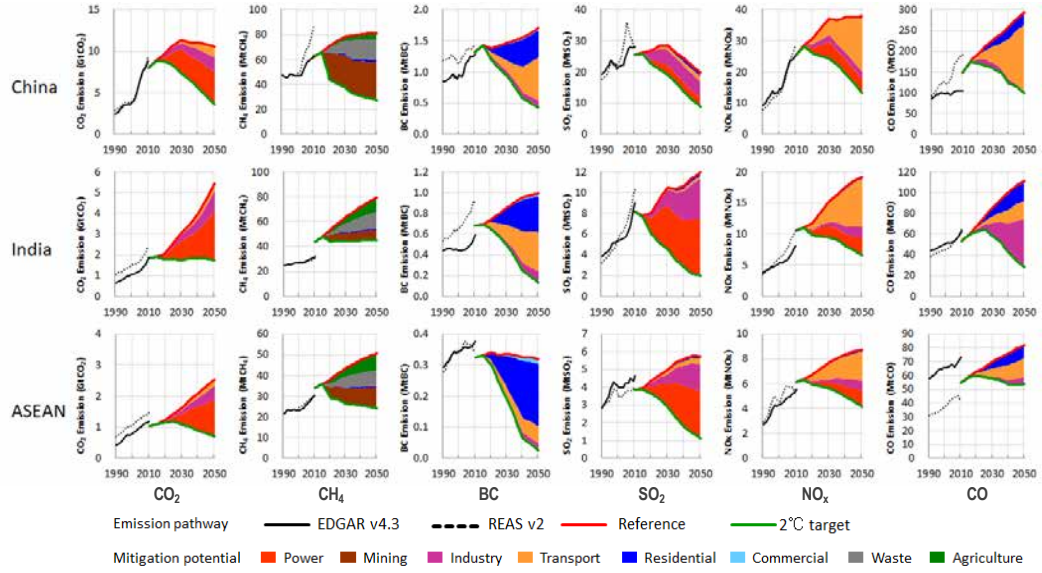


Fig. 4 Emission projections of the reference and 2-°C target scenarios and potential reductions in major sectors in Asia. BC, black carbon; EDGAR, Emission Database for Global Atmospheric Research; REAS, Regional Emission inventory in ASia

As part of sub-theme 2, we focused on the Green Climate Fund (GCF)—a funding mechanism established in 2010 for developing countries—and developed a dataset of projects that were conducted by the GCF. This was an important exercise, because 2020 was the tenth anniversary of the GCF and a review process was to be conducted. From the dataset, we found that (1) as of January 2019, 48 countries or regions had pledged a total of USD 10.2 billion to the GCF, but only 7.9 billion had been transferred; (2) 111 projects had been approved by the GCF, but only USD 0.6 billion had been funded thus far; (3) in the balance between mitigation and adaptation, there was a good balance in terms of the number of projects, but more funds were being spent on mitigation projects; and (4) with 33 mitigation-related projects and 28 mitigation- and adaptation-related projects, a total of 1544 million tCO_2eq of emission reduction could be expected. Simply by dividing the amount of GCF funding allocated to those projects by the emission reduction figure, we found an emission-reduction cost of USD 1.7/tCO_2eq for mitigation-related projects and USD 6.7/tCO_2eq for mitigation- and adaptation-related projects in developing countries (Table 1). These costs are much lower than those in the developed countries.

Table 1 Expected emission reductions and funding amounts, by project size, in developing countries, under the Green Climate Fund

Project size (USD million)	Expected GHG emission reduction (Units: $MtCO_2eq$)		
	Mitigation	Mitigation and adaptation	Total
Micro (less than 10)	0	4.1	4.1
Small (10 or more but less than 50)	11.1	19.0	30.1
Medium (50 or more but less than 250)	79.7	121.0	200.7
Large (250 or more)	1191.2	118.3	1,309.5
Total	1,282.0	262.4	1,544.4
Project size (USD million)	Funding allocated from GCF (Units : Million USD)		
	Mitigation	Mitigation and adaptation	Adaptation
Micro (less than 10)	0	31.2	122.1
Small (10 or more but less than 50)	131.5	219.7	497.1
Medium (50 or more but less than 250)	744.4	560.8	600.5
Large (250 or more)	1,340.0	954.6	31.0
Total	2,215.9	1,766.3	1,250.7

Sustainable Material Cycles Research Program

To encourage understanding of the future vision for an international material cycle strategy, and in harmony with this vision, this program will elucidate supply chain structures and the factors that shape those supply chains. Measures toward a sustainable material-cycle-based society will be proposed on the basis of an assessment of resource and environmental conservation and future social change. The program will develop and evaluate measures for the advancement of sustainable, integrated waste management systems in Japan and the broader Asian region. It will also be used to propose the fundamental technologies and social systems needed for waste prevention or minimization, reuse, and recycling in harmony with a low-carbon-footprint society and other initiatives.

We have worked to implement the following five research projects, with a view to three cross-cutting key points, namely "future of supply chain and waste management," "high efficiency of material utilization and implementation," and "safety in material cycles." Figure 1 highlights some of our accomplishments across the entire Sustainable Material Cycles Research Program and their connections with these three viewpoints.

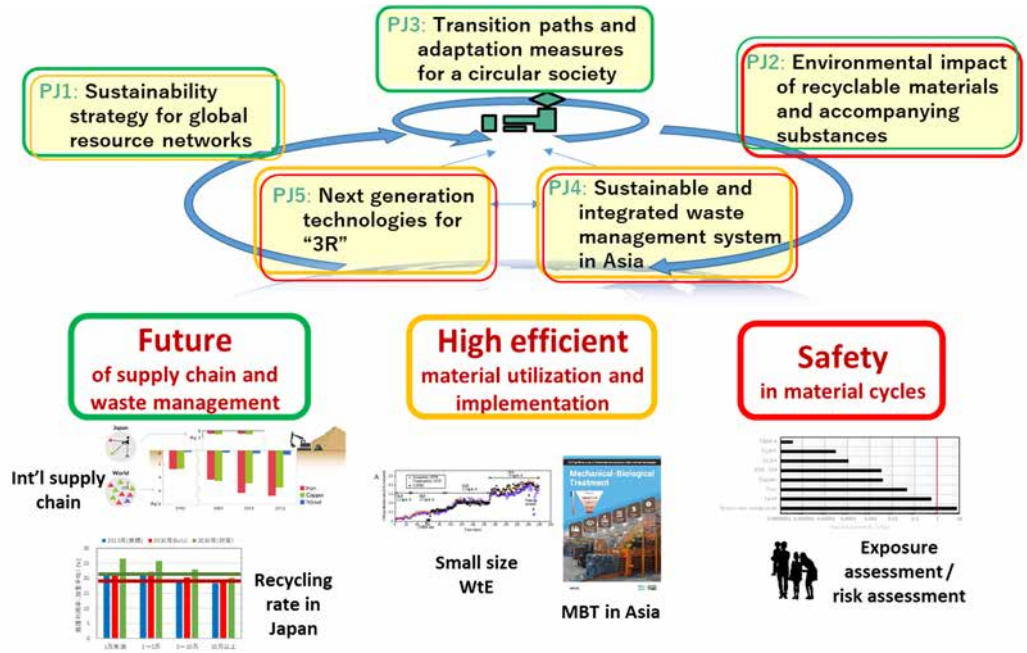


Fig. 1 Positioning of our highlights in the entire Sustainable Material Cycles Research Program and their relationships with the five projects and three cross-cutting viewpoints.
Each of the three viewpoints-—"Future," "High efficiency," and "Safety"—is related to several projects, as shown by the colors of their frames.

1. Designing a sustainability strategy for global resource networks from a consumption-based perspective (Research Project 1)

This project aims to propose resource management strategies that contribute to sustainability. To do this, we analyze the environmental and social impacts through the supply chain induced by Japan's economy, and we formulate quantitative future scenarios based on these analyses.

Critical metals are vital to the functionality of various emerging technologies, yet they have a potentially unstable supply. This calls for strategic planning based on the expected long-term demand and supply of these metals and the implications of this demand and supply. Nevertheless, we currently lack a comprehensive picture of the progress of long-term outlook studies on critical metals. A review of critical metal dynamics to 2050 for 48 elements (Watari et al. 2020) as part of this project has given us a comprehensive view of the progress of long-term outlook studies of critical metals such as various minor metals (Fig.2). It has also enabled us to understand a variety of perspectives related to metals sustainability (e.g., life cycles, supply chains, circularity) and to detect five unaddressed issues. These issues are: (i) no long-term demand outlooks are available for some highly critical metals; (ii) the potential growth of future demand driven by emerging industries such as medical devices and robots has been largely overlooked; (iii) the social and environmental implications of the growth in metal demand have been barely quantified; (iv) consideration of the spatial divergence occurring between consuming and producing countries as a result of international resource trade has been underemphasized; and (v) little attention has been given to various circular economy strategies, such as component reuse and remanufacturing. These findings emphasize the need for additional scientific research that explores the long-term outlook for critical metals and is strongly connected to sustainable development goals and implementation of the Paris Agreement.

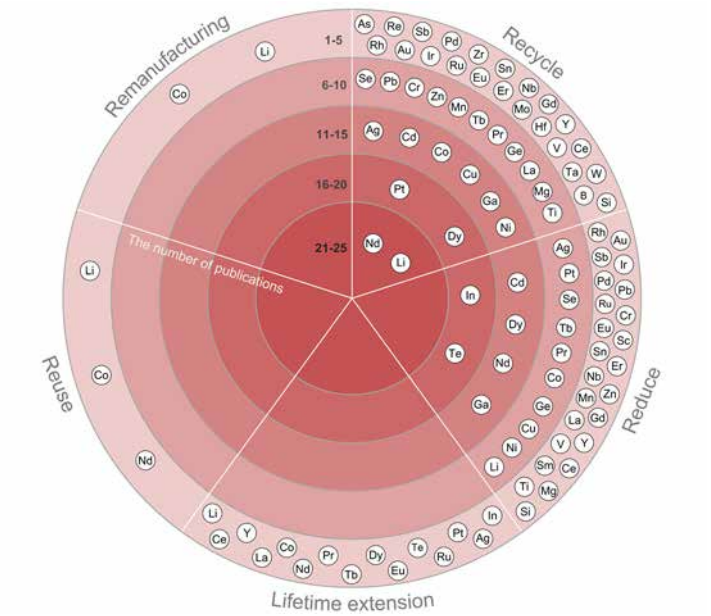


Fig. 2 Wheel diagram indicating the number of publications covering each circular economy strategy; the most explored elements appear in the inner circle (Watari et al. 2020).

Reference:
Watari T., Nansai K., Nakajima K. (2020) Review of critical metal dynamics to 2050 for 48 elements, Resources, Conservation and Recycling, 155, 104669

2. Assessment of resource efficiency and environmental impact in the cycles of recyclable materials and accompanying substances (Research Project 2)

We estimated the flows of plastics in Japan originating from waste electrical and electronic equipment (WEEE) and the flows of brominated flame retardants (BFRs) contained in those plastics. We found that WEEE plastics were recovered mainly as mixed plastics or shredder residues. In 2017, a large proportion of recovered mixed plastics were being exported. Owing to China's import ban on plastic waste, the amount of mixed plastics exported from Japan was expected to decrease significantly after 2018; however, it appeared that a substantial amount of the recycled pellets from WEEE plastics was still being exported to China and other Asian countries. We also found that a large proportion of BFR-containing plastics in bulk mixed WEEE plastics that were processed in Japan were being removed through wet specific-gravity separation and X-ray sorting.

To identify those chemicals with high priority for risk management in WEEE-dismantling areas, we estimated the daily chemical intakes of workers engaged in WEEE dismantling, and we assessed their health risks from chemical exposure via indoor dust ingestion or inhalation and intake of free-range chicken eggs. The median-based hazard quotients—namely, the exposures as ratios to tolerable weekly intake, provisional tolerable weekly intake, or reference doses—clearly indicated that large amounts of exposure would increase the potential non-cancer health risks posed by lead and dioxin-like compounds to the

WEEE-dismantling workers (Fig. 3). Our findings suggest that the dust emitted to the surrounding environment should be controlled, and that measures against indoor dust exposure should be implemented to reduce the adverse health effects of lead and dioxin-like compounds in WEEE-dismantling areas.

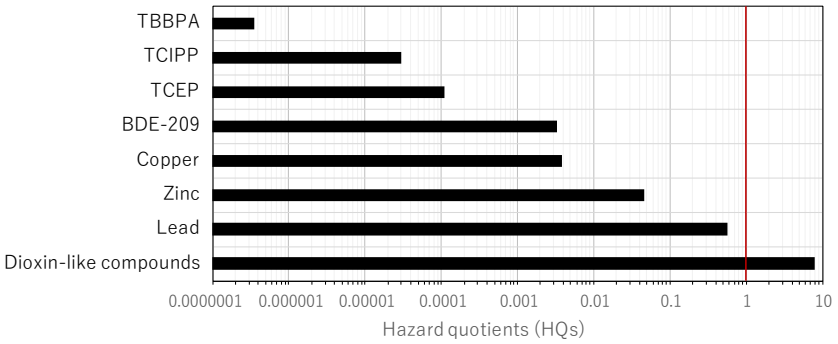


Fig. 3 Median-based hazard quotients (HQs) of chemicals derived from the WEEE-dismantling areas. (The potential for health risk increases if the HQ is greater than 1.)

3. Proposal of transition paths and adaptation measures for a circular society (Research Project 3)

We continued to develop a municipal waste model—referred to as the MINOWA (Municipality-Input Nation-Output WAste management) model—that simulates how different policies of municipalities affect national-level policy outcomes. First, we developed a new submodel for calculating greenhouse gas (GHG) emissions from waste collection based on the investigated relationship between the frequency of waste collection in a week and GHG emissions. Second, we used the new submodel and a revised policy package to conduct a policy analysis, with a focus on variations of waste management among municipalities. The calculated increased recycling rates under a business-as-usual scenario were larger in the less populous municipalities. Third, we put forward five different circularity indicators and evaluated municipal waste flows in Japan. Energy recovery was the most influential item in this evaluation. Fourth, we continued to study the consolidation of waste facilities and analyzed plausibility of facility consolidation based on the gravity model. Although the plausibility parameters still need to be scrutinized, we have created four consolidation scenarios for reducing the number of waste incinerators to between 67% and 70% of their current number by 2030.

To clarify problems with the waste collection system in an aging society, we conducted a questionnaire survey of the leaders of neighborhood associations in city of Tsukuba. We analyzed the relationship between perceived problems with the use and management of waste collection points and the weakening of residents' social bonds and aging. The results revealed that violation of disposal rules occurred more in neighborhoods with elderly people suffering major neurocognitive disorders and in neighborhoods with larger numbers of households using waste collection points. In addition, the populations in need of

nursing care and the amounts of diaper waste generated from 2020 to 2045 were estimated for 29 municipalities in Mie Prefecture. In step with the aging of the population, the generation of diaper waste will steadily increase. We also published an English version of a guidebook for local governments and community-based organizations to support elderly people to take out their trash.

To improve the quality of resource circulation and reduce natural resource consumption, we reviewed advanced cases of enhancement of the value creation and quality of resource use. Approximately 50 cases were categorized into six types: upcycling products, materials recovery, natural decomposition, social value creation, community revitalization, and online marketing. These included cases of the utilization of previously unused and discarded resources and the creation of social value (e.g. creating jobs for disabled people). We also developed a product lifetime model that can quantitatively analyze the impacts of promoting product lifetime extension. The results showed that if the number of consumers who used their durable products for 1.4 times longer than normal consumers were to increase to 20% of all the consumers, product demand and end-of-life product generation would decrease by 5% to 10%.

4. Establishment of a robust, sustainable, and integrated waste management system for Asia (Research Project 4)

In Japan and the rest of Asia, it is important to create a sustainable and resilient waste management system that is compatible with the environment, economy, and society of each region's treatment system, given the region's urban characteristics, economic conditions, and social acceptance. We also need to establish future waste treatment systems and methods for evaluating them that are in harmony with high-level urban planning, and we need to develop and upgrade integrated technology systems for incineration, landfill, and other related technologies. This project will present a baseline model of waste treatment systems that is universal and customizable to the Asian region. Below are some of the results we obtained in FY 2019.

We focused on composting and incineration in Vietnam; these intermediate waste management technologies have begun to be introduced in developing countries. We attempted to organize and structure the associated challenges faced on site. Lack of consideration for the quality of the raw materials (waste) and products (compost and incinerated ash) was the main challenge.

We proposed a business model for the phased introduction of resource recovery and sanitation facilities in emerging Asian countries as part of the development of high-end residential areas or large commercial facilities. We discussed the introduction of the business model with real estate developers and other relevant entities, and we also developed our own resource recovery and sanitation system, including the acquisition of a registered trademark.

At isolation-type landfill sites in Japan, we investigated the condition of the specially controlled wastes delivered to the site. Sludge, soot, and slag were the major waste items landfilled. Specifically, there was CRT (cathode ray tube) glass scrap containing lead, furnace refractory ceramics containing chromium, and electric furnace dust containing cadmium and lead. The leaching characteristics of heavy metals by weathering and the alteration and insolubilization characteristics of the abovementioned wastes in response to biological action were also revealed. A numerical landfill model was also developed for an isolation-type landfill that used reinforced concrete structures. The cracking width of the landfill was estimated to be 0.5 mm in an earthquake event equivalent to Level 1 or 2 earthquake motion defined in Japan (Fig. 4). The concentrations of heavy metals and fluxes leaking from the site were calculated.

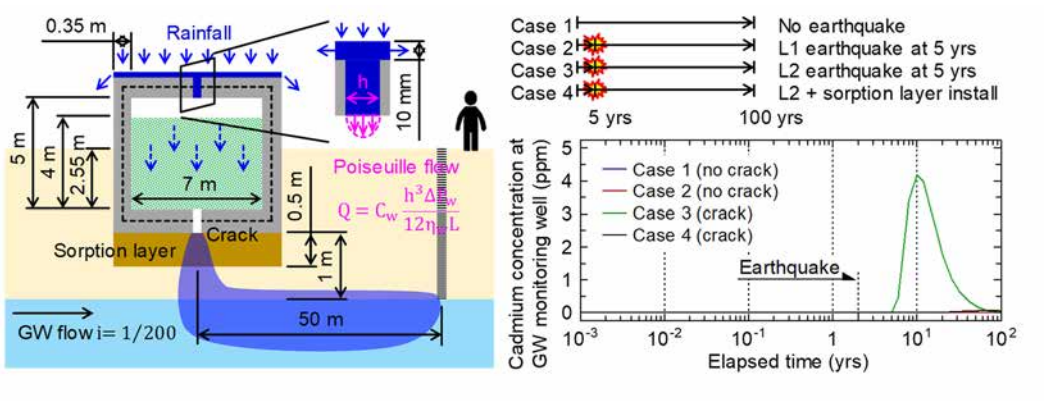


Fig. 4 Numerical simulation conditions for long-term environmental safety evaluation of an isolation-type landfill site in Level 1 or 2 earthquake motion . Also shown are the simulation results obtained from a seismic structural analysis and reactive chemical transport analysis.

5. Development of next-generation technologies for "3R" (Research Project 5)

As part of the development of waste-to-energy technologies, we have been investigating the tolerance of microorganisms to long-chain fatty acids (LCFAs) in the anaerobic co-digestion of oily waste and food waste for biogas (methane) production under two typical conditions [mesophilic and thermophilic continuously stirred tank reactors (CSTRs)]. This year, we newly conducted a semi-continuous experiment on anaerobic co-digestion using a continuously stirred fluidized bed reactor (CSFBR) in an effort to achieve both high process stability and high organic loading rate (OLR) under thermophilic conditions. Methane production using the CSFBR was almost the same as that using the thermophilic CSTR. However, the CSFBR maintained much lower concentrations of volatile fatty acids and LCFAs than did our previous mesophilic and thermophilic CSTRs. These results demonstrated that the CSFBR simultaneously provided high process stability and capacity for high OLR in the co-digestion of food waste and oily waste. This CSFBR will help substantially to enhance the energy efficiency of small-scale on-site biogas production systems for urban uses.

As part of the development of waste-to-material technologies, as a resource recycling method for municipal solid waste (MSW) incineration ash, we proposed a draft method in which metallic particles were separated by using an air-table sorting apparatus and aging of the separated ash residue was accelerated by ventilation with a gas enriched with carbon dioxide. An air-table sorting device was introduced to sort MSW bottom-ash particles according to size and density, and the dependence of the elemental composition of the ash particles on particle size and density was clarified (Fig. 5). Because the metal particles are not crushed during the ash-crushing process, this process is effective in recovering the metal particles, with enrichment of precious metals such as gold and silver.

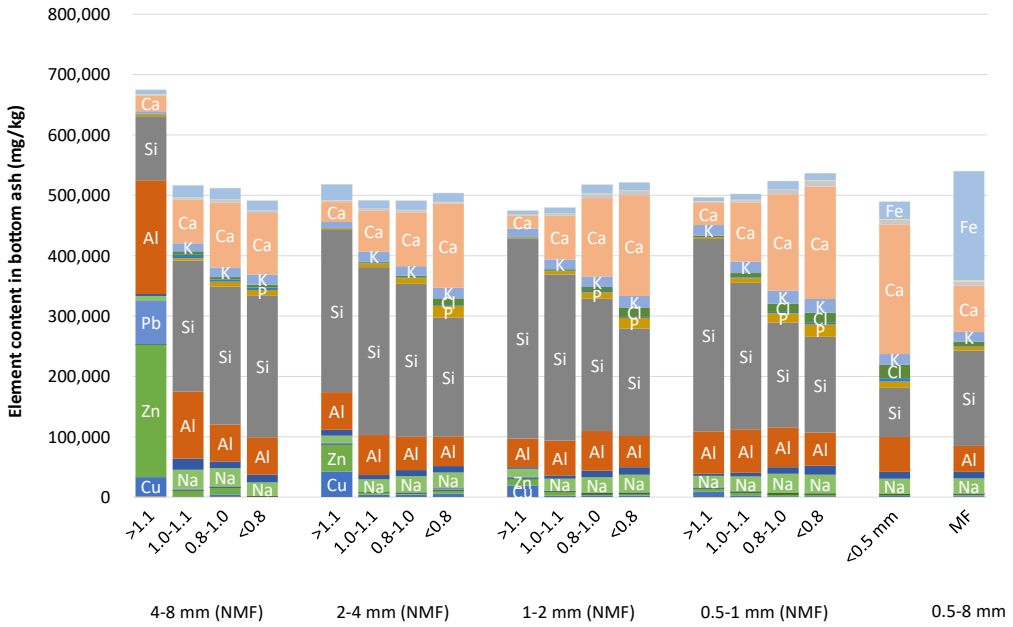


Fig. 5 Elemental composition of municipal solid waste incineration bottom ash [non-magnetic fraction (NMF) and magnetic fraction (MF)] according to particle size and bulk density

Harmonization with Nature Research Program

The Harmonization with Nature research program is structured to address the four biodiversity crises described in the National Biodiversity Strategy and Action Plan of Japan in order to achieve the Aichi Biodiversity Targets of the 2010 Convention on Biological Diversity (Fig. 1). Project I responds to the first crisis, namely that resulting from development and other problems caused by human activities (e.g., habitat destruction or overfishing), and the second crisis, namely that caused by reduced stewardship of nature (abandonment of cultivation and reduction in the abundance of *satoyama* landscapes). Project II responds to the third crisis, caused by organisms and materials introduced by humans (e.g., invasive species or pollution). Project III responds to the fourth crisis, caused by large-scale environmental changes (e.g., climate change). Project IV was established to set up biodiversity conservation measures in an integrated manner. On the basis of the conservation of biodiversity through these efforts, Project V works on the evaluation and sustainable use of ecosystem functions and services, including the conservation of land–sea continua.

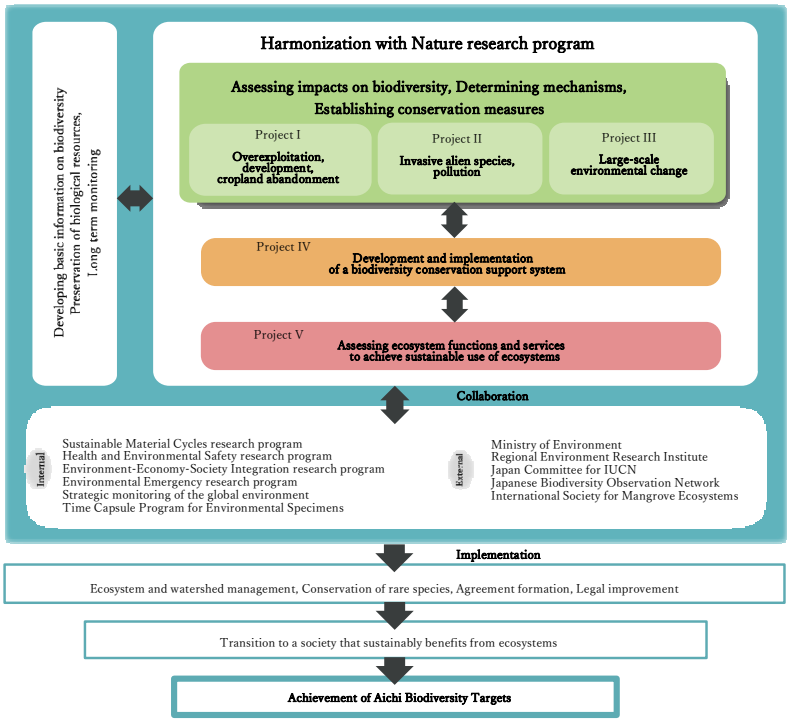


Fig. 1 Overall structure of the Harmonization with Nature research program

The research is being conducted at the global, national (Japan), and local scales. Figure 2 shows our specific research sites in Japan, as described in this report.

Fig. 2 Locations of the study sites referred to in this report

1. Biodiversity assessment of impacts of large-scale human activities (Project I)

1.1. Effectiveness of protected areas in halting biodiversity loss

Here, we aimed to investigate the effectiveness of global protected areas in conserving species' habitats by assessing whether protected areas slow the rate of forest habitat loss compared with the rate outside these areas. Especially, we examined 1) the impacts of human activities, including forest area change and the establishment of protected areas (PAs), on forest species extinction risk, and 2) the effectiveness of protected areas in halting forest habitat conversion.

For this purpose, we integrated global datasets of species range maps provided by the International Union for Conservation of Nature (IUCN) for more than 10,000 terrestrial forest species; deforestation maps for the period 2001–2010 at 30-m resolution; and PA maps from the IUCN World Database on Protected Areas. First, we examined whether forest loss is affecting the temporal change in the extinction risk of species, as assessed by using the Red List Index (RLI). We treated the change in the IUCN RLI over time as the change in extinction risk. To explain the change in extinction risk, we employed factors related to human activities (PA cover and forest area change over a species' distribution), as well as species characteristics (species distribution area, number of species habitats besides forests, and latitudinal distribution of species). We used Bayesian hierarchical regression models to quantify the impacts of these factors on forest species' extinction risk. Secondly, we examined the effectiveness of PAs in halting forest habitat conversion. Here, we simply considered the forest area change in a species' distribution range, and we determined whether the forest area changes differed between inside a PA and outside the PA. We found that: 1) increasing PA cover and reducing deforestation is essential for preventing increases in the

extinction risk for Mammals and Birds, but not Amphibians and Reptiles (Fig. 3a, b). Moreover, species characteristics such as multi-type habitat use and larger distribution area also contributed to improve the species extinction risk (Fig. 3c, d), indicating that these characteristics should be taken into account for conservation; and 2) the effectiveness of PAs in halting habitat conversion varies among countries. PAs generally prevented impacts from the threats of commodity-driven deforestation or shifting agriculture, but they were not effective against the threats of forestry and wildfire. Overall, though, PAs should play an effective role in curbing biodiversity loss. However, our findings suggested that the effectiveness of PAs could vary spatially and taxonomically. Therefore, consideration of the types of impacts and assessment of their spatiotemporal consequences in terms of biodiversity are crucial to achieving effective and efficient PA management and planning to reduce the risk of species extinction.

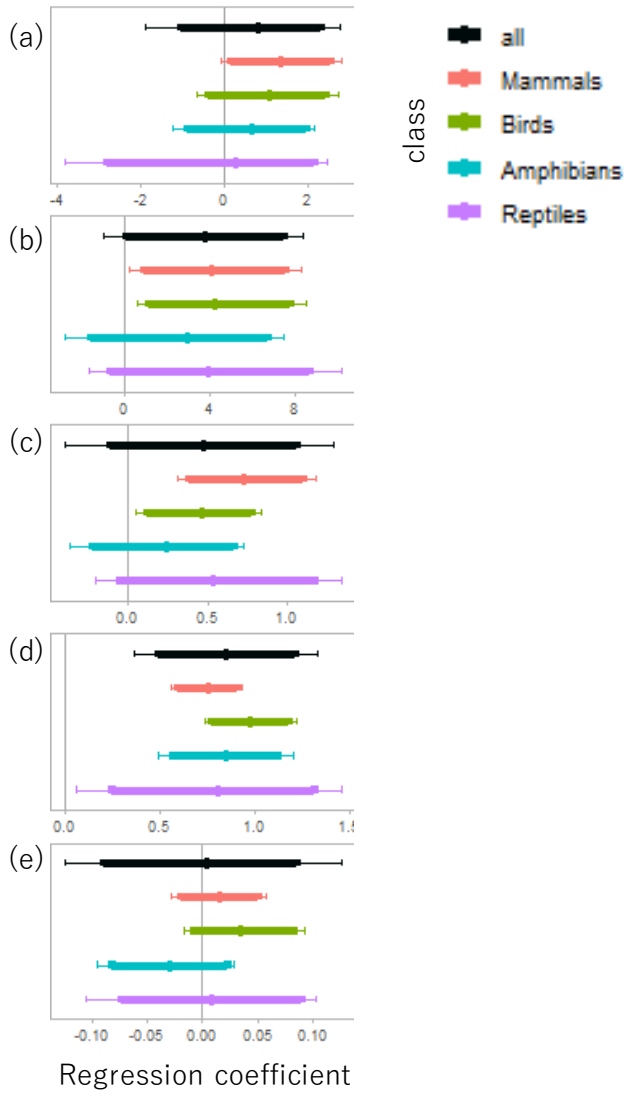


Fig. 3 Coefficients analyzed by using a hierarchical Bayesian model: (a) protected area cover; (b) forest change ratio; (c) number of species habitats besides forests; (d) species distribution area; and (e) absolute values of latitude (0°–90°). The x-axis indicates estimated regression coefficients. Outer thin lines indicate the 95% confidence interval (CI) and inner thicker lines indicate the 90% CI.

2. Development of intensive control methods for invasive alien species management (Project II)

2.1 Fire ant detection

Since the *Invasive Alien Species Act* was enacted in 2004, the top priority of the Ministry of the Environment (MOE) has been to control, and ultimately eradicate, invasive alien species established in Japan, while also preventing the introduction of new alien species. We have conducted invasive alien species risk assessments and research into the development of eradication methods to support national policy.

Since the first detection of the fire ant *Solenopsis invicta* in Japan in June 2017, both the MOE and NIES have promoted emergency control of the newly invasive ant. Because it is important to detect ant invasions as soon as possible, we have developed a molecular technique to identify the presence of the fire ant by using DNA barcoding and LAMP (loop-mediated isothermal amplification) methods (Fig. 4). Furthermore, we have constructed a chemical control strategy for the ant in collaboration with private companies developing insecticides. We were faced with the establishment of a fire ant nest in Shinagawa Port in Tokyo in 2019; we applied the chemical bait developed in this project and succeeded in eliminating the nest and its occupants. To strengthen our monitoring of the fire ant invasion, we are promoting cooperation with DASKIN Corporation to deliver LAMP kits to 200 DASKIN branches across Japan and to create a country-wide monitoring system by the end of 2020.

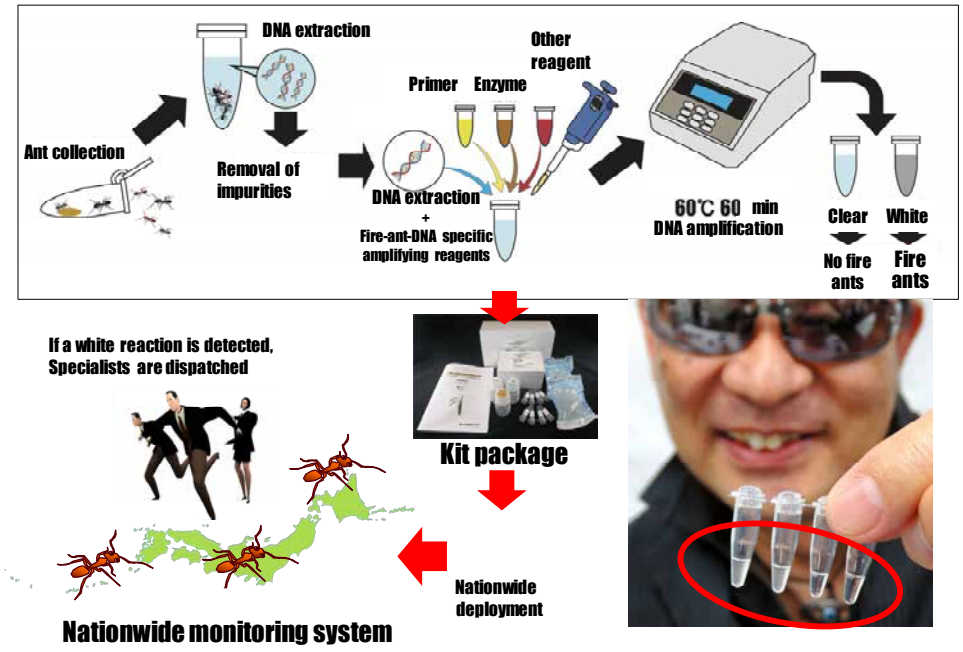


Fig. 4 Flow chart for use of the LAMP kit to quickly detect fire ant DNA. By using specific primer sets, we can amplify specific fire ant DNA within 2 h.

3. Ecological responses to large-scale environmental changes (Project III)

3.1 Shifts from macroalgae to corals

Global and local degradation of coral reefs and macroalgal beds can have ecosystem-wide impacts on biodiversity, ecological functioning, ocean resources, and biogeochemical cycles. However, recently reported community shifts from temperate macroalgae to tropical corals (Fig. 5) offer conservation potential for corals at the expense of macroalgae under climate warming. Although such community shifts are reported sporadically from different regions across the world, our understanding of the patterns and driving processes behind these shifts is still limited. Here, we reconstructed long-term climate-driven range shifts for 45 species of macroalgae, corals, and herbivorous fishes from over 60 years of records (mainly 1950–2015), stretching across 3000 km of the Japanese archipelago from tropical to subarctic zones. We found that tropical corals and herbivorous fishes are expanding into existing temperate Japanese macroalgal communities, which in turn are contracting faster than they are expanding. Furthermore, we presented novel evidence that the macroalgal-to-coral shifts are facilitated by ocean warming, aided by the dominant poleward-flowing current system. The contrasting range dynamics of corals and herbivorous fishes suggest that ocean warming is promoting macroalgal-to-coral shifts both directly (by increased competition from the expansion of tropical corals into the contracting ranges of temperate macroalgae) and indirectly (via deforestation caused by expansion of the ranges of tropical herbivorous fish). Beyond individual species' effects, our results provide novel evidence of the important role of the interaction between climate warming and ocean currents in shaping community-level responses, with concomitant changes to ecosystem structure and functioning. We also found that the community shifts from macroalgae to corals might accelerate with future climate warming. This highlights the complexity of managing these evolving communities under future climate change: conservation of these communities might require more proactive management for climate adaptation (Kumagai et al. 2018, *PNAS* 115:8990–8995).

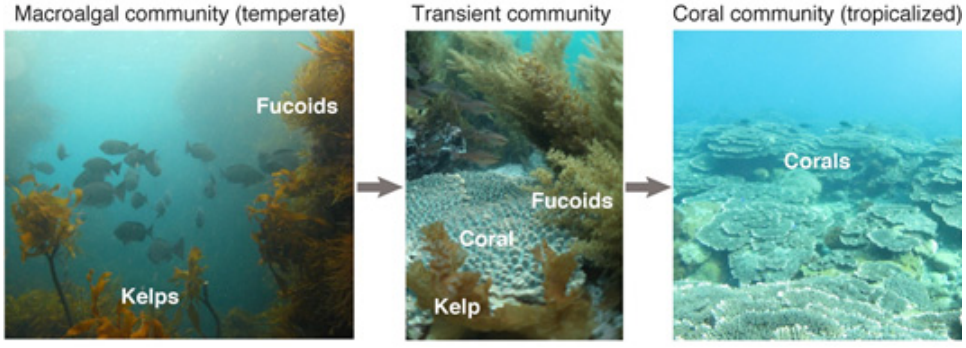


Fig. 5 Kelps and fucoids are dominant in Japanese coastal communities, but they are gradually being replaced by expanding tropical corals, with which they compete.

4. Evaluation of biodiversity and development of a system for supporting conservation design (Project IV)

4.1 Biodiversity conservation in Daisetsuzan National Park

National parks are major protected areas for both biodiversity and ecosystem services, and it is essential to incorporate strategies for adaptation to climate change into their management plans, especially in mountainous and marine areas, which can be particularly vulnerable to climate change. We applied SecSel—a conservation planning tool that we developed for this project—to the planning of adaptation strategies for alpine vegetation in Daisetsuzan National Park in Hokkaido, northern Japan. This research was conducted in cooperation with NIES's Climate Change Adaptation research program.

Daisetsuzan National Park is composed of high mountainous regions and is characterized by cold winters with heavy snow and highly diverse alpine plants (365 species). The alpine plants are of importance as both targets of conservation and resources for tourism.

We categorized the alpine vegetation into four types for consideration as biodiversity features to conserve, and we classified the habitat quality of each grid cell (approximately 1 × 1 km) for each vegetation type into four classes (snow bed, fellfield, wilderness, and alpine shrub) on the basis of the area of the vegetation type within the cell. We considered the sum of the areas of snow bed and fellfield vegetation as the quality of ecosystem services, because these types of vegetation form attractive flower fields. Because tourism can pose threats to conserving vegetation—for example, through trampling and illegal digging—we considered conservation and tourism to be competing uses of a site. In terms of conservation features, alpine shrub outcompeted other types of alpine vegetation, and we considered that there were conflicts of space occupancy among these vegetation types.

Options for conservation management include patrolling against illegal digging, monitoring changes in the state of vegetation, and cutting back sasa bamboo and shrubs, which are likely to outcompete alpine vegetation under climate change. Accessibility is important for all of these types of conservation management, as well as for tourism. We therefore considered the time required to reach each cell as a cost in the analysis.

Under a simple setting, without considering cost or boundary length, the northern and southern regions of the Park were often selected as a whole for prioritization and the central region was selected somewhat less frequently (Fig. 6a). In particular, selection frequency was high in the high-altitude areas near the center of the northern and southern parts. When we considered the accessibility cost, the sites selected were concentrated close to trail entrances and trails (Fig. 6b), and

the cost function worked as expected.

Although the target vegetation types overlapped between tourism use and biodiversity conservation, the sites selected were separate for these objectives because there was conflict between them. SecSel can provide information on which site is selected for conserving for which feature (Fig. 6c, d); this is very useful information for specifying the management required at each site and for planning adaptation strategies.

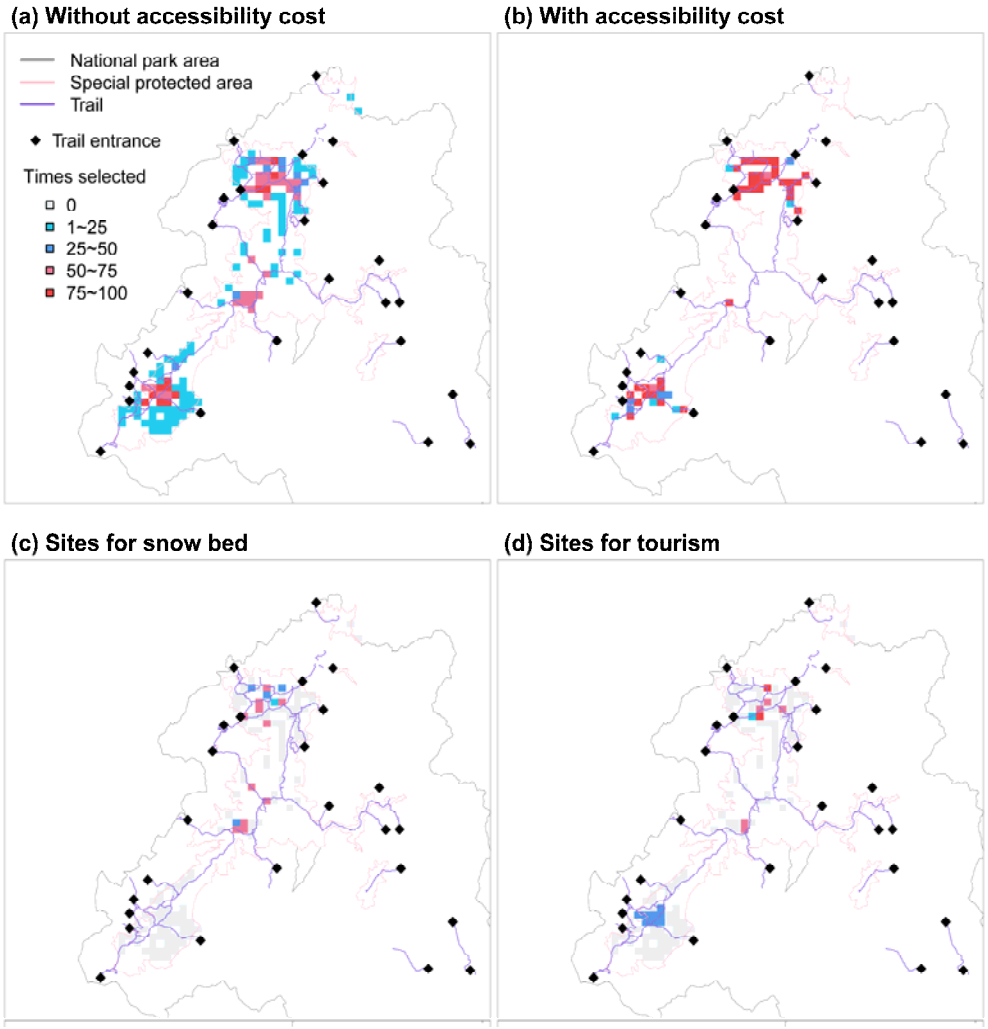


Fig. 6 Results of the use of SecSel to apply prioritization strategies for adaptation to climate change of alpine vegetation in Daisetsuzan National Park. The selected sites were concentrated close to trail entrances and trails when the accessibility cost was taken into consideration (b), in comparison with when this cost was not considered (a). Different sites were selected for features that required conflicting management for adaptation. For conservation of snow beds, to avoid human disturbance, it was preferable to exclude sites for tourism use (c) and to establish separate sites as tourism resources (d).

5. Evaluation of ecosystem functions and services and their sustainable use (Project V)

5.1 Interactions among multiple ecosystem services in the Lake Kasumigaura watershed

By focusing on the whole watershed of Lake Kasumigaura (the second-largest lake in Japan), we evaluated multiple ecosystem services and biodiversity across 50 sub-watersheds. We identified the spatial synergies and trade-offs among multiple ecosystem services and between ecosystem services and biodiversity. We are seeking a new watershed–lake management framework and strategy to sustain multiple ecosystem services and biodiversity. Here, we reveal four highlights of this sub-project (Fig. 7).

i) We assessed native fish diversity in each sub-watershed by using environmental DNA (eDNA). To enable a more accurate assessment of fish diversity, we developed a novel statistical method to appropriately correct false negatives in the eDNA metabarcoding (Fukaya et al. in preparation). When this method was applied, the richness of the fish species estimated to be present increased substantially. Our statistical model should be useful for detecting endangered fish species by using eDNA.

ii) We evaluated 10 ecosystem services and one type of biodiversity across the 50 sub-watersheds and identified spatial synergies and trade-offs among these variables (i.e., bundle types). The synergies included those among five ecosystem services, including carbon storage, flood regulation, and climate regulation. We also found substantial trade-offs between crop production and surface water quality.

iii) Despite the trade-offs between crop production and surface water quality, several sub-watersheds had high levels of cropland cover as well as high water quality. We developed an indicator, called the mitigation effectiveness score, to quantify the extent to which the trade-off was mitigated in each sub-watershed (Matsuzaki et al. 2019, *Ecosphere*). Mitigation effectiveness scores were positively associated with wetland cover. These results suggest that wetlands can mitigate the trade-off between crop production and water quality services and enhance the likelihood of win–win outcomes in agricultural landscapes.

iv) We found a bottom-up linkage between nutrients, primary production (a supporting service), zooplankton abundance, and planktivorous fish abundance (a providing service) within the lake by applying convergent cross-mapping—a numerical test of causal associations—to our long-term monitoring data (Matsuzaki et al. 2018, *Ecology*). Our results suggest that nutrients from the watershed can increase both primary production and fisheries production but decrease water quality. Our project clearly underscores the need for watershed

ecosystem management to resolve the linkages and conflicts among agricultural production, water quality, and fisheries production.

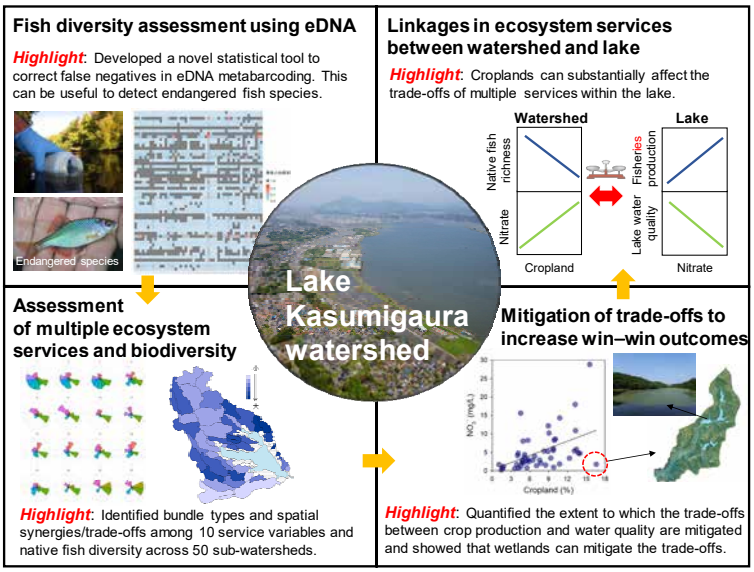


Fig. 7 Highlights of Project 5, conducted in the Lake Kasumigaura watershed

5.2 Sustainability of ecosystems on the Ogasawara Islands

We have been observing small freshwater stream ecosystems on Chichi-jima (Chichi Island) in the Ogasawara Islands since 2016. In the first half of 2017, the Ogasawara Islands suffered a serious drought. We investigated changes in species diversity and the composition of small freshwater stream ecosystems on Chichi-jima (Fig. 8). Before the drought (July 2016), 23 species were observed in the stream ecosystems (Fig. 8a). During the drought (January 2017), the species diversity in the stream ecosystems decreased to 18 (Fig. 8a). After the drought (March 2018), the species diversity increased to 26, and thereafter it remained above 20 (Fig. 8a), indicating that species diversity recovered quickly. However, the species composition was not restored. Of the 23 species observed before the drought, 12 could not be found during the drought (Fig. 8a). Only 15 of the 23 species observed before the drought had been restored by November 2018.

Response to the drought differed among taxonomic groups. The species diversities of mollusks, decapods, and other arthropods (arthropods other than insects and decapods) decreased during the drought. The species diversity of decapods recovered quickly, but those of mollusks and other arthropods did not. Four insect species disappeared in the drought, but four new species appeared, so insect species diversity did not change. Insect species diversity had doubled by March 2018 but had decreased to 10 by July 2018. Of the 10 insect species observed in November 2018, six had been present before the drought, but four were newly observed after the drought, indicating that species composition was altered by the drought. Therefore, the increase in insect species diversity in March 2018 cannot be interpreted as the temporal appearance of disturbance-dependent

species. The freshwater stream ecosystems on Chichi-jima may have complicated dynamics.

Our finding that species diversity in the freshwater ecosystems on Chichi-jima recovered quickly, but species composition did not, suggest that mollusks and other arthropods on the island need to be conserved carefully. Our results also suggest that the potentially complicated dynamics of freshwater ecosystems on Chichi-jima may make it difficult to conserve the island's stream ecosystems. We hope to reveal the detailed dynamics of the stream ecosystems by continuing our field survey.

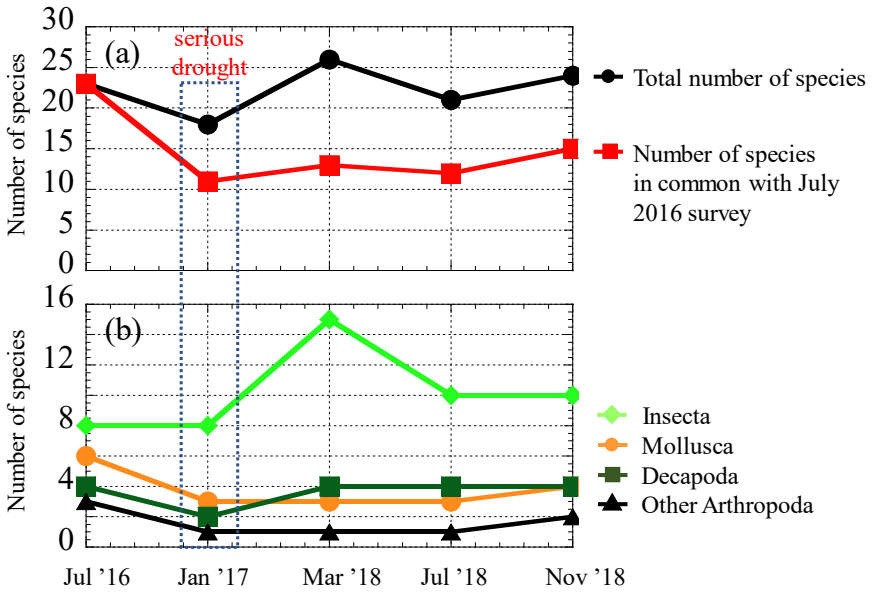


Fig. 8 The black line in (a) represents the total species diversity, and the red line represents the number of species common to the survey in July 2016. (b) Temporal changes in species diversities of insects, mollusks, decapods, and other arthropods (arthropods other than insects and decapods).

5.3 Ecosystem functions, services, and connectivity in basin ecosystems between rivers and sea

This study aims to propose a management approach to biodiversity conservation and sustainable use of ecosystem services in anthropologically modified basin ecosystems (Fig. 9). Three illustrative examples are presented below.

Provision of drinking water through the construction of reservoirs is a notable ecosystem service available from well-preserved forests and rivers. However, sustainable use of reservoirs faces a challenge when these water bodies are critical habitats for endangered species. A PIT (passive integrated transponder) tagging study revealed that 70% of a population of Sakhalin taimen (Parahucho perryi)—a critically endangered salmonid species—in a river in northern Hokkaido returned across 2 consecutive years to their natal streams, with 50% to 87% accuracy of homing (i.e., natal philopatry). Furthermore, an otolith strontium isotopic analysis revealed that individuals of the species constantly migrated out

to sea from a reservoir constructed to supply drinking water to a nearby city. For decades the reservoir has been an important sanctuary for Sakhalin taimen. However, its sustainability as critical habitat is threatened by the constant loss of genetic variation as a result of continuing emigration of the species from the reservoir and the resultant reduced anadromy, together with intense selection against anadromy in the remaining semi-landlocked above-dam population.

The endangered Japanese eel, *Anguilla japonica*, is a symbolic indicator species that links marine ecosystems to watershed ecosystems via rivers. Unfortunately, the abundance of the resources used by the Japanese eel has decreased dramatically in Japan since the 1970s. The main reasons for this drastic decrease in watershed resources are habitat degradation in the riparian zone and migration obstruction by river structures. Our aim was to restore the natural function of freshwater ecosystems by removing or adjusting barriers that prevent the passage of migrating fish and improving habitat quality. Therefore, we estimated the spatiotemporal changes in habitat potential for Japanese eel across entire Japanese watersheds. Additionally, we used a statistical data analysis, including an analysis of water quality and GIS data, to try to discover the cause of the decrease in the freshwater eel's resources. Through these analyses, we evaluated the long-term changes in the eel's habitat and detected some watersheds with marked habitat loss and degradation.

Is there always a trade-off between natural habitat modification and biodiversity? In urban coastal areas, land-use change or reclamation, or both, have reduced the quality of natural coastal ecosystems, and flood controls have also been implemented for the safety of the people who live there. In the Ohta River basin in Hiroshima, in response to past disaster experiences, a floodway with movable floodgates has been constructed on the city's fringes to prevent flooding in the city. Comparison of the floodway—the gates of which are almost always closed under normal conditions—with urban tributaries that are open under normal conditions revealed that the effects of tidal fluctuations on water quality and bottom sediment structure were very different. The large difference between the two in terms of saline environment and muddy sediment distribution meant that the urban tributaries were dominated by brackish organisms such as Japanese bascket clams, and the floodway was dominated by marine organisms such as Japanese littleneck clams. In this way, the biodiversity of the entire basin has been enhanced. This is a case where the relationship between habitat modification and biodiversity is not always regarded as a trade-off, but can be evaluated as a synergistic effect.

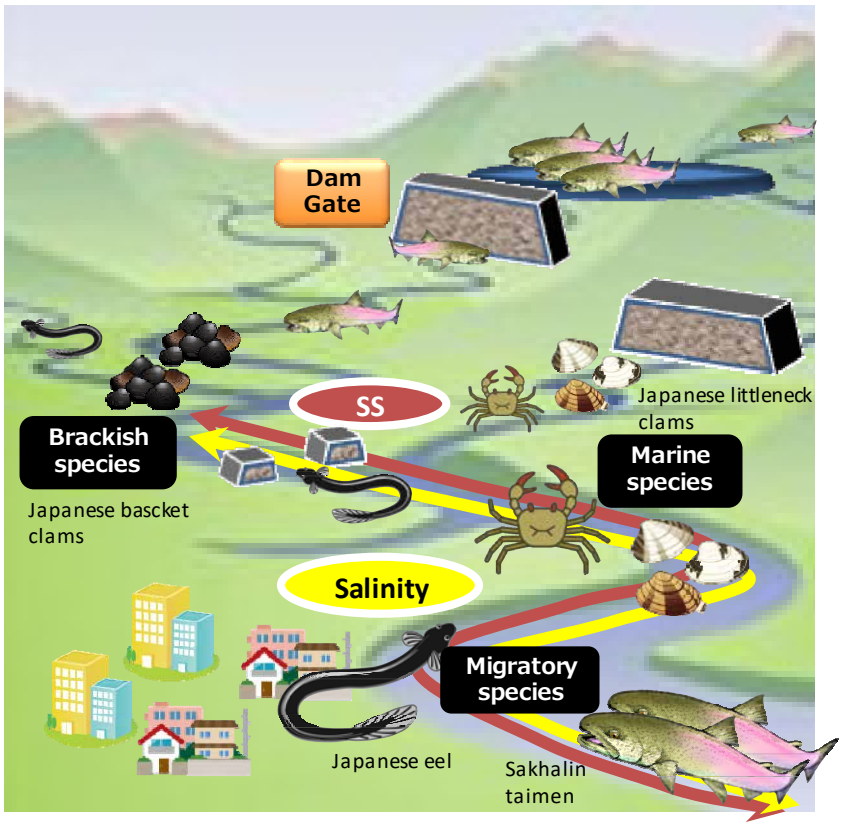


Fig. 9 Schema of ecosystem functions, services, and connectivity in a basin ecosystem between rivers and the sea. SS = suspended solids

Health and Environmental Safety Research Program

To ensure the establishment of a Safe and Secure Society, as described in the Fourth Basic Environment Plan of the Ministry of the Environment, we need to address current environmental concerns about chemical contamination and ensure that major environmental pollution events, such as the outbreak of Minamata disease in Japan, do not happen again. This is the basis for the establishment of all other sustainable goals in the Low-carbon, Sound material-cycle, and Natural symbiosis fields. The aim of this research program is to provide scientific support to establish a safe and secure society through new findings on hazards, analytical technologies, fate processes and models, and abatement technologies, as well as advanced risk assessment methodologies and management frameworks for environmental chemicals. To achieve this aim, the program is using a multifaceted, systematic approach to gain new insights into health and environmental hazards and develop methods for assessing the health and environmental risks posed by environmental chemicals and abatement technologies for those risks. The program is examining the effects of chemicals on higher-order biological functions and multi- or transgenerational impacts. It is developing new systems for assessing the ecological impacts of chemical bioaccumulation, as well as advanced high-throughput chemical analyses, to give us a more comprehensive understanding of the dynamics of environmental chemicals. In addition, the program is examining the atmospheric processes and adverse health effects associated with exposure to PM2.5 and other air pollutants. It is developing advanced methods for conserving regional aquatic environments and for the global fate and risk management of mercury. The projects are described below (Fig. 1).

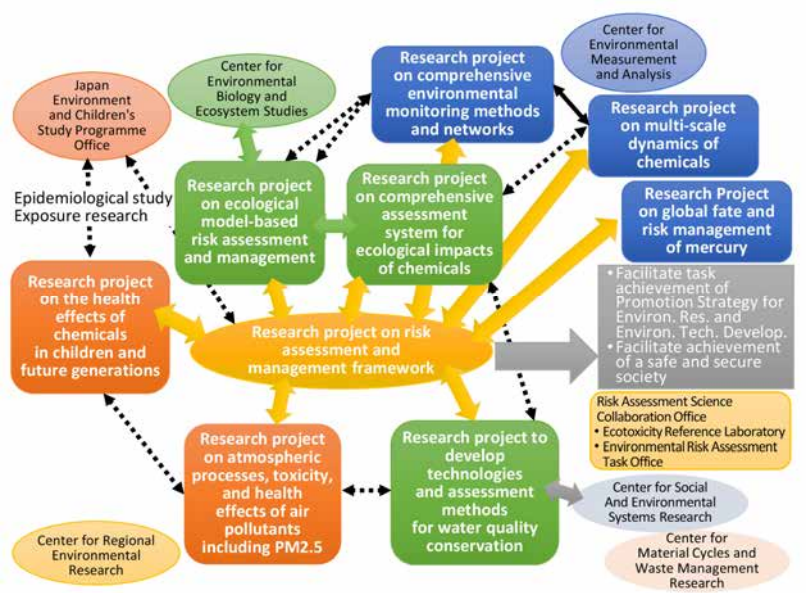


Fig. 1
The Health and Environmental Safety Research Program consists of nine research projects. The projects' outcomes are integrated to establish a general scientific basis for a safe and secure society.

1. Research project on the health effects of chemicals in children and future generations (Project 1)

This project is examining the risks posed by chemicals to higher-order biological functions and the inter- and transgenerational impacts of chemicals by using animal models and cultured cells. Our main research outcomes this year were as follows.

We examined whether oral exposure to tris(2-butoxyethyl) phosphate (TBEP) aggravates allergic asthma in mice. Treatment with 2 μg/kg/day TBEP and ovalbumin (OVA) tended to enhance allergic pulmonary inflammation and significantly elevated mRNA levels of interleukin-5, eotaxin-1, and estrogen receptor alpha in the lungs. In the mediastinal lymph nodes, TBEP (0.2 or 2 μg/kg/day) with OVA significantly increased total cell numbers and promoted conventional dendritic cell activation and cell proliferation after *in vitro* re-stimulation with OVA compared to OVA alone. In addition, we are analyzing the effects of oral exposure to bisphenol S on high-fat diet-induced obesity.

We have found that developmental exposure to estrogenic tris(2,6-dimethylphenyl) phosphate induces changes in sex-related brain structures and impairs female reproductive functions in mice. Furthermore, we observed autism-like behaviors and altered gene expression in rats exposed perinatally to diesel-exhaust-derived secondary organic aerosol. Simultaneous blood and brain microdialysis coupled with gas chromatography–mass spectrometry in a mouse was developed to test the blood–brain barrier permeability of chemicals. Moreover, chemoinformatic analyses revealed that chemicals that tested positive as causing hyperactivity in rats had significantly more chemical similarities than the negative chemicals in terms of the Tanimoto coefficient (Fig. 2). We also trialed the use of mouse embryonic stem cells and avian embryos as alternatives in developmental neurotoxicity testing.

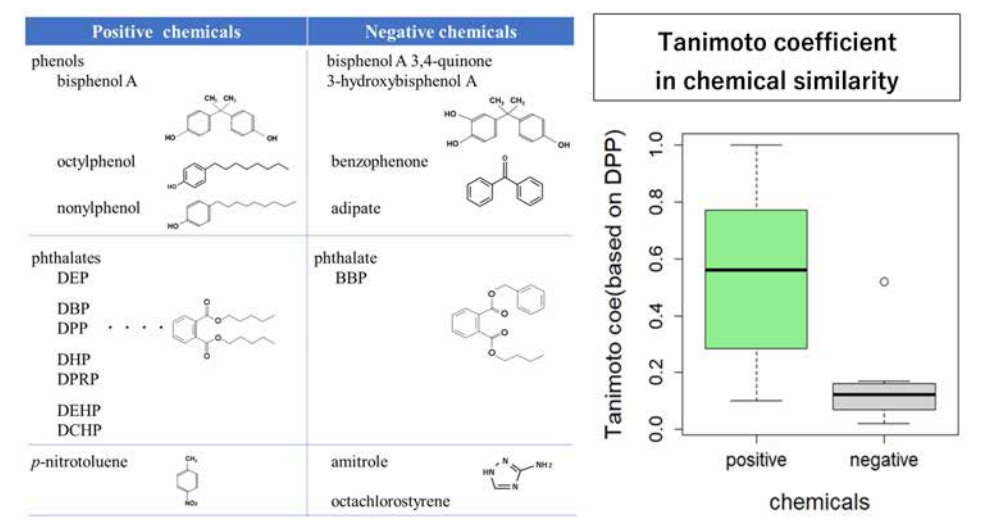


Fig. 2
Chemoinformatic analyses of chemical causes of rat hyperactivity. (*left*) Chemicals that were screened in the study. (*right*) Significant differences in the Tanimoto coefficient between the two chemical groups

To explore the molecular mechanisms underlying paternal effects on the F2 generation, we used reduced representation bisulfite sequencing (RRBS) to investigate DNA methylation changes in the sperm of mice gestationally exposed to arsenic. We found that gestational arsenic exposure increased the number of hypo-differentially methylated cytosines (hypoDMCs); moreover, the number of hypoDMCs was significantly greater in long interspersed nuclear element (LINE) and long terminal repeat (LTR) retrotransposons than in the other genetic regions. As reduced DNA methylation activates retrotransposons, the results suggested that the harmful effects of gestational arsenic exposure could be passed down to the subsequent F2 generation through epigenetic changes in germ cells.

2. Research project on comprehensive environmental monitoring methods and networks (Project 2)

The purpose of this project is to develop advanced comprehensive analytical methods and networks to monitor environmental chemicals that affect human health and the environment. This year we conducted the following studies.

As a high-throughput method for detecting pollutants in air and water environments, we prepared a bioassay battery including eight types of human-cell-based *in vitro* bioassays, and we have been evaluating the usefulness of this battery by using reference compounds. To date, we have examined 18 of the 21 organic pollutants and 29 of the 35 inorganic pollutants (17 kinds of chemicals listed in Japan's Air Pollution Control Law and 12 kinds of chemicals listed in the Water Pollution Control Law) (Fig. 3). This year, we evaluated a total of 23 substances, including selenium compounds and polychlorinated biphenyls (PCBs).

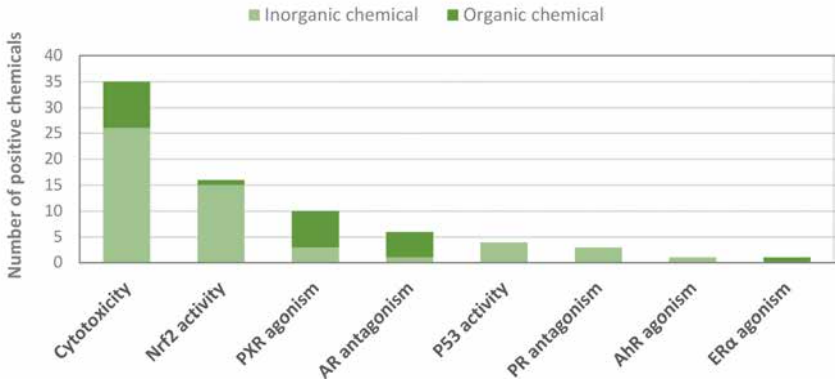


Fig. 3
Numbers of chemicals positive in bioassay battery detection of eight different endpoints; 18 organic pollutants and 29 inorganic pollutants have so far been tested.

To develop a comprehensive target analysis method, liquid chromatography coupled to quadrupole time-of-flight mass spectrometry (LC-QTofMS) analysis parameters created up to before last year and targeting substances with human estrogen receptor (hER)-binding activity were transferred to the LC-MS/MS system to improve sensitivity. After the transfer of 20 major substances to MS/MS, a sensitivity improvement of several to 100 times was observed. In addition, with

the ultimate goal of a comprehensive analysis of thyroid hormone receptor (TR)-binding active substances, we started to develop a molecularly imprinted polymer (MIP) to isolate these substances. In addition, we performed a parallel analysis of LC-inductively coupled plasma (ICP)-MS/MS and LC-electrospray ionization (ESI)-MS/MS for fat-soluble organic arsenic as a method of analyzing organometallic compounds by their morphology.

Furthermore, by using in an integrated manner the methods developed in this project over the last 4 years, we searched for estrogen-like active substances in environmental samples. First, with sewage treatment plant effluent as our environmental sample, we measured hER-binding activity by using our rapid bioassay battery. In the mammalian cell culture assay, we observed hER-binding activity of 1.3 ng/L estradiol equivalent (E2-EQ); in the yeast two-hybrid assay, an hER binding activity of 7.3 to 7.8 ng/L E2-EQ was observed. Next, the sample was treated with ER_MIP to isolate the active substances with hER-binding activity while retaining their binding activity. Analysis of the isolates by using LC-QToFMS, LC-MS/MS, and gas chromatography (GC)/MS methods resulted in the detection of hER-binding active substances such as estrone, estradiol, bisphenol A, bisphenol B, bisphenol E, and p-n-nonylphenol. Currently, not all active substances can be detected because our system is not sensitive enough to find all of them in actual environmental samples. However, 26 peaks were extracted as candidates as described above when non-targeted analysis was done by using GC×GC-high-resolution TofMS. It is possible that some unidentified active substances are present in these peaks. Therefore, additional study is needed to search for active substances in environmental samples by improving the quality of each method and integrating the methods.

3. Research project on ecological model-based risk assessment and management (Project 3)

Pesticides are critical causes of damage to the biodiversity of stream invertebrates. In ecological risk assessments of pesticides, not only laboratory toxicity tests using single standard test species but also analyses of datasets derived from field observations are important, because community-level responses of aquatic organisms to pesticide exposure are difficult to predict from the results of laboratory toxicity tests. Moreover, indicators of the integrity of river ecosystem functions need to be monitored in field surveys. This is because a decrease in the abundance of a functional feeding group (FFG) disrupts the pathways of material flows in river ecosystems through ecological interactions among FFGs. This is a critical impact from an ecological perspective.

To assess the ecological risks posed by imidacloprid and dinotefuran to river ecosystem functions in urban rice-paddy areas, we evaluated the associations between the estimated concentrations of those neonicotinoid insecticides and the total abundances of seven FFGs of benthic invertebrate communities in four

Japanese regions. Moreover, we examined the interregional consistency of the observed associations to evaluate whether the associations could be generalized. To evaluate the targeted associations while removing biases derived from other environmental factors, we applied a partial redundancy analysis (partial RDA) to each regional dataset of benthic invertebrate communities and environmental variables. The datasets were developed by using country-wide biomonitoring databases.

In two of the four regions, the associations of the total abundances of the seven FFGs with neonicotinoid concentrations were significant (Fig. 4), suggesting that imidacloprid and dinotefuran had negative effects on river ecosystem functions in these two Japanese regions. Furthermore, for the imidacloprid concentrations, we found that the pattern of associations with the abundances of six of the seven FFGs (shredders, filter feeders, collectors, grazers, predators, and scavengers) showed a consistent pattern among the four regions. This indicates that there is a need for country-wide management of imidacloprid to conserve river ecosystem functions in Japan's urban rice-paddy areas.

As a next step, to obtain information about the effectiveness of management intervention for neonicotinoid insecticide concentrations (e.g., by setting environmental quality standards), we intend to estimate the size of the causal effect of these substances on benthic invertebrate communities on the basis of statistical causal inference.

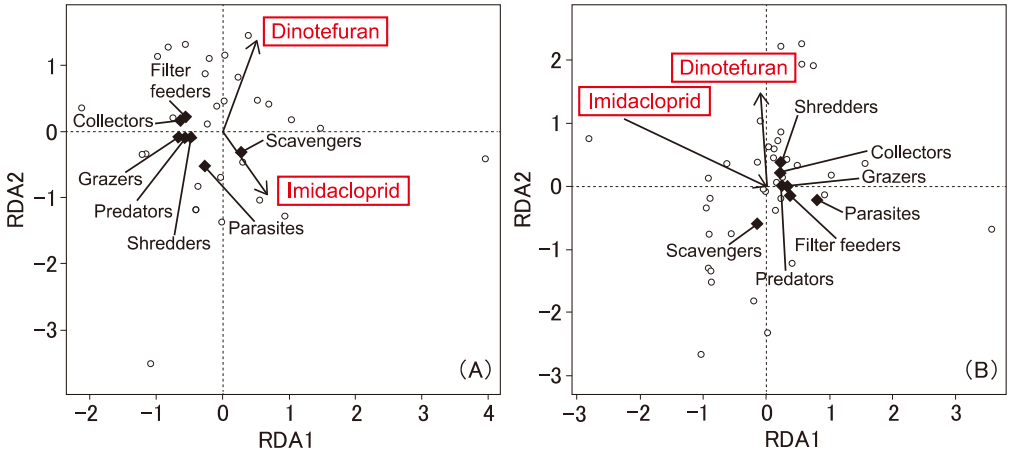


Fig. 4
Biplots of partial redundancy analyses for the total abundances of seven functional feeding groups of benthic invertebrate communities in (A) central Honshu and (B) the Chugoku and Shikoku regions

4. Research project on comprehensive assessment system for ecological impacts of chemicals (Project 4)

We have developed linear regression models for fish early-life-stage toxicity tests that use quantitative structure–activity–activity relationships (QSAARs) and quantitative activity–activity relationships (QAARs). Acute *Daphnia magna* toxicity, various quantum chemistry parameters, the octanol–water partition coefficient (log K_{ow}), and water solubility were used to improve the predictivity

of the models. As part of Integrated Approaches to Testing and Assessment (IATA), the assessment factors used in ecological risk assessments conducted under the Chemical Substances Control Law were compared in a case study to confirm the protective capacity of the risk assessments.

We have continued to develop new test methods for evaluating the toxicity of various chemical compounds by using a range of organisms, including marine and estuarine algae, invertebrates, and fish, as well as benthic organisms. By using marine and estuarine organisms, we have developed growth inhibition tests that use marine cyanobacteria (*Cyanobium* sp.), diatoms, and green algae; interlaboratory validation tests for these growth inhibition tests were conducted in cooperation with four outside collaborators (National Research Institute of Fisheries and Environment of Inland Sea, Marine Ecology Research Institute, Kagoshima University, and Idea Consultant Co.). We have also conducted additional validation testing of short-term chronic toxicity tests by using an estuarine mysid (*Americamysis bahia*), a copepod (*Acartia* sp. and *Tigriopus japonicus*), and an amphipod (*Ptilohyale barbicornis*). These tests mainly use metamorphosis or growth, or both, as endpoints. Japanese sea bream (*Pagrus major*), mummichog (*Fundulus heteroclitus*), and Javanese medaka (*Oryzias javanicus*) were used for short-term tests examining the fish embryo and sac fry stages.

For benthic organisms, we used a freshwater amphipod species, *Hyalella azteca*, to examine the toxicity of hydrophobic organic chemicals such as polycyclic aromatic hydrocarbons in a water-only versus a water–sediment system and to clarify the exposure pathways and key parameters—such as the freely dissolved or particle-bound concentration of overlying water and pore water and organic content of the sediment—that affect sediment toxicity (Fig. 5). We also investigated the effects of the different type of formulated sediments on chemical partitioning behavior and toxicity with aim of harmonizing *H. azteca* sediment toxicity tests as an OECD test guideline. An estuarine benthic amphipod (*Grandidierella japonica*) was also used to clarify species sensitivity differences and the effects of salinity (in collaboration with the University of Tokyo).

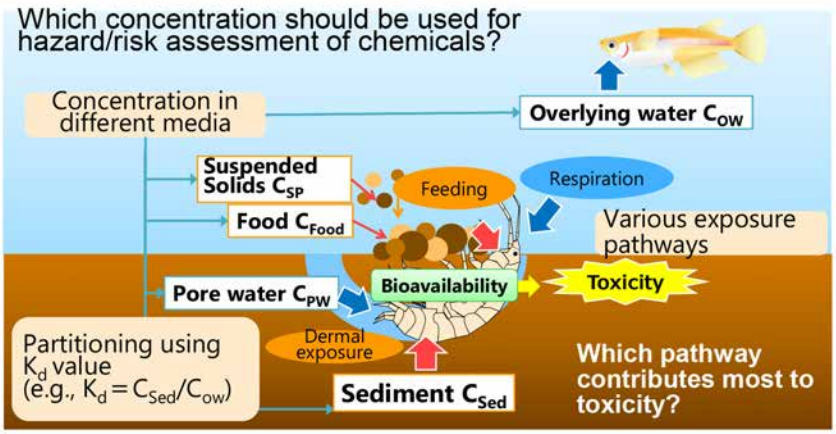


Fig. 5
Different exposure pathways in aquatic and benthic organisms

In Tokyo Bay, we have conducted fisheries-independent trawl surveys over a total of 36 years (1977–1995 and 2003–2019) to collect samples of the megabenthos from the entire bay. We have also obtained environmental data from the published record to investigate the relationships among the biota and the environment. We have found long-term changes in the stock size and species composition of the megabenthic community for both vertebrates and invertebrates. The abundance- and biomass-based densities of the megabenthos increased until the late 1980s. This was followed by an abrupt decline, which we attribute to changes in the densities of small- to mid-sized dominant species. In the 2000s, although abundance-based density remained low, biomass-based density increased substantially owing to an increase in the numbers of large fish, such as the Japanese sea bass and elasmobranchs. In the early 2010s, a marked increase was observed in the abundance- and biomass-based densities of a particular bivalve, Kobelt's ark shell (*Arca boucardi*); this was followed by a substantial decline from 2015 to 2019. The survey period was divided into seven time periods by cluster analysis, allowing us to examine the population compositions and densities of several characteristic species in the bay among these periods. A multivariate analysis also revealed that changes in water temperature, dissolved oxygen concentration, dissolved inorganic nitrogen concentration, and copepod density were accompanied by changes in the megabenthic community. Examination of sediment samples showed that the composition of the bottom sediment in Tokyo Bay has changed since 1991, with the ratio of silt and clay to sand increasing markedly. This may have been associated with changes in the abundance and biomass, as well as the species composition, of the macrobenthic community in the bay; organisms in this community are important prey for the megabenthos community.

We also investigated the mixture toxicity of two groups of chemicals, the alkyl esters of acrylic acid and those of phthalic acid, by using a green alga (*Raphidocelis subcapitata*), daphnid (*Ceriodaphnia dubia*), and fish (*Danio rerio*) and short-term chronic toxicity tests. Relative potency factors were determined for the methyl, ethyl, and butyl esters of acrylic acid and the dimethyl, diethyl, dibutyl, and diethyl-hexyl esters of phthalic acid. Whereas the toxicities were similar for the esters of acrylic acid, slightly stronger toxicity was found for dibutyl phthalate, followed by the diethyl and dimethyl phthalates. Diethyl-hexyl phthalate was found to be very hydrophobic and showed a trend different from those of the shorter-chain alkyl esters.

Also, by using a whole-mixture approach, in FY 2019 we collected over 30 river water samples from across Japan and conducted screening aquatic toxicity tests by using the algal growth inhibition test and the *C. dubia* reproduction test. A significant reduction in algal growth rate was found for 12 water samples and a significant reduction in daphnid reproduction was found for six samples. These water samples were then subjected to detailed short-term chronic toxicity testing by using the algal growth inhibition test and *C. dubia* reproduction test; the

growth rate in fewer samples than in the screening test was found to be significantly different from that in the control. Ten river water samples were also subjected to short-term toxicity testing in *D. rerio* fish in the embryo or sac fry stage; no sample was found to be toxic.

5. Research project on multi-scale dynamics of chemicals (Project 5)

In this project, we are examining the dynamics of chemicals at various spatiotemporal scales by using state-of-the-art analytical techniques and constructing mathematical models to better understand and predict the concentrations and dynamics of environmental chemicals.

We determined the vertical distribution of seawater total dissolved mercury (Hg) concentrations in the East China Sea to assess the environmental impacts of this element emitted from Eastern Asian regions. Hg concentrations ranged from 0.11 at the surface to 0.18 ppt at a depth of more than 1000 m. This range and pattern correspond well with the previously determined distribution of seawater Hg concentrations in the World Ocean. Localized Hg pollution was not found in this region.

We performed a simulation by using a global model for mercury (FATE-Hg) over the period of past three centuries. The simulated total mercury (THg) in the lower troposphere and in the surface (0 to 70 m), intermediate (70 to 1000 m), and deep (1000 to 5500 m) oceans has increased during the past 160 years (1850–2010) by factors of 2.3, 1.9, 1.8, and 2.2, respectively. The estimated overall turnover time of oceanic THg was 320 years—considerably shorter than previous model-based estimates.

We have developed a fate model of hydrogen peroxide (H_2O_2)—which is emitted to the environment via household and institutional use and is also produced by solar-radiation-driven photochemical reactions of dissolved organic matter in surface waters—in river networks in Japan to calculate the diurnal changes of H_2O_2 concentrations in river water. By using the model, we found that the average H_2O_2 concentration exceeded the predicted no-effect concentration (approx. 380 nM) during dry weather in the summer in about 3% of all rivers in Japan.

As part of a study of the indoor-scale dynamics of chemicals, we experimentally measured the transfer, over a period of 1 week, of two organophosphate additives from polyethylene terephthalate (PET) and polyvinyl chloride (PVC) sheets to artificial dust attached to the sheet surfaces. Similar levels of transfer rates were observed for both compounds, but higher rates were observed in the dust on the PET sheets than on the PVC sheets (Fig. 6). Interestingly, by using a micro-chamber method, we observed a similar-magnitude higher flux to air of triphenyl phosphate from the PET sheets than from the PVC sheets. The results also suggested that the rate of transfer depended on the surface geometry or

finishing of the material (Fig. 6).

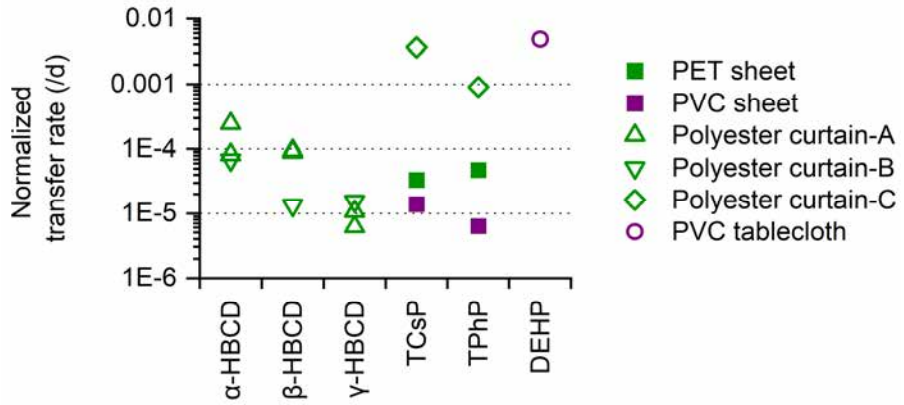


Fig. 6
Normalized transfer rates (concentration in dust/concentration in material/experiment duration) obtained in our transfer experiments using artificial dust. Results in previous years are included (curtains and a table cloth, in open symbols). HBCD, hexabromocyclodo-decane; DEHP, diethylhexyl phthalate; TCsP, tricresyl phosphate; TPhP, triphenyl phosphate

6. Research project on atmospheric processes, toxicity, and health effects of air pollutants including PM2.5 (Project 6)

Rapid economic growth in East Asia has resulted in a marked increase in energy consumption, leading to increased emission of air pollutants. High concentrations of PM2.5 have been reported in Japan, and their adverse health effects are now of major public concern. To control air pollution, to collect evidence of its adverse health effects, and to construct alert systems for air pollution, we are developing an integrated air-quality modeling system and are conducting *in vitro* toxicity studies and epidemiological studies. In the fourth year of this project, we have obtained the following results.

To improve current emission models, we created a new emission inventory. By reexamining the method used to estimate the emissions of particulate matter, we have found that industrial processes are important and essential emission sources that were not considered in our conventional emission inventory.

To monitor the vertical distribution and optical properties of aerosols in the troposphere, a lidar (laser-radar) network has been operating continuously in the East Asian region. By treating the dust extinction coefficient near the surface as an index of exposure of pregnant women to long-range-transported Asian dust, we found an association between Asian dust particle exposure and placental abruption (Fig. 7).

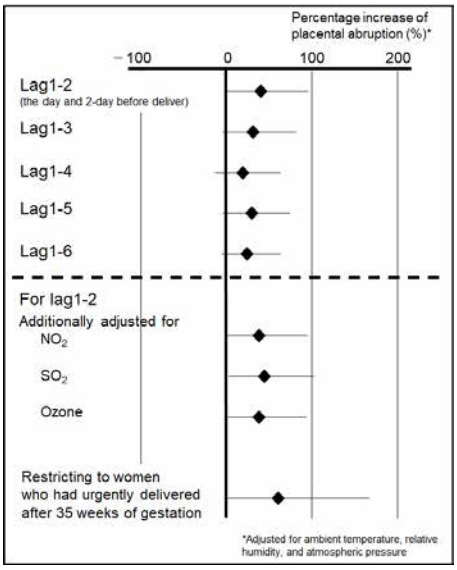


Fig. 7
Association between exposure to Asian dust and placental abruption

We used a reporter gene assay to compare the ability of particles to induce cellular oxidative stress. Anthropogenic secondary organic aerosol (SOA), including SOA formed from naphthalene, as well as biomass burning, induced strong oxidative stress. Copper increased the oxidative stress responses to these organic extracts synergistically. These results revealed that copper and the organic components of combustion products were candidate causes of adverse health effects from PM2.5.

We conducted a multi-city case-crossover study of the association between short-term exposure to PM2.5 and mortality in Japan for FYs 2012–2014. A 10-μg/m^3 increase in PM2.5 concentrations for the average of the day of death and the previous day was associated with an increase of 1.3% [95% confidence interval (CI), 0.9% to 1.6%] in total non-accidental mortality. For cause-specific mortality, PM2.5 was positively associated with cardiovascular and respiratory mortality. After adjustment for PM2.5, we observed a 1.4% (95% CI, 0.2% to 2.6%) increase in total mortality with a 10-μg/m^3 increase in coarse PM.

7. Research project to develop technologies and assessment methods for water quality conservation (Project 7)

In many domestic areas of developing countries and provincial cities in Asia, the introduction of technologies to conserve the aquatic environment has been delayed because of economic constraints. The aims of this project, which are addressed in separate sub-projects, are to develop technologies for conserving and evaluating the water environment in areas under economic constraint. The first sub-project concerns the development of appropriate technologies to conserve the aquatic environment, and the second sub-project concerns the development of technologies and methods that use various indicators to evaluate the water environment. Our main research outcomes to date are as follows.

In the first sub-project, we conducted a performance evaluation of a full-scale aerobic trickling-filter system (ATF) installed in company housing complex in Thailand as a post-treatment system for domestic wastewater currently received by a septic tank (Fig. 8). The existing septic tank could not meet the effluent discharge standard (biochemical oxygen demand 30 mg/L, total Kjeldahl nitrogen 35 mg/L) because of a lack of performance. Adding the ATF as a post-treatment made it possible to maintain water of good quality—far below the effluent discharge standard—for a long period of time with a short treatment time (less than 2 h). In addition, long-term operation proved that the ATF was easy to maintain, and the treated water was used for irrigation because of its excellent quality and the ATF's ability to remove pathogenic bacteria.

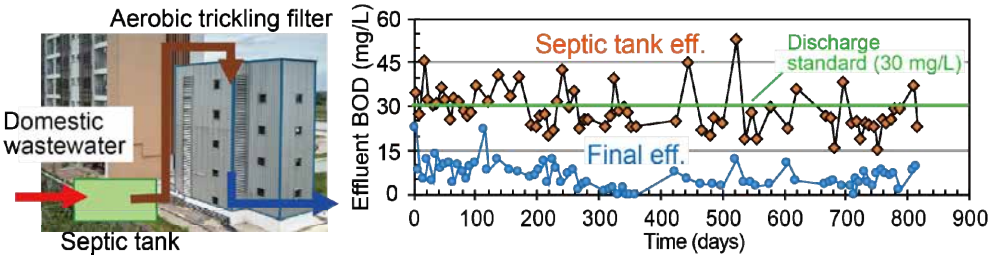


Fig. 8
Overview of the aerobic trickling-filter system for post-treatment of septic tank effluent from a company housing complex (left). Time course of effluent biochemical oxygen demand (right)

In Bangkok, surface water pollution due to insufficient treatment of domestic wastewater remains a serious issue. In the second sub-project, to help address this issue, we studied the relationship between water pollution and microbiological risk (e.g., risk of infection by pathogenic bacteria) in contaminated canal water.

We examined the seasonal changes in *Escherichia coli* (as an indicator of sanitation) and *Arcobacter* spp. populations on the basis of 16S rRNA gene analysis in surface waters (four canals and one river) with different levels of contamination. Even though the concentration of *E. coli* was close to, or below, the limit of detection at sites with low contamination, the concentration of *Arcobacter* spp. remained greater than 10^5 cells/mL in all of the canals throughout the year. This indicates that *Arcobacter* spp. are highly viable, even in surface waters with low contamination, and should be taken into consideration when conducting hygiene assessments. Notably, in long-term operation, the ATF system for domestic wastewater treatment has been confirmed to be effective in removing *Arcobacter* spp.

8. Research project on risk assessment and management framework (Project 8)

A sound management framework to manage the risks posed by environmental chemicals to human health and the environment can be established by integrating the social context, public concerns, and accumulated social and natural scientific knowledge. The aim of this inter-disciplinary project is to develop a robust framework for managing environmental chemicals that reflects both the social

context and the latest outcomes of Projects 1 to 7 and 9. To achieve this aim, this project is developing risk assessment and management strategies that are acceptable to the public and incorporate the latest scientific information on the impacts of environmental chemicals on human health and the environment. Furthermore, the project is developing an ecological management framework based on the comprehensive characterization of ecotoxicity by using a newly developed system of testing protocols. It is also developing a system for the environmental management of coastal, oceanic, atmospheric, and aquatic pollution that will incorporate new technologies as they become available, and a management approach that incorporates comprehensive monitoring methodologies to assess new chemicals as they arise from technological development. Our aim is for Project 8 to summarize the scientific outcomes of all the other projects into the context of sound chemical management in our society.

This year we continued to study a new direction for incorporating the precautionary approach into chemical risk management on the basis of both the scientific nature of chemicals and their social context. We reevaluated several pollution incidents, including the one that caused Minamata disease, to explore how preliminary observations that may not be scientifically sufficient can still be used to trigger precautionary or other management actions. Time-series information on the scientific knowledge available at a given point in time was analyzed in terms of the uncertainties of scientific evidence and was then compared with the social or political decisions taken at the time. We then discussed the relationship between uncertainties of scientific evidences and social decisions taken at the time in terms of uncertainties and management actions. Also, we began to evaluate the potential impact of the immunological effects of bisphenol A (BPA) on the basis of a new research outcome on the newly found health effect implication of BPA in Project 1. This year, we compiled and reviewed information on BPA production and use, and we reviewed the relevant literature and exposure estimates for this chemical.

9. Research project on the global fate and risk management of mercury (Project 9)

Establishment of a sound scientific basis to support the global management of mercury is essential for supporting the implementation of the Minamata Convention on Mercury. Project 9 aims to provide scientific information on the global fate of mercury in the environment, the material flows of mercury in the technosphere, and the combined health impacts of mercury and persistent organic pollutants.

We determined methylmercury (MeHg) and total mercury (T-Hg) concentrations in coastal and freshwater plankton (>100 μm in size). The higher the chlorophyll concentrations in aquatic ecosystems, the lower the MeHg concentrations in these plankton were. The ratios of MeHg concentrations to T-Hg in the samples were

similar to one another (in the range of 20% to 30%), except in contaminated coastal and hypereutrophic ecosystems.

We performed simulations covering the past three centuries (1750–2010) by using our global model (FATE-Hg) to investigate human impacts on the fate of mercury in the World Ocean. We used the simulations to estimate the geographic sources of total mercury in the upper ocean (Fig. 9). The results showed that North America, Europe, and East Asia were the dominant source regions of this mercury in most sections of ocean in the Northern Hemisphere, although the emissions from North America and Europe have fallen considerably since the 1970s. This result indicated that a substantial amount of mercury that was emitted in the past persists in present-day seawater.

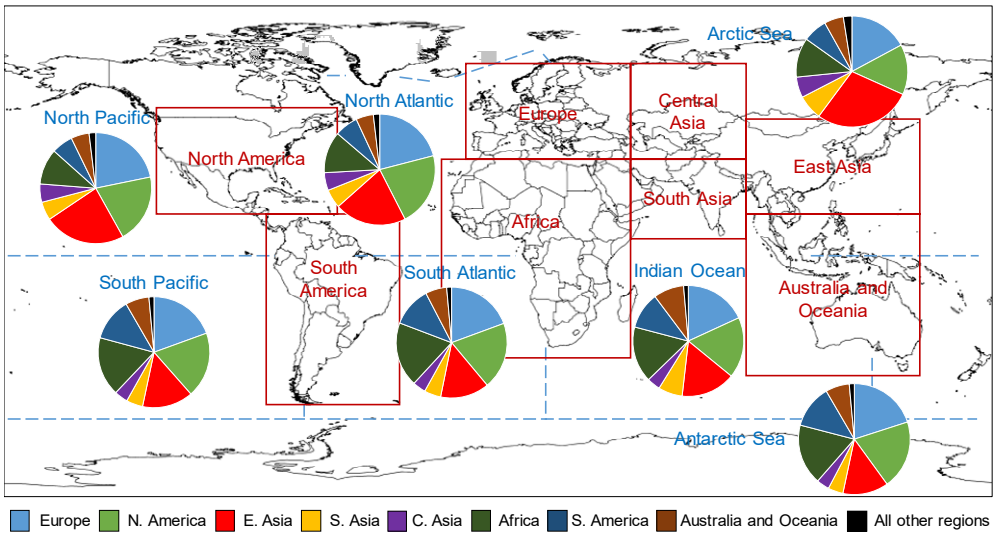


Fig. 9
Estimated source attributions of total mercury in the present day (2010) ocean mixed layer of seven oceans (North and South Pacific, North and South Atlantic, Indian Ocean, Arctic Sea, and Antarctic Sea). The results are based on long-term (1750–2010) simulations using FATE-Hg. The eight source regions considered are bordered in red.

We evaluated the effects of prenatal exposure to both MeHg and PCBs on the immune systems of mouse offspring. MeHg (0.5 μg/kg/day) and a mixture of PCBs (Aroclor 1254; 0.02 μg/kg/day) were orally administered to pregnant C3H/HeJ mice from postnatal day 5 to 16 for 10 days. In blood analyses, we found that prenatal exposure to MeHg or PCBs, or both, had different effects depending on age and sex. To reduce the impact of mercury exposure on vulnerable populations, we are conducting research to reduce MeHg exposure in Japanese women. We investigated the awareness of mercury among women aged 20 to 50 years (N = 350). Among the respondents, 85% answered that they knew of mercury, whereas only 33% knew of MeHg. When questioned about the main exposure sources of MeHg, 80% of respondents knew about MeHg intake via fish, but the remaining 20% answered incorrectly.

We evaluated the accuracy of Pollutant Release and Transfer Register (PRTR) reports on the amounts of mercury released to water from sewage treatment plants; in the PRTR report data, these plants account for most of the mercury releases to water. We conducted a numerical analysis by using the results of a

questionnaire survey of staff at sewage treatment plants and a highly sensitive analysis of several plants in previous years. The results showed that the PRTR-reported release amounts overestimated the actual mercury releases to water from sewage treatment plants by a few orders of magnitude.

We examined the composition of the microbial community in sediment samples collected in summer and winter from Tokyo Bay, some areas of which experience a decline in water condition (e.g., hypoxic water) during summer. The microbial composition was determined by metagenomic analysis. Across all sampling areas and both seasons, Proteobacteria species were the most abundant (60% to 75%) species. Among the detected Proteobacteria, Deltaproteobacteria species, which are known to possess mercury methylators, were the most or second-most abundant species, although the Deltaproteobacteria composition varied according to the sample area and season. These results indicate that changes in the aquatic environment according to region or season affect the sediment microbial community that possesses mercury methylation genes.

Passive sampling can potentially provide data on the time-integrated concentrations of atmospheric mercury with relatively low cost and effort. A literature review of passive sampling methods revealed that the latest passive samplers for mercury have overcome the issues that early types of samplers had, such as relatively large variability in sampling rates and saturation of sorbent material during sampler deployment. Overall, we concluded that passive sampling methods have sufficiently high accuracy and precision and will be useful for monitoring the levels of atmospheric mercury.

Environment-Economy-Society Integration Research Program

Starting with integration of the mitigation of, and adaptation to, climate change, this program develops multilayered models that quantitatively analyze solutions to environmental problems. These problems include those related to socioeconomic activities and the need for sustainable material cycles, harmonization with nature, and health and environmental safety, on a variety of scales from urban and regional to national and global. From the perspectives of environmental, economic, and societal sustainability, the program conducts quantitative and qualitative analyses pertaining to the future visions of stakeholders at each scale. It also designs and evaluates the international and local or urban policies needed to realize these intended future visions. The program will establish a system to support the implementation and realization of proposed policies, countermeasures, and innovative green technologies. Figure 1 illustrates the framework of the program and five aspects of the research integration. The program consists of three projects: Project 1 provides sustainable development scenarios for the world and Asian countries; Project 2 develops a local environmental sociologic integration roadmap focusing on climate change mitigation and adaptation; and Project 3 evaluates policies for an environmentally sustainable society.

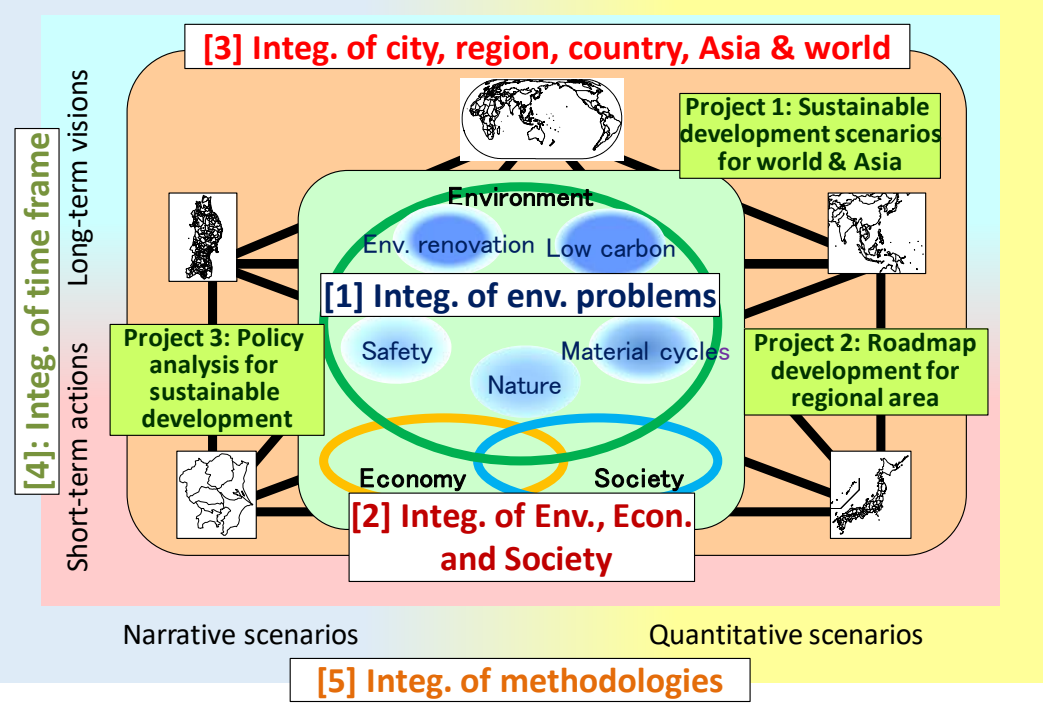


Fig. 1 Framework of the Environment-Economy-Society Integration Research Program. Shown are the three projects and the five numbered aspects of the Program.

1. Sustainable development scenarios for the world and Asian countries

This project is developing integrated assessment models (IAMs) for analyzing sustainable development scenarios that pursue the simultaneous attainment of

global or regional societal goals, such as a low carbon society, resource recycling, natural symbiosis, and safety from various risks. The project consists of two sub-themes. Sub-theme 1 provides global sustainable development scenarios, and sub-theme 2 provides national sustainable development scenarios for Asian countries. Sub-theme 1 is also developing methodologies for downscaling global socioeconomic scenarios and will provide spatial socioeconomic scenarios with resolutions appropriate for supporting the regional or national-scale analyses conducted in the research program.

To improve the global IAM for assessing multiple political goals in an integrated manner, in sub-theme 1 we analyzed the changes in nutrient intake under changing atmospheric concentrations of CO_2. Field experiments suggest that the nutrient contents of food crops will decrease substantially under elevated CO_2 conditions, and this will have nutritional consequences additional to those related to the expected reductions in crop yield. By using individual-level dietary survey data for Chinese adults, we analyzed the nutritional consequences under a 550-ppm atmospheric CO_2 scenario, paying special attention to the distributional impacts of nutritional degradation on different income groups. Our results suggest that the Chinese adult population would ingest about 2.17% to 4.75% less protein, iron, and zinc; consequently, the prevalence of nutrient deficiency would increase by 1.35% to 4.42%. We also found a disparity in the nutrient loss rate and risk of deficiency among income groups: nutrient loss rates for the lowest-income group were 1.37 to 1.54 times those for the highest-income group. Moreover, we found that the intakes of all three nutrients would be reduced simultaneously in the lower-income group, leaving this population more vulnerable to nutritional health risks. Our study therefore revealed marked inequalities in the impacts of elevated atmospheric CO_2 concentration.

In sub-theme 2, an 80% reduction in greenhouse gas (GHG) emissions in Japan by 2050, which is this country's long-term strategy, was assessed by using the national-scale CGE (Computable General Equilibrium) model, named AIM/CGE [Japan], under the medium economic growth assumption of an average economic growth rate during 2015–2050 of 0.6% per year. In this model, advanced energy-saving technologies can be selected as a GHG mitigation option to minimize the annual GHG mitigation cost. When the mitigation target is introduced in the conventional way, with a short payback period, the GHG price will be high—at more than 100,000 JPY/tCO_2eq—in 2050, and a gross domestic product (GDP) loss compared with the reference case will occur (Fig. 2). However, if we introduce measures such as more renewable energies, a long payback period for our chosen technologies, early retirement of the remaining less-efficient technologies after 2030, and appropriate compensation for the introduction of energy-saving technologies, then our GHG reduction capacity in 2050 will be expanded. As a result, the GHG price in 2050 will decrease to 25,000 JPY/tCO_2eq, and the GDP in 2050 will exceed the reference case. In addition to our simulation analysis for Japan, national CGE models for Indonesia,

Thailand, and Laos we have developed independently. From the results of simulations using these national CGE models, we assessed national mitigation targets in collaboration with researchers and policy makers in these countries.

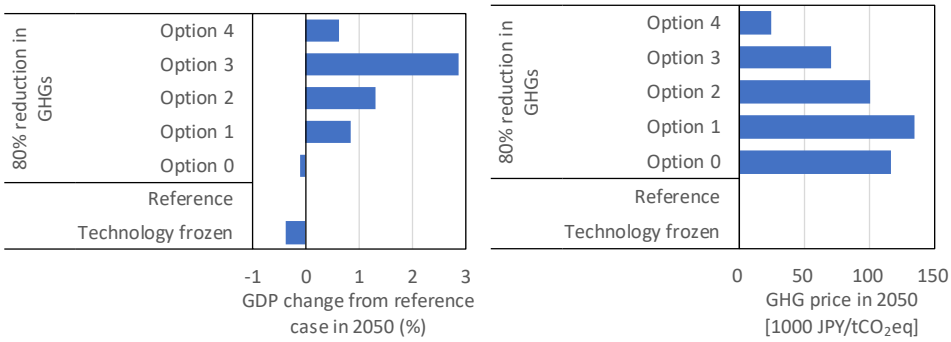


Fig. 2 GDP changes and GHG prices required to realize an 80% reduction in GHGs in Japan by 2050

Note: Option 0: Introduction of GHG reduction constraint without any options

Option 1: GHG reduction constraint with compensation for additional investment.

Option 2: Option 1 + introduction of long payback period

Option 3: Option 2 + early retirement of conventional technologies after 2030 with full compensation for retired stock

Option 4: Option 2 + early retirement of conventional technologies after 2030 with appropriate compensation for retired stock, taking into account improved efficiency

2. Research into a regional environmental sociologic integration roadmap focusing on climate change mitigation and adaptation

Sub-theme 1 is “Development of an Environmental Impact Assessment Model for Regions and Cities.” As a leading research institute for “Research into the Development of Technologies for the Assessment of Climate Change Impacts,” which is theme 3 of the Ministry of Education, Culture, Sports, Science, and Technology’s Social Implementation Program on Climate Change Adaptation Technology (SI-CAT), we continued to develop technologies to support local governments with the scientific knowledge they need for climate change impact assessment and examination of adaptation measures. Also, to develop an integrated assessment platform, we made a projection model of land-use change by using a cellular automaton. This year, the land-use model was developed into a time-evolution cellular automaton model and applied to medium- and long-term forecasts (to 2030). We had a problem related to over-learning due to an excess of learning data, and transitions in land-use patterns could not be expressed because there were too few learning data. A theory to optimize the amount of data for machine learning was developed.

Sub-theme 2, “Development of an Integrated Evaluation Model of Economy, Society, and Technology for Countries, Regions, and Cities,” is aimed at an integrated roadmap analysis focusing on mitigation. For this purpose, we developed a series of analytical models, including a regional energy system model that designs an optimal energy system on the basis of a region’s energy demand and its supply of renewables, and a low-carbon policy evaluation model to design

scenarios and roadmaps. We also developed a simplified analytical tool that employs both Excel macros and Web systems.

The models and tools were applied to specific cities to gain insight into how to transition from high- to low-carbon regions. Changing urban structure was identified as key in the creation of low-carbon regions. Transitioning to compact cities will help to counteract the effects of population decline and decrease overall energy demands and CO_2 emissions, but rapid transitioning will increase the amount of construction waste. Also, we identified regional cooperation as extremely important. Some regions with large urban areas have large energy demands but less renewable energy (demand-excess areas), whereas others have large supplies of renewable resources but lower energy demands (supply-excess areas). Enhancing cooperation among these areas will increase the utilization of renewable energy and reduce CO_2 emission. Many regions, however, will still need to rely on low-carbon electricity from the grid.

We classified a total of 1724 municipalities in Japan into about 50 types on the basis of their sectoral shares of CO_2 emissions. We analyzed a regional low-carbon scenario for 16 of these 50 types by using an improved regional low-carbon scenario assessment model. In addition, we developed a simplified assessment tool for a regional low-carbon scenario and applied it to a city in the Kanto area. A series of workshops was organized to examine the potential for using the tool to encourage discussions among stakeholders, including local governments, businesses, and non-government organizations. By developing an assessment model of prefectural willingness to pay (WTP), we assessed policy actions for promoting renewable energy; the result clearly showed a positive relationship between household income and level of WTP. We also developed an electricity demand analysis model incorporating statistical methodology; the model can explain levels of electricity consumption by using a combination of time-dependent and spatial factors.

Sub-theme 3 is “Research into Social Implementation Support Measures and Social Monitoring for Sustainable Society Measures.” By using a monitoring system developed in previous years and introduced to Indonesia and Fukushima Prefecture, data on the electricity and fuel consumption of houses, offices, and factories were collected and used to develop a model to explain power consumption and fuel consumption; the model used deep learning, which is a kind of machine learning method. In addition, to efficiently reduce CO_2 emissions from the use of heat (steam) in the industrial sector, a supply of steam from a waste incineration plant to neighboring factories was assumed, and the steam transportation potential was evaluated from the geographical distribution of the waste generation and factories. After considering the conditions in real-life steam-transfer projects and performing theoretical estimations of steam temperature decay and economic cost–benefit, we set the range for steam supply to about 5 km and examined the spatial distribution of the matching of steam

supply and demand in Aichi Prefecture. The result (Fig. 3) confirmed that most of the heat recovered at waste incineration plants could be utilized by factories.

To implement this system in our society, we strengthened our stakeholder-related activities. For example, an Industrial Smart Energy Sharing Study Group was set up at the Kitakyushu Foundation for the Advancement of Industry, Science and Technology in January 2019, and discussions have commenced with local municipalities and companies to implement low-carbon projects in industrial parks.

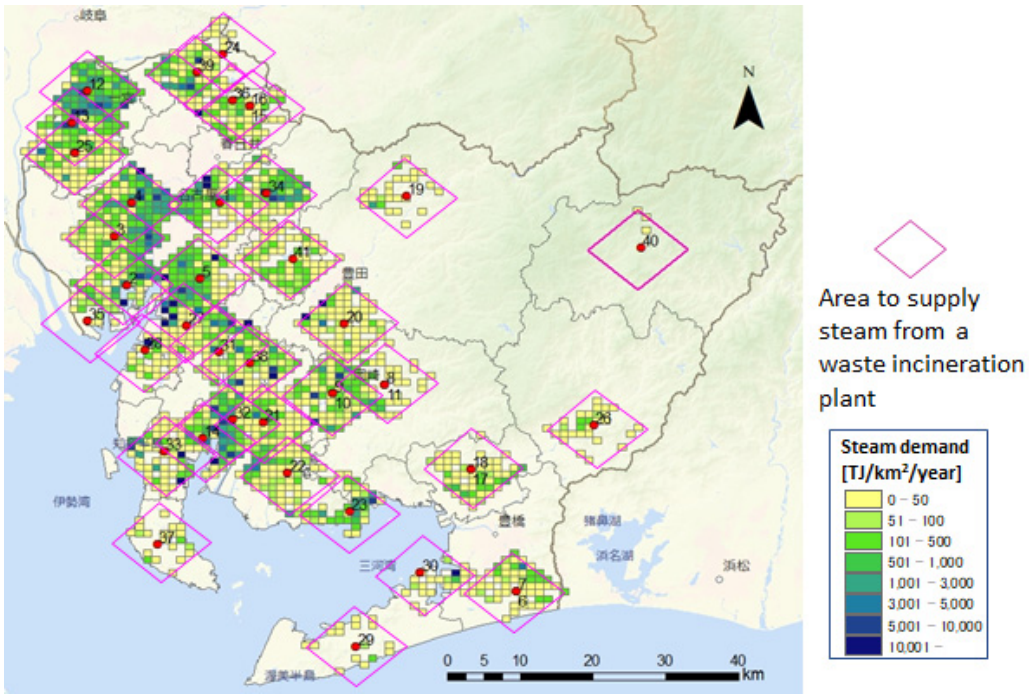


Fig. 3 Comparison of the spatial distributions of heat transfer potential between waste incineration facilities and factories in a case study in Aichi Prefecture

In these ways, our studies have focused on the spatial distribution patterns of land use, energy supply and so on in cooperation with each sub-theme. Our ultimate aim is to find an integrated solution for environmental problems from a global scale to the scale of industrial parks and city blocks by analyzing the current situation, proposing future plans, and implementing these plans socially.

3. Evaluation of policies for an environmentally sustainable society

Project 3 aims to elucidate effective policy and planning for an environmentally sustainable society. In sub-theme 1, sustainable visions for various regions and lifestyles are designed and assessed, and the planning approaches and tools to accomplish these visions are developed. In sub-theme 2, national and regional laws and policies are evaluated and submitted from the perspective of their effectiveness and validity. Below are the main results for FY 2019.

To design sustainable regions and lifestyles, our estimations of the carbon

emissions from household sectors in municipalities were revised by using survey data on household energy consumption and statistical data at multiple scales. A multiple regression model was improved by applying missing data processing using the multiple imputation method and nonlinear multiple regression. As a result of these developments, we calculated the annual carbon emissions per household in about 1000 municipalities of Japan (Fig. 4); the data were provided in 10 regions (bold lines) or 47 prefectures (thin lines). The per-household emissions reflected such factors as the average household size; the percentages of houses that were detached, had solar panels fitted, or were serviced with gas; the power company used; and the number of degree-days. Capturing emissions per household by taking into account the characteristics of each municipality will help to identify municipalities in need of focused reduction measures and to cross-reference effective reduction measures among municipalities with similar regional characteristics.

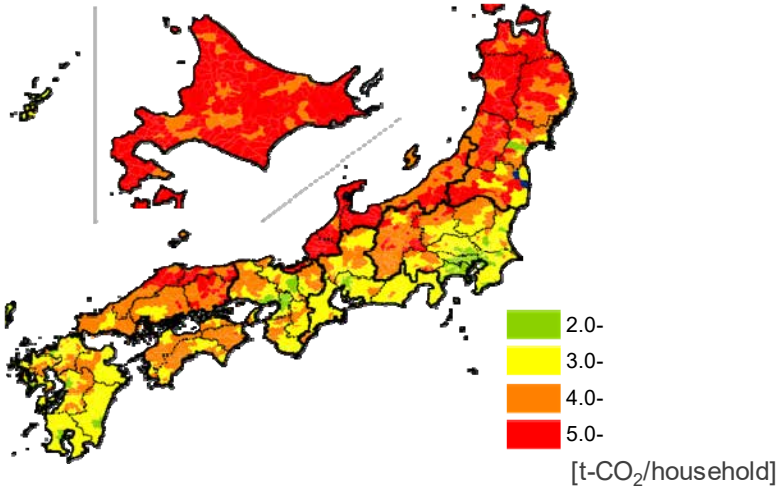


Fig. 4 Annual carbon emissions per household, as estimated in about 1000 municipalities across Japan (t-CO_2/household). Statistical data were provided for 10 regions (bold lines) or 47 prefectures (thin lines).

Environmentally friendly agriculture is one of the issues in Japan's SDGs [Sustainable Development Goals] Action Plan 2019. However, currently the area of land on which environmentally friendly agriculture is implemented (especially organic farming) in Japan is only 0.5% of the total cultivated land area, short of the government's goal of 1%. In this study, we used an econometric analysis to clarify the characteristics of farmers who are engaged in environmentally friendly agriculture, including organic farming. The target area was Ibaraki Prefecture, which has Japan's third-largest agricultural production and abounds in dry-field faming. The analysis revealed three characteristics of farmers engaged in environmentally friendly agriculture. First, small- to medium-scale farmers have an affinity for environmentally friendly farming aimed at high value-adding. They are likely to be conscious of consumer needs for food safety and security. Secondly, environmentally friendly farming is labor or capital intensive owing to the additional costs of such tasks as pest control. Environmentally friendly farmers input more labor more than other farmers, and many of them are engaged in protected cultivation of vegetables. Finally, environmentally friendly farmers

prefer shipping to markets that are not included among Japan Agricultural Cooperatives and wholesale markets. In particular, those who mainly sell directly to consumers are trying to differentiate themselves by providing safe and eco-friendly food. In the future, an effective way to expand our efforts to develop environmentally friendly agriculture will be to target farmers with these characteristics and to expand support, such as financing and recruitment of a labor force.

Environmental Emergency Research Programs

Environmental Emergency Research Programs

Immediately after the Great East Japan Earthquake and the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident, NIES undertook disaster-related environmental research. This research has helped in the environmental restoration and recovery of the devastated areas. By using the accumulated outcomes of this research, and with the NIES Fukushima Branch (which was established at the Fukushima Prefectural Centre for Environmental Creation in April 2016) as a research hub, this program conducts Environmental Recovery research, Environmental Renovation research, and Environmental Emergency Management research in collaboration with the government of Fukushima Prefecture, the Japan Atomic Energy Agency, other related institutions in Japan and abroad, stakeholders, and other entities. In addition to contributing to environmental recovery in the devastated areas, the Environmental Emergency Research Programs delineate paths leading to environmental restoration and creation and are helping to create a disaster-resilient society on the basis of the lessons of the Great East Japan Earthquake and other major disasters. Below, we outline the major projects conducted under the three sub-programs.

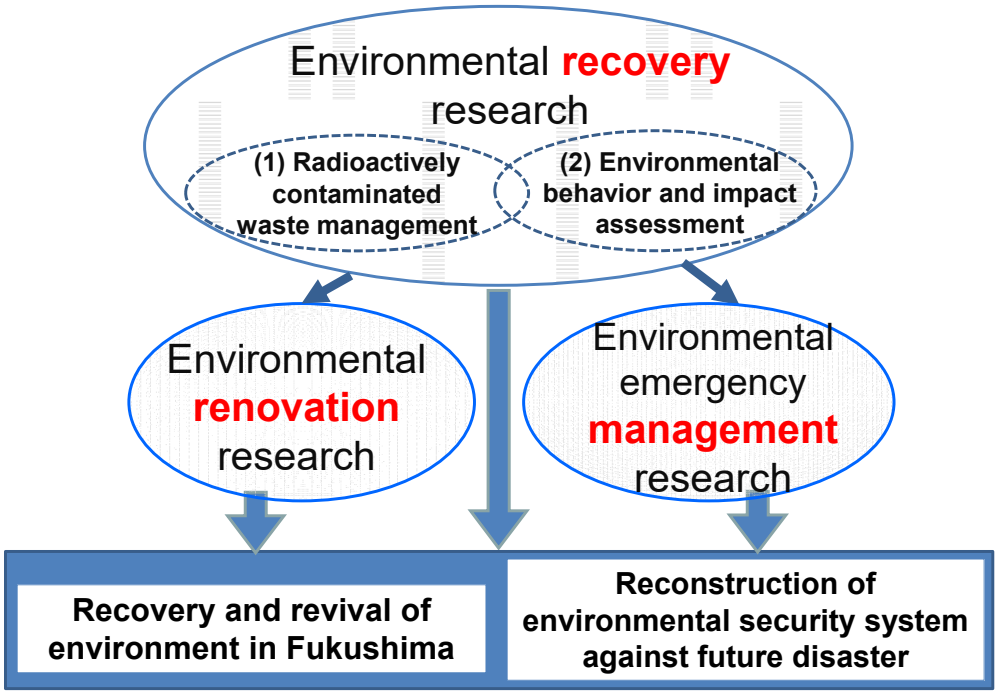


Fig. 1 Outline of the Environmental Emergency research programs

1. Environmental Recovery Research Program

This program is conducting research and development for volume reduction and other technologies for the purposes of intermediate storage and final disposal of radioactively contaminated off-site waste; these are urgent tasks of the highest priority for the nation. The program will also perform research and development for technological solutions to problems with the treatment and disposal of

designated wastes and other contaminated wastes. Additionally, it will conduct studies from a long-term perspective on the environmental fate of radioactive substances remaining in forests, water bodies, and other environments. Furthermore, it will apply long-term environmental risk-management methods to secure a livelihood platform where people can live safely and free of concern, and it will implement an ecosystem assessment that will include ecosystem services.

1.1 Development of management systems for radioactively contaminated off-site wastes

The FDNPP accident resulted in serious radiocesium contamination of solid wastes and soil in the surrounding area. We are performing various types of emergency response research into the appropriate management of waste contaminated by radioactive substances (Fig. 2). We are also collaborating with central and local governments in the practical implementation of our research. Our research results are being reflected in various measures, including technical guidelines published by the Ministry of the Environment (MOE), discussions by an MOE panel, and implementation of the Act on Special Measures Concerning the Handling of Pollution by Radioactive Materials.

Our recent areas of interest are: 1) volume-reduction technologies for radioactively contaminated off-site wastes; 2) management and optimization of stocks and flows through recycling and disposal of radioactively contaminated off-site wastes; and 3) optimization and long-term management of processes in the final disposal of radioactively contaminated off-site wastes and interim storage of removed soil. Below are representative results of these studies in FY 2019.

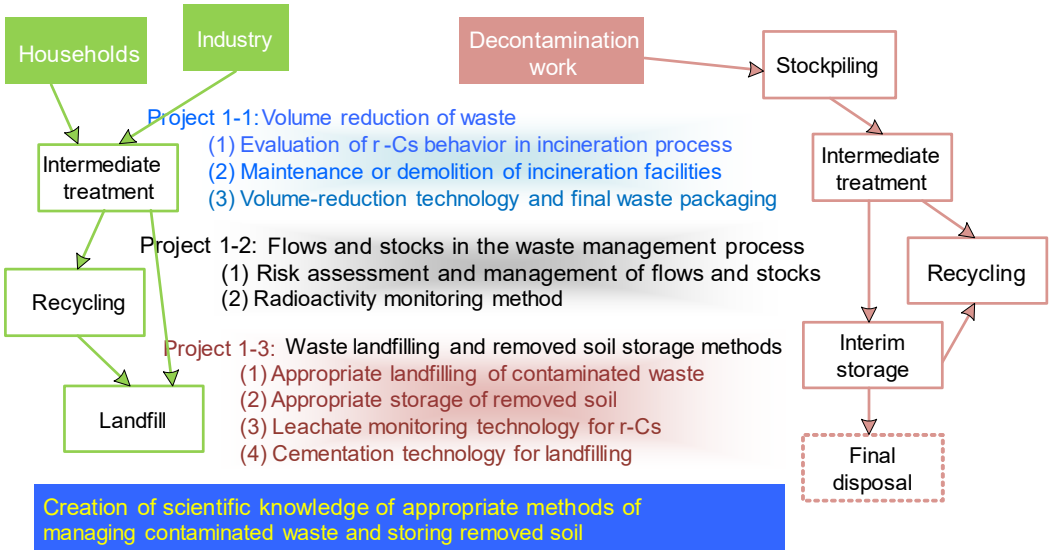


Fig. 2 Outline of the research project on the development of management systems for radioactively contaminated off-site waste. r-Cs, radioactive cesium

1.1.1 Understanding the behavior of radiostrontium and radiocesium during thermal treatment

We investigated the partitioning behavior of radiostrontium during the incineration of radioactively contaminated municipal solid (MSW) waste and decontamination waste (DW). We found that radiostrontium tends to remain in the bottom ash. This behavior differed significantly from that of radiocesium during MSW incineration. We developed a numerical model, based on the multizonal equilibrium calculation, which represents the chemical forms of strontium and other elements during DW incineration. The calculated results indicated that strontium exists in silicates or the slag phase. Furthermore, we established a method of rapid element analysis of incineration residues to support an ash-melting plant at the Interim Storage Facility, which stores decontaminated soil and waste from the FDNPP accident. We also predicted the behavior of radiocesium during the combustion of wood chips and bark, because a power plant based on burning woody biomass contaminated by radiocesium is to be constructed in Fukushima Prefecture.

1.1.2 Evaluation of the environmental safety of the removed soil for storage at the Interim Storage Facility, and potential future reuse

Modification agents containing polymer powder are being used to improve the handling of removed soil in Fukushima Prefecture. We conducted two lysimeter tests, on modified and unmodified soils, to investigate their leachate quality. These tests lasted for more than 500 days. Soil modification (addition of 3% modification agent) halved both the peak 137Cs concentration in the leachate (from 6.6 Bq/L to 3.3 Bq/L) and the accumulated leaching ratio of 137Cs (from 0.12% to 0.06%). Leaching of total organic carbon from the modified soil was 60% higher than that in the unmodified soil, and leaching of K+ and ammonia nitrogen (NH4-N) was 35% lower. With the cooperation of the Japan Environmental Storage & Safety Corporation, we constructed two test embankments. Removed soil was reused as a geomaterial after particle size improvement or application of an alkali modification agent. We developed appropriate methods for reusing large amounts of removed soil safely in the future by focusing on organic matter and radiocesium.

1.1.3 Research aimed at achieving final disposal of contaminated wastes

Since the FDNPP accident, intensive decontamination has been performed off site, and contaminated materials are now being transported to the Interim Storage Facility. To achieve final disposal, NIES and the Society for Remediation of Radioactive Contamination in the Environment (SRRCE) convened a research committee to devise a strategy to develop the technologies required for the final disposal of contaminated wastes outside Fukushima Prefecture. Several scenarios for final disposal, and the information required for these scenarios, have been discussed from a scientific viewpoint. These activities can be summarized in three phases: (1) several scenarios were proposed and their characteristic points were

explained; (2) the scenarios were analyzed by introducing a mass balance calculation that quantified the impacts of some of the parameters on the process; and (3) other research activities, such as cost evaluation and stakeholder consultation for public acceptance, are ongoing. An outline of these activities was presented at the annual meeting of SRRCE in 2019; the results, with updated information on the possibility of reducing the volume of contaminated wastes such as incineration ashes to 1/60,000, and on related issues, will be reported at the same meeting in 2020 by web conference.

1.2. Analysis and prediction of behavior of radioactive substances in multimedia environments

1.2.1 Factors controlling dissolved radiocesium (^{137}Cs) concentrations in east Japan rivers

To investigate the main factors that control dissolved radiocesium concentrations in river water in the area affected by the FDNPP accident, we assessed the correlations between the dissolved ^{137}Cs concentrations at 66 sites (normalized to the average ^{137}Cs inventories for the watersheds) as well as land use, soil components, topography, and water quality factors. We found that the topographic wetness index was significantly and positively correlated with the normalized dissolved ^{137}Cs concentration. Similar positive correlations have been found for European rivers; wetland areas with boggy organic soils that weakly retain ^{137}Cs are found mainly on plains. Moreover, in small Japanese river watersheds, the building area ratio in the watershed strongly affected the dissolved ^{137}Cs concentration. One reason for this is that the high concentrations of solutes (such as K^+ and dissolved organic carbon) discharged in urban areas inhibit ^{137}Cs absorption to soil particles. A multiple regression equation was constructed to predict the normalized dissolved ^{137}Cs concentration, with topography, land use, soil component, and water quality data as explanatory variables. The best model had building area ratio as the primary predictor. When our comparison of two multiple regression models in which the explanatory variables were limited to (1) land use and soil composition and (2) water quality, the water quality model underestimated the high normalized dissolved ^{137}Cs concentration in urban areas. This poor reproducibility indicates that the dissolved ^{137}Cs concentration value in urban areas cannot be explained solely by the solid–liquid distribution of ^{137}Cs owing to the influence of water quality; instead, specific ^{137}Cs sources in urban areas must control the dissolved ^{137}Cs concentration.

1.2.2 Different factors determine ^{137}Cs concentration factors in freshwater fish and aquatic organisms in lake and river ecosystems

Determination of radionuclide concentration factors (CFs) allows us to estimate the transfer of environmental radionuclides and the potential risks of consuming fish contaminated with radionuclides. Although it is known that biotic and abiotic factors affect fish CF, only a few studies have examined whether these factors differ among ecosystems. We estimated the ^{137}Cs CFs of 30 different fish species

and other aquatic organisms by monitoring three lakes and five rivers in Fukushima 2 to 4 years after the FDNPP accident. The relative effects of biotic and abiotic factors on ^{137}Cs CFs in freshwater organisms were compared between river and lake ecosystems by using generalized linear models. Our analysis demonstrated the following (Fig. 3). (1) The factors critically affecting fish CF differed between rivers and lakes. The negative effects of suspended solids (SS) concentration, total organic carbon (TOC), and salinity were significant for rivers, but not for lakes. Biomagnification of ^{137}Cs in piscivorous fish was significant only in the lakes. (2) Fish size significantly affected the CF in both rivers and lakes. Nevertheless, the positive correlation between ^{137}Cs concentration and piscivorous fish size was stronger in lakes than in rivers. (3) SS, TOC, and salinity simultaneously influenced the CF at every trophic level. However, feeding habit was a stronger determinant of ^{137}Cs bioaccumulation than water chemistry in organisms at higher trophic levels, such as aquatic insects, amphibians, and fish. Our findings indicate that ^{137}Cs accumulation in aquatic organisms is ecosystem dependent because of differences in environmental factors and food web structures.

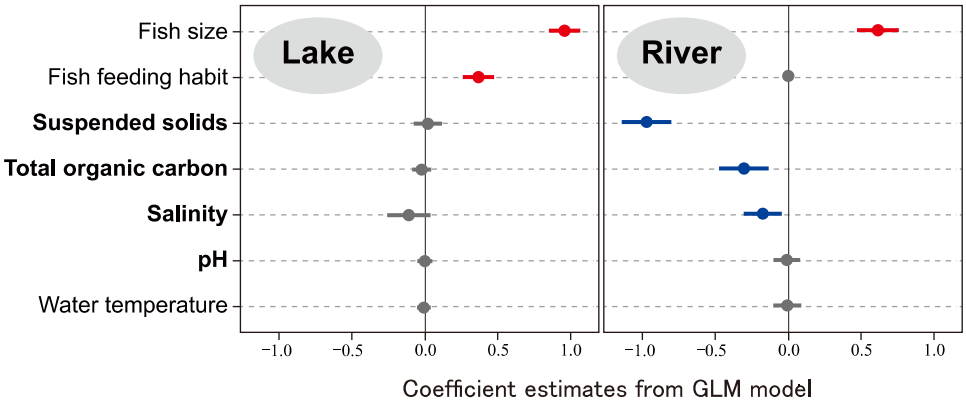


Fig. 3 Factors affecting the ^{137}Cs concentration factor in freshwater fish. For each dependent variable, the point estimate and the 95% confidence intervals are shown. Significant positive and negative effects are shown in red and blue, respectively.

1.3. Research on impacts of the FDNPP accident on organisms and ecosystem

1.3.1 Compiling open data on frog distribution from acoustic monitoring inside and outside the evacuation zone

The FDNPP accident affected biodiversity and ecosystems not only through the direct effects of the radiation, but also through landscape changes caused by cessation of farming and the other anthropogenic activities following the evacuation order. Since 2014, we have been monitoring the dynamics of mammals, birds, frogs, and flying insects inside and outside the evacuation zone in response to the FDNPP accident. Distribution data for mammals and birds have already been published, and a rapid evaluation of flying insects has also been reported. Now, a data set for frogs in 2014 and 2015 has been compiled and will be published in *Ecological Research* as a data paper (Yoshioka et al., *Ecological Research*.2020, 35, 765-772).

The frog data set is based on an acoustic survey of frog callings, using digital

voice recorders set up at more than 50 monitoring sites (mainly in the yards of schools or community centers) in early summer. At each site, the recorders were used in a timed-recording mode from 20:00 to 20:10 daily until the batteries were depleted. The recorded audio files were split into 20-s segments in MP3 format. Then, some of the segments was sampled and checked by us or by collaborating experts to record the presence–absence of each frog species. Eight frog species were identified from a total of 1962 audio segments. In particular, the acoustic monitoring enabled us to obtain an adequate amount of data on *Rhacophorus schlegelii* (Fig. 4) for ecological analyses (e.g. statistical modelling). Adult individuals of this species were hardly observed in the field survey because they often stay on trees or underground. Most of the common frogs in Japan inhabit rice paddy fields and can be good environmental indicators of change of agricultural landscapes following the cessation and restarting of rice farming. Frog monitoring has continued after 2015, and the published dataset will be updated after compilation. Addition of the frog data will enhance our understanding of the nuclear accident's impact.

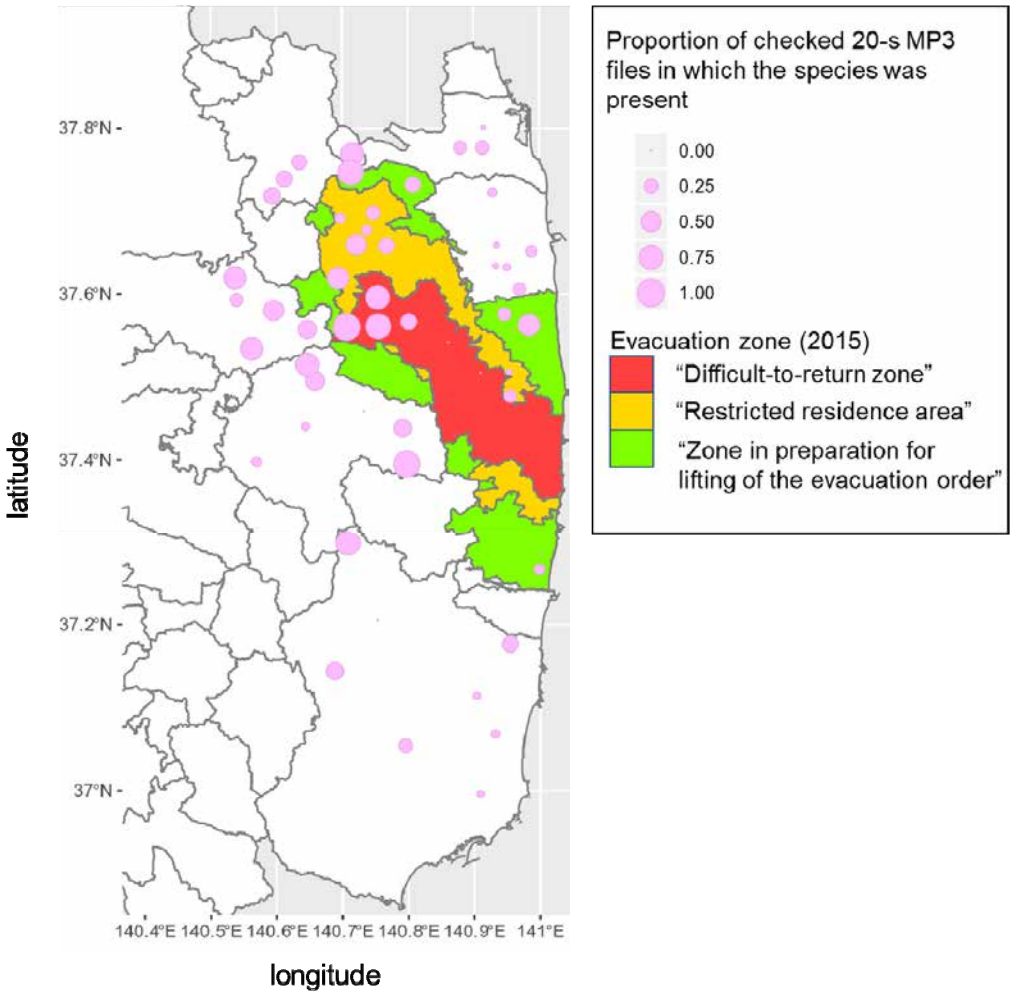


Fig. 4 Distribution map of *Rhacophorus schlegelii* between 2014 and 2015, based on acoustic monitoring by NIES. The species' call was assumed to be absent in those sound files in which only obscure or uncertain calls were recorded. Municipal boundaries are based on National Land Numerical Information (Ministry of Land, Infrastructure, Transport and Tourism).

1.4. Exposure modeling of radiation and chemical contaminants for environmental emergencies

1.4.1 Assessment of early ^{131}I inhalation doses on the basis of atmospheric ^{137}Cs and $^{131}I/^{137}Cs$ observation data and multi-ensemble of atmospheric transport and deposition models

We used an internal exposure model to estimate the maximum potential thyroid doses in residents of eastern Japan due to inhalation of radioiodine (^{131}I) during the first 2 weeks after the FDNPP accident (11 to 23 March 2011). The following data were used in the model: hourly ^{137}Cs concentrations in suspended particulate matter at 101 monitoring sites; a new multi-model ensemble (MME) method of simulating ^{137}Cs concentrations by using two atmospheric transport and deposition models (ATDMs); and $^{131}I/^{137}Cs$ ratios obtained from measurement data analysis. The maximum potential doses in 1-year-old children at the 101 sites ranged from <0.1 to 4.3 mSv (except in the coastal area of Fukushima Prefecture, where they reached 3.1–160 mSv) (Fig. 5A). Thyroid doses were modeled in 18 evacuation scenarios for comparison with previously published estimates. Thyroid doses that considered higher $^{131}I/^{137}Cs$ ratios of some plumes ("Plume-specific case") were also estimated. The results were almost congruent with those of previous studies, with the exception of the thyroid doses contributed by highly contaminated plumes on 12 and 15 March (Scenarios 4, 9, and 13–18, Fig. 5B). We also developed a tool to estimate the doses in different evacuation scenarios. We were able to reduce the uncertainties by refining the ATDMs and the exposure model (Takagi et al., *J. Environ. Radioactiv.* 2020, 218, 106233). The tools we developed can be used to estimate other chemical exposures through inhalation.

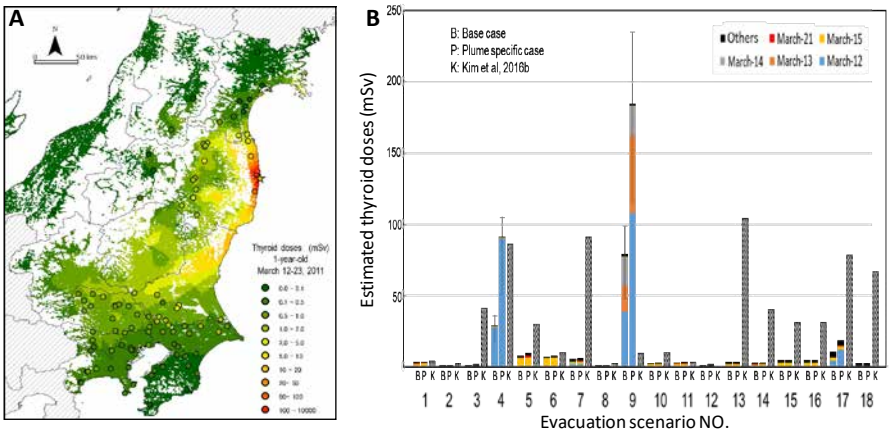


Fig. 5 (A) Spatial distribution of estimated maximum potential thyroid doses in 1-year-old children at radiocesium measurement sites (open circles) and in 1-km grids (colors). (B) Estimated thyroid doses in 1-year-old children under 18 evacuation scenarios

2. Environmental Renovation Research Program

This program is working with the staff of Shinchi, Mishima, and other municipalities in Fukushima Prefecture where reconstruction is under way to develop research theory and methods that will support the process of restoration

and environmental re-creation in post-disaster regional environments. It also studies the use of these methods to support policymaking by local governments. Moreover, we are considering such items as global warming countermeasures and resource recycling strategies tailored to the characteristics of affected areas, and we are conducting practical research aimed at building regional environmental resource and energy systems and formulating quantitative eco-city policy targets and roadmaps to achieve those targets. Figure 6 presents the framework of our Environmental Renovation Research Program.

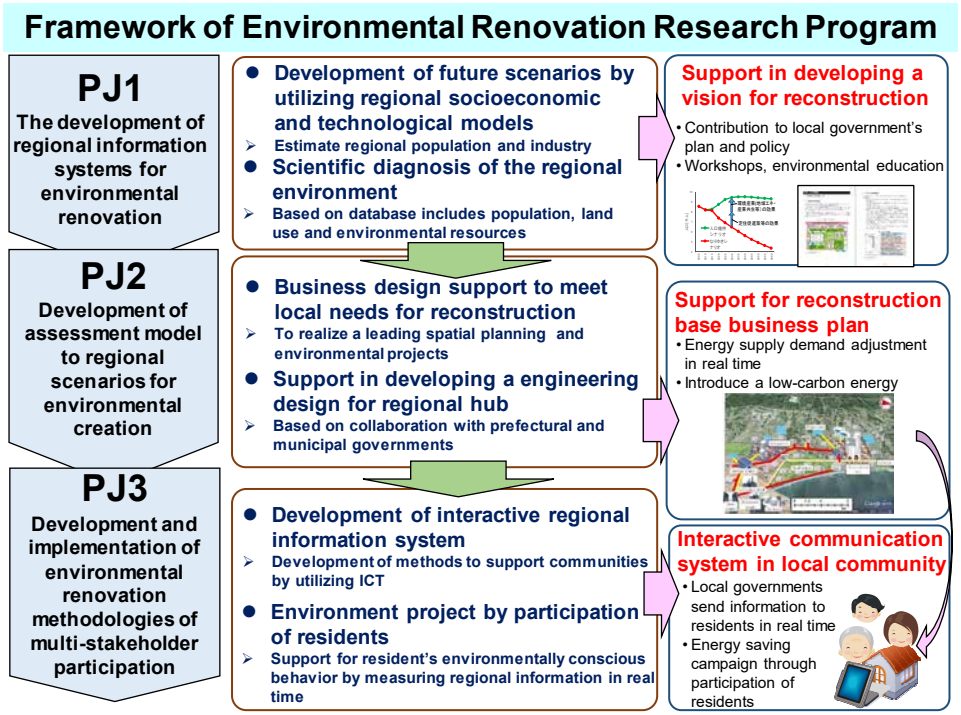


Fig. 6 Outline of the Environmental Renovation Research Program. ICT, information and communications technology

2.1 Development of regional information systems for environmental renovation (Project 1)

We developed a spatial regional database as a common information base for environmental renovation research. It includes information on time-series land use and land-use changes, population and other socioeconomic data, roads and other infrastructure, building stocks, zoning for urban planning, energy demand, industrial activities, and potential use of renewable energy. As part of our research into adaptation to climate change, we added future climate data and data on projected impacts of climate change, such as river flows and water quality, suitability of agricultural crops, landslide risk, risk of heat-related health problems, and habitats of insect vectors of infectious diseases. We also developed a framework for the collection of indicators for future research into Sustainable Development Goals and the establishment of a Regional Circular and Ecological Sphere. Since the evacuation order was lifted in several municipalities in 2017, the database has collected population information from the evacuation area and information on the construction and operation of facilities such as public offices,

schools, retail shops, and factories to determine the current status of recovery. Figure 7 presents the population living in the former evacuation area of each municipality as a ratio of the whole population of registered residents in the area. We have found that population recovery is slower in areas where the return started later (such as Iitate and Katsurao) than in areas where it started earlier (such as Tamura and Kawauchi) and in areas nearer to the FDNPP (such as Namie and Tomioka), although the figure suggests that other factors are also influential.

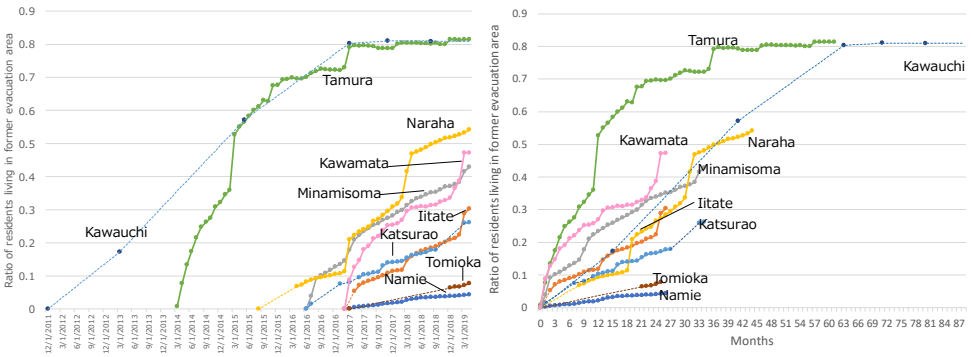


Fig. 7 Progress of population recovery after the FDNPP accident (ratio of registered citizens who actually live in the area to all registered residents) by month (left) and by months since the evacuation order was lifted (right)

Figure 8 is a series of maps showing facilities in operation in 2015, 2017, and 2019. These kinds of figures can help us communicate about various aspects of the recovery after the FDNPP disaster. To enhance communication with stakeholders by using these data, 3-D projection mapping systems were developed for Fukushima Prefecture (3D-Fukushima) and the Hamadori area. They were used in NIES outreach activities at the Fukushima Branch and elsewhere.

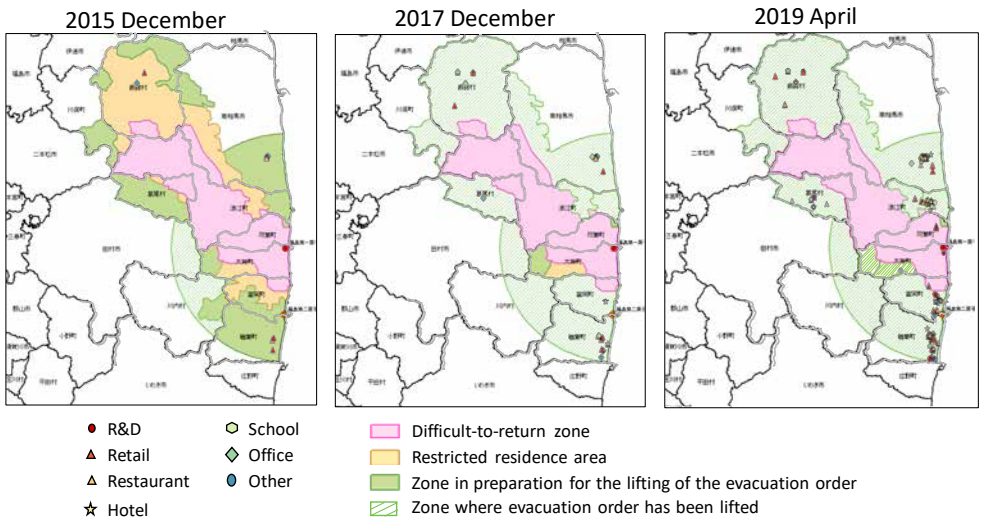


Fig. 8 Progress of recovery after the FDNPP accident, as indicated by facilities in operation.

2.2 Development of a model for assessing regional scenarios for environmental creation (Project 2)

Uncertainty in the outlook for mid-to-long term energy demand and supply has increased since the FDNPP accident. Expansion of distributed energy systems has

been receiving increased attention as a foundation for achieving a sustainable society. Promoting regional resources and installing distributed energy systems should be key to the revitalization of relatively small-scale municipalities. In this project, we are studying regional resources; modeling the process of designing a distributed energy system; and matching energy demands and supplies temporally and spatially. In this section, we report on two topics from the project's studies in the Oku-Aizu region: a forest survey at the individual tree level with local stakeholder communication and a regional energy system design.

(1) Woody biomass is becoming an important resource in Japan. However, Japanese plantations have been not well managed because of their small size and fragmented nature, the absence of plantation owners, a lack of forestry labor, and the low-profit structure of domestically produced timber. To revitalize rural areas by using woody biomass, we need to develop more accurate and detailed methods of using forests as a resource. In general, in forests that have been not managed well, the individual trees vary greatly in size. Information on the amount and quality of timber is needed as part of the implementation of a biomass project. Almost all trees are suitable for chipping as fuel, but few individual trees are suitable for use as construction materials (class A timber) with high added value in the wood market.

We conducted a trial forest survey in cooperation with the community in the town of Mishima, Fukushima prefecture. With our collaborators, we developed a technique for automatically classifying tree size from 3-D point group position data obtained from the forest by light detection and ranging (LiDAR) by drone operator. The dataset from the trial survey will tell both residents and policy makers whether or not the forest needs to be thinned for biomass production. The trial survey is cheaper than conventional inventory surveys, which need direct measurement of trees and large amounts of labor. This type of LiDAR observation and automatic classification technology may guide the next stage of Japanese forestry toward more efficient production of woody biomass and construction materials.

(2) To study the use of resources and energy throughout the Oku-Aizu region, we needed to focus on villages, which are the region's basic unit of organization. Each village was assumed to be a unit for decision-making in optimizing energy system design and operational plans for renewable energies in accordance with the variations in demand among villages. First, we developed a mathematical optimization model to identify the rough direction for creating a concrete energy system. By applying the model to the central town of Mishima in the Oku-Aizu area of Fukushima Prefecture, we quantitatively evaluated the cost-reduction effects and CO_2-reduction effects of introducing alternative energy systems such as the use of forest biomass resources. We then expanded the analysis to all villages located in Mishima. The results were summarized as "village clinical record" and included basic information about each village.

We used the summation of each "village clinical record" to evaluate the effects of energy optimization on the total resource and economic circulation in the region. We found that introducing all-electric systems using solar power generation could significantly reduce energy costs, whereas the use of boilers and cogeneration using forest biomass resources could further reduce CO_2 emissions and promote regional resource circulation. In addition, the use of renewable energies could play an important role in the formation of regional circular economy through reallocation of the flows of money and resources in the region.

2.3 Development and implementation of environmental renovation methodologies with multi-stakeholder participation (Project 3)

At Shinchi in Fukushima Prefecture, we continued a social demonstration experiment using the local ICT (information and communications technology) system to promote technology development and enhanced social communication. By analyzing electricity consumption data from the local ICT system, we evaluated the patterns of residential power consumption and its temperature sensitivity. In particular, with data on household attributes such as the possession of heating and cooling equipment, the temperature sensitivity characteristics were analyzed by focusing on the energy applications of cooling, heating, and hot water supply.

We also conducted an energy supply and demand analysis in Shinchi. As part of the reconstruction of the tsunami-damaged area around Shinchi Station, a high-efficiency community energy supply project was launched for which NIES provided planning help. We obtained supply and demand data from the energy supply facility (the Shinchi Energy Center), which started operating in March 2019, to determine the conditions of heat source and power supply equipment operation and to evaluate efficiency. In addition, as part of the development of a consulting system for expanding regional energy supply to other regions, we developed a prototype of a system for evaluating the cost and efficiency of regional energy supply, and we examined a supply and demand optimization policy based on a supply expansion scenario. To investigate the potential for introducing renewable energy to reduce environmental loads on the regional energy supply, we observed the vertical profile of wind speed from December 2019 to February 2020, and we examined the feasibility of wind power generation.

We also examined the status of operation of the entire supply chain of woody biomass fuel in several regions (i.e., a chain of business entities), and its providers as an example of methods to achieve both low-carbon measures and revitalization of social communities in the region. In this study, we conducted an interview survey of several operators of entities using firewood stoves, firewood boilers, chip boilers, pellet stoves, pellet boilers, and power generation, in order to clarify the conditions required for the stable and sustainable operation of biomass energy providers utilizing forest resources in Japan. In each case examined, the supply

chain was divided into four components: raw material supply, fuel production, energy supply, and energy demand. We analyzed these from three perspectives: business feasibility, connections between components, and supply and demand balance. The results showed the importance of coordination from upstream to downstream within the region to construct a stable supply chain.

3. Environmental Emergency Management Research Program

Our Environmental Emergency Management Research Program (Fig. 9) aims to establish practical management systems and technologies for handling disaster waste during and after disasters. It also aims to develop a strategy for environmental and health-risk management in times of emergency to create more resilient social environmental systems and foster the communities within them.

This program will devise technologies and systems for integrated disaster waste management aimed at achieving smooth and appropriate management of these types of wastes. Additionally, to create a strategy to manage the environmental and health risks associated with disasters, the program will investigate approaches to setting risk management targets, focusing especially on chemical risks when disasters strike and methods and organizational arrangements for emergency environmental surveys. Furthermore, to build a research hub for an environmental emergency research network, the program will design and develop an information platform and capacity-development system for environmental emergencies. This research will be pursued in collaboration with NIES's Environmental Emergency Management Office.

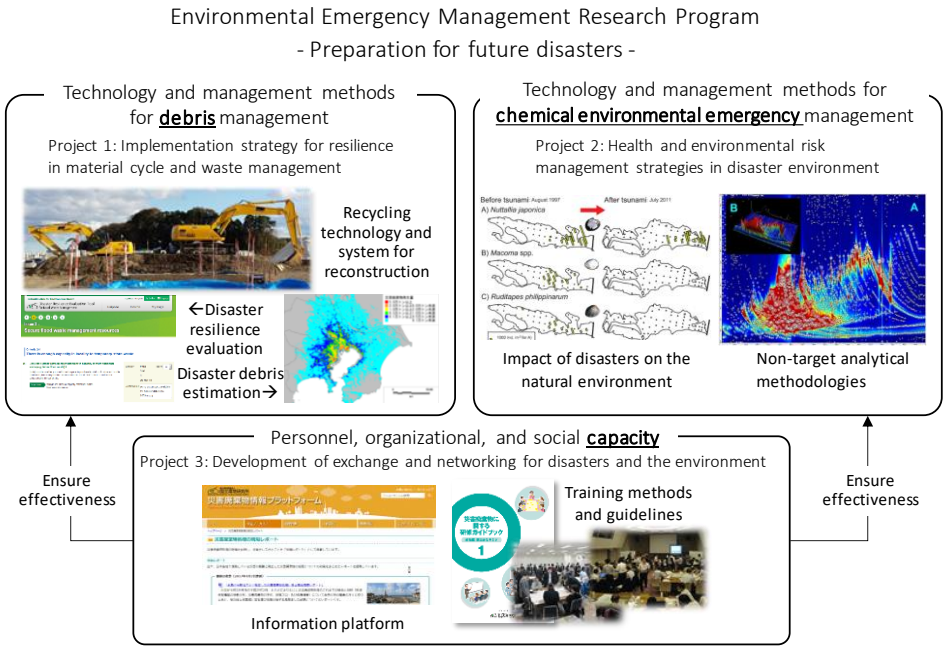


Fig. 9 Outline of the Environmental Emergency Management Research Program

3.1 Establishment of disaster-resilient waste management systems and strategies (Projects 1 and 3)

Disaster waste management (DWM) tasks undertaken in eight recent disaster waste management cases in small and medium-sized cities in Japan were investigated in depth. We proposed a comprehensive structure for a DWM project, including the individual project components and their specific tasks, to analyze these eight cases and to characterize the DWM framework for small and medium-sized cities. The results showed that the processes most demanding of the local authority's resources were "overall management" and "temporary storage," and within these the "logistics" and "finance and administration" functions required a great deal of direct management, suggesting that these components should be given special attention during preparedness planning and training.

We also collected data on the typical DWM issues and situations faced by local authorities. The results will be organized in a database that can be used by local authority officers for planning their preparedness plans and training programs. We also updated our online self-evaluation tool by which local government officials can evaluate the disaster resilience of their waste management systems. In addition to our evaluation system based on 29 indicators, between three and five specific criteria were added to each indicator to enable self-evaluation with greater confidence. The new system was tested and validated in three prefectures.

We also restructured our online DWM information platform (https://dwasteinfo.nies.go.jp/) to improve user access to DWM information. In addition, a new database for DWM planning was developed to help practice and study preparedness planning.

3.2 Health and environmental risk management strategies in disaster environments (Project 2)

Health and environmental risk assessment and management of hazardous chemicals are currently general practices applied when such chemicals are used in normal environments. However, the risks posed by the accidental release of hazardous chemicals in disaster environments have not yet been sufficiently evaluated or managed.

This research project focuses on establishing a risk assessment and management methodology for the accidental release of hazardous chemicals in disaster environments. The project consists of several sub-projects, which are briefly summarized as follows: Project 2-1, setting target control levels for chemical contamination in disaster environments; Project 2-2-1, establishing comprehensive analytical technologies and emergency response teams for contaminant chemicals; Project 2-2-2, establishing non-target analytical methodologies and sampling technologies for emergency contamination; Project

2-3, clarifying the impacts of emergency contamination events on terrestrial ecosystems and environmental epidemiology in emergency events; and Project 2-4, clarifying the long-term impacts of emergency contamination events on coastal ecosystems in the field. This fiscal year, we collected detailed information on past chemical accidents and their emergency responses through questionnaires and interview surveys and analyzed related factors of chemical release (Project 2-1); developed a rapid and comprehensive analytical screening method for gas chromatography–mass spectrometry (Project 2-2-1); conducted monitoring and performance tests of portable air samplers with different adsorption properties (Project 2-2-2); conducted monitoring and research on the mechanisms of groundwater contamination after the 2016 Kumamoto earthquakes and joined a workshop held on DR2 (Disaster Response Research) tools by the U.S. National Institutes of Health (Project 2-3); and performed a field survey of the impact of a disaster on a coastal ecosystem (Project 2-4). Through these achievements, the project aims to demonstrate comprehensive strategies for managing the health and environmental risks posed by hazardous chemicals in a variety of disaster environments.

Research Projects

Satellite Observation Center

The Satellite Observation Center contributes to improved scientific understanding of the carbon cycle, more accurate prediction of the future climate, and climate-change-related policy-making by the Ministry of the Environment (MOE) through activities that use data from the Greenhouse Gases Observing Satellite (Ibuki/GOSAT, launched in 2009) and its successor (GOSAT-2, launched in 2018). Activities include developing and operating data-processing systems for GOSAT and GOSAT-2. These systems are being used to calculate the concentrations and fluxes of greenhouse gases (GHGs) and to verify, archive, or distribute GOSAT or GOSAT-2 products. The Center has also started to develop a data-processing system for Global Observing SATellite for Greenhouse gases and Water cycle (GOSAT-GW), which will succeed GOSAT-2. GOSAT Series projects are jointly promoted by MOE, the Japan Aerospace Exploration Agency (JAXA), and NIES.

Major achievements of the Satellite Observation Center in FY 2019 are as follows:

1. GOSAT

Operational data processing for GOSAT, which has been in space for more than 10 years, continued, as did the generation, validation, and distribution of GOSAT products, such as the concentrations and fluxes of carbon dioxide (CO_2) and methane (CH_4). Concentration products up to June 2020, CO_2 flux products up to October 2017, and CH_4 flux products up to September 2015 are freely available from the data distribution website (GOSAT Data Archive Service, GDAS; https://data2.gosat.nies.go.jp). Maintenance and operation of GOSAT DHF (the GOSAT Data Handling Facility), which is the computer system needed for these activities, were also done. Since March 2019, GOSAT CO_2 concentration products have also been available from the World Data Centre for Greenhouse Gases, which is operated by the Japan Meteorological Agency under an agreement with the World Meteorological Organization.

2. GOSAT-2

GOSAT-2 data have been distributed by the GOSAT-2 Data Processing System (G2DPS) for Research Announcement users since May 2019 and for General Users since August 2019. CAI-2 Level 1 Product up to June 2020 and CAI-2 Level 2 Cloud Discrimination Product up to May 2020 are available from the GOSAT-2 Product Archive Service. FTS-2 SWIR Level 2 Column-averaged Dry-air Mole Fraction Product and Chlorophyll Fluorescence and Proxy-method Product up to September 2019 are also available, but only for Research Announcement users. These FTS-2 Level 2 products will be publicly released after we have improved their quality and validation by using ground-based data. Meetings of the GOSAT-2 Science Team and its Calibration Working Group were held periodically.

3. GOSAT-GW

A GOSAT-GW advisory board and working groups were established, and their meetings were held several times to obtain useful suggestions from domestic experts in space application, atmospheric science, and climate-change-related policies. The conclusion of the joint research agreement on nitrogen dioxide data from GOSAT-GW were discussed among the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the National Institute of Information and Communications Technology (NICT), and NIES. A preliminary study of the data-processing system for GHG data from GOSAT-GW was started, and its basic strategy and development schedule were investigated.

4. Collaboration with other organizations

Research Announcements on Greenhouse Gases Observing Satellite Series (GOSAT Series RA) have been issued jointly by MOE, JAXA, and NIES since 2018 to solicit research proposals covering both GOSAT and GOSAT-2 from around the world. Those proposals that are evaluated as appropriate by the GOSAT Series RA Selection and Evaluation Committee will be adopted to conclude joint research agreements. The second GOSAT Series RA was issued in October 2019 and eight proposals were adopted. Currently, a total of 44 joint studies are in progress.

On the basis of an agreement concluded between NIES and SYKE (the Finnish Environment Institute) in FY 2017, a NIES researcher visited Finland to discuss in-situ measurement of solar-induced fluorescence in the forests of Finland.

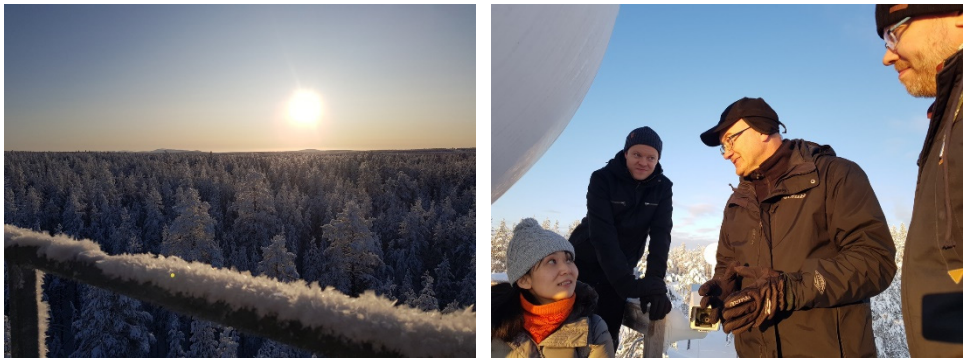


Fig. 1 (Left) Finnish forests as seen from the tower at Sodankyla, Finland, and (right) an on-site discussion between Japanese and Finnish scientists

In response to agreements concluded with NASA (the US National Aeronautics and Space Administration), ESA (the European Space Agency), CNES (the Centre National d'Etudes Spatiales), and DLR (Deutsches Zentrum für Luft- und Raumfahrt, the German Aerospace Center), several informal meetings were held to exchange technical information and discuss future collaboration. These meetings were held at large conferences such as IWGGMS-15 (described in the next section) and the American Geophysical Union's Fall meeting in December 2019.

5. Hosting of meetings

The 15th International Workshop on Greenhouse Gas Measurements from Space (IWGGMS-15) was held in Sapporo, Hokkaido, Japan, in June 2019 and was co-hosted by NIES, MOE, and JAXA. A total of 130 researchers and experts from 16 countries participated in IWGGMS-15 to exchange the latest information and innovative ideas on GHG observation from space. Over the 3 days of the workshop, we had fruitful discussions with 55 oral and 55 poster presentations. Following IWGGMS-15, the 1st GOSAT Series RA PI (Principal Investigators) Meeting was held at the same venue to deepen collaboration with researchers at home and abroad and extend the use of GOSAT and GOSAT-2 data. This meeting was also jointly organized by NIES, MOE, and JAXA. With 54 participants, we had a valuable opportunity to develop further collaboration.

Fig. 2 Group photo of participants in IWGGMS-15 in Sapporo, June 2019

6. Participation in international events

To promote the use of GOSAT and GOSAT-2 data in Earth-science- and climate-change-related policy-making, the Satellite Observation Center participated in the following international events and conducted presentations, lectures, and exhibits:

• Land Cover/Land Use Changes (LC/LUC) and Impacts on Environment in South/Southeast Asia—International Regional Science Meeting (July, Johor Bahru, Malaysia)
• WGIA17 (17th Workshop on Greenhouse Gas Inventories in Asia) (July–August, Singapore)
• GEO Week 2019 and the GEO Ministerial Summit (November, Canberra, Australia)
• UNFCCC COP25 (United Nations Framework Convention on Climate Change 25th session of the Conference of the Parties) (December, Madrid, Spain)

7. Press releases

One press release related to the Satellite Observation Center was issued in FY 2019:

1) “Analysis result of the proxy-method based retrievals from GOSAT-2 data: methane and carbon monoxide” (July 2019). See:
https://www.nies.go.jp/whatsnew/20190705/20190705-e.html
https://www.eurekalert.org/pub_releases/2019-07/nife-aro071819.php
[retrieved 13 August 2020]

Graphs of the results of these retrievals are shown in Figure 3.

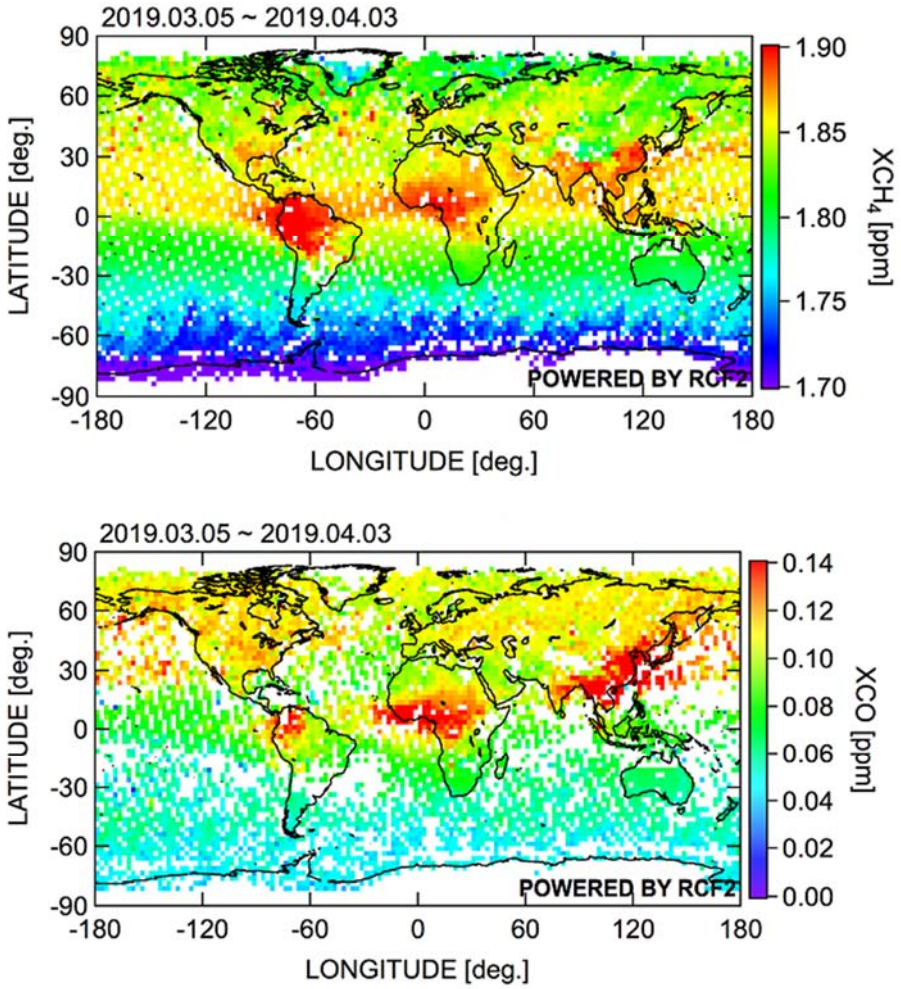


Fig. 3 Global distributions of methane and carbon monoxide column-averaged dry-air mole fractions (XCH_4 and XCO), retrieved by the proxy-method from GOSAT-2 FTS-2 data acquired from 5 March to 3 April 2019

Japan Environment and Children's Study

The Japan Environment and Children's Study (JECS) is a large-scale birth cohort study that aims to investigate the impact of the environment on children's health and development. NIES serves as the JECS Programme Office, supporting the Regional Centers that conduct surveys in 15 study areas throughout Japan in cooperation with the Medical Support Centre situated in the National Center for Child Health and Development, which provides medical expertise.

1. Aim

The aim of JECS is to identify environmental factors that affect children's health to develop better environmental risk management policies. Specifically, JECS focuses on the effects of exposure to chemical substances during the fetal period or in early childhood. JECS gives priority to five major health domains: reproduction and pregnancy complications; congenital anomalies; neuropsychiatric/developmental disorders; allergy and immune system disorders; and metabolic and endocrine system dysfunction. The environment is defined broadly as the global or ambient environment (including chemical substances and physical conditions), the built environment, behaviors and habits, socioeconomic factors, family and community support, and genetic factors.

2. Study design and subjects

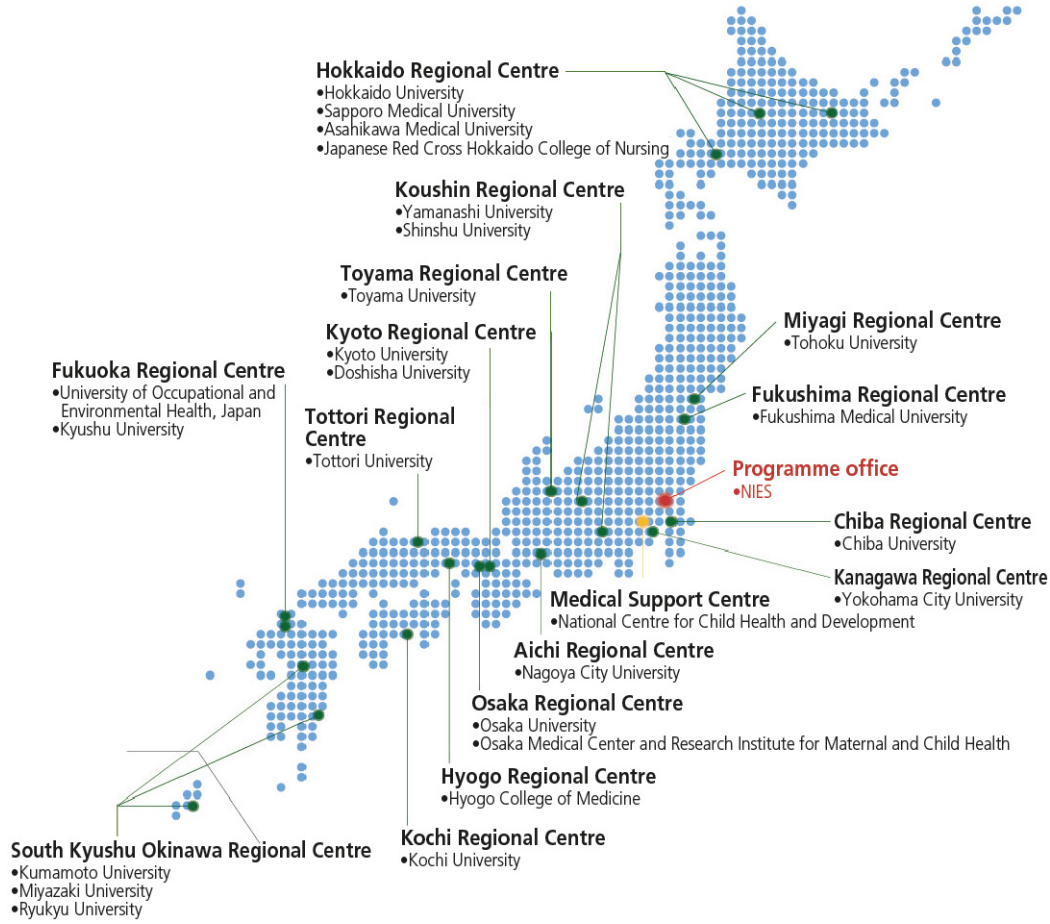
We started recruiting participants in January 2011, and recruitment continued until March 2014, by which time the number of participating mothers had reached 103,099. Recruited participants were pregnant women and their partners (when accessible). JECS began to collect data when the mothers were pregnant and plans to follow their children until they reach 13 years of age. For the Main Study, JECS acquires information about participant health and development and potentially relevant environmental factors by administering questionnaires twice a year. The Sub-Cohort Study, which involves 5000 children selected randomly from among participants in the Main Study, is also being conducted to investigate environmental factors and outcome variables more thoroughly. It includes extensive assessment through home visits, ambient air measurements, psycho-developmental testing, and examinations by pediatricians.

3. JECS study organization and role of the Programme Office

For appropriate data collection and analysis, the Programme Office plays key roles, including developing standard operation procedures; accumulating the data collected by the 15 Regional Centers (Fig. 1); operating the data management system; maintaining a repository of biological and environmental specimens; performing exposure and environmental measurements, including chemical analyses of biological samples; and administering questionnaires. The Programme

Office also performs administrative tasks, provides administrative and technical support for Regional Centers, and is responsible for risk management and public communications. The Programme Office strives to play a leadership role in facilitating collaboration among the different research groups conducting environmental birth-cohort studies in both Japan and other parts of the world, working as a platform for information exchange among researchers.

Fig. 1 JECS organization



4. Study protocol

Details of the study protocols of JECS can be found in the following literature:

1. Kawamoto T, Nitta H, Murata K, et al. Rationale and study design of the Japan environment and children's study (JECS). *BMC Public Health*. 2014. 14:25. (doi:10.1186/1471- 2458-14-25)

2. Michikawa T, Nitta H, Nakayama SF, et al. Baseline profile of participants in the Japan Environment and Children's Study (JECS). *J Epidemiol.* 2018. 28(2):99–104. (doi:10.2188/jea.JE20170018)

5. Activity report in FY 2019

The children participating in the Main Study reached the ages of 5 to 8 years in FY 2019. We continued to administer questionnaires to participants to collect a wide range of information on the children's health and development and exposure to environmental factors. We completed analyses of 20,000 maternal urine samples for phthalates and neonicotinoid pesticides. As part of the Sub-Cohort study, approximately 2400 six-year-old participants were tested developmentally and examined by a pediatrician, as well as having blood and urine samples collected and tested.

Risk Assessment Science Collaboration Office

The Risk Assessment Science Collaboration Office provides domestic leadership for the promotion of regulatory science with the aim of achieving a safe and secure society. The office consists of the Ecotoxicity Reference Laboratory and the Environmental Risk Assessment Task Office. The Laboratory conducts ecological toxicity research, international collaboration for the development of advanced testing methods, and standardization of test implementation. The Task Office conducts projects to assess environmental risks scientifically in collaboration with other organizations; it also constructs databases and disseminates knowledge and technical methodologies (Fig. 1).

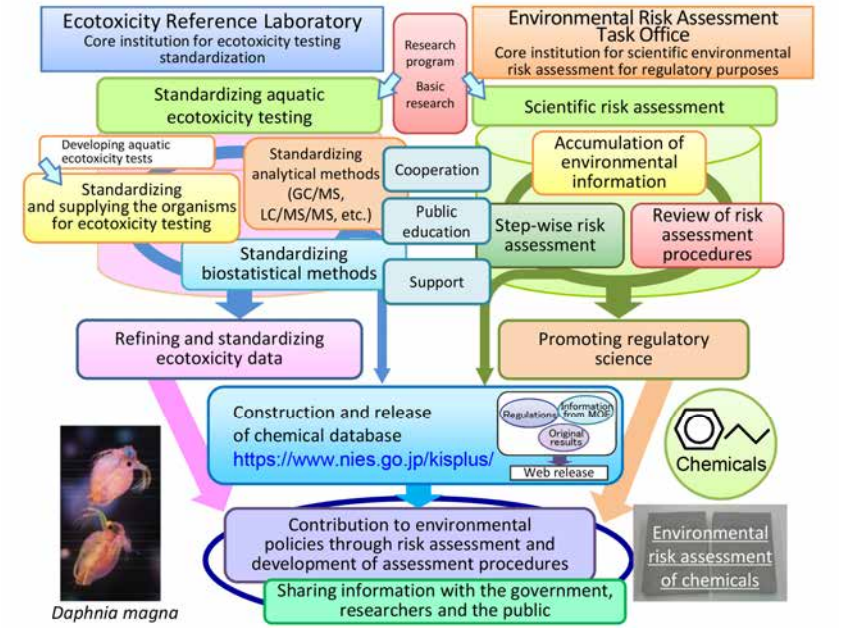


Fig. 1 The Ecotoxicity Reference Laboratory and Environmental Risk Assessment Task Office work in collaboration in regulatory risk assessment science through ecotoxicological testing, scientific risk assessment, and database development.

1. Ecotoxicity Reference Laboratory

As a leading reference laboratory for ecological toxicity research and testing, the Ecotoxicity Reference Laboratory helps to realize and secure a safe society by proactively promoting regulatory science. Two kinds of new ecotoxicity test methods, namely a method of detecting anti-androgens by using medaka (juvenile medaka anti-androgen screening assay: JMASA) and a simple method of detecting juvenile-hormone-like chemicals by using *Daphnia magna* (juvenile hormone activity screening assay: JHASA), were proposed by our laboratory in 2016 for the Organisation for Economic Co-operation and Development (OECD). Ring tests for interlaboratory validation were conducted this year for both assays; we plan to report the results to the meeting of the OECD's Validation Management Group for Ecotoxicity testing (VMG-eco) this year for approval next year. The two methods contribute to the Extended Tasks on Endocrine Disruption (EXTEND) 2016 project of the Ministry of the Environment (MOE),

namely “Future correspondence regarding the endocrine-disrupting action of chemical substances.”

The revision of a fish acute toxicity test (OECD Guideline for Testing of Chemicals, No. 203) was approved in June 2019. The major two points in this revision are i) the change in the size of fish and ii) the voluntary collection of data about sublethal clinical signs to link with lethality. Clinical signs highly linked to lethality were investigated in Japanese medaka; some signs, such as loss of equilibrium, were closely linked to lethality and could be considered to indicate a moribund state.

We have also investigated the toxic effects of specific chemicals, such as chelating agents, mostly in a green alga (*Raphidocelis subcapitata*), a diatom (*Navicula pelliculosa*), and a cyanobacterium (*Synechococcus leopoliensis*). The toxicities of major chelating agents such as ethylenediaminetetraacetic acid (EDTA) and nitrilotriacetic acid (NTA) were determined at different hardnesses.

The Laboratory continuously supplies stable test organisms (15 species in total, mostly fishes and crustaceans) to personnel in Japan, both outside and inside NIES, for ecotoxicity testing. In FY 2019 more than 100 orders were received from contract laboratories, universities, and municipal institutes all over Japan.

This year the Laboratory held an education seminar on ecotoxicity test techniques. The seminar covered growth inhibition testing using an alga and duckweed. About 20 people from universities, local environmental laboratories, and private enterprise attended the seminar.

In collaboration with universities, local environmental laboratories, and private enterprise, the Laboratory also promotes ecotoxicity testing and performs scientific risk assessments (Fig. 2).

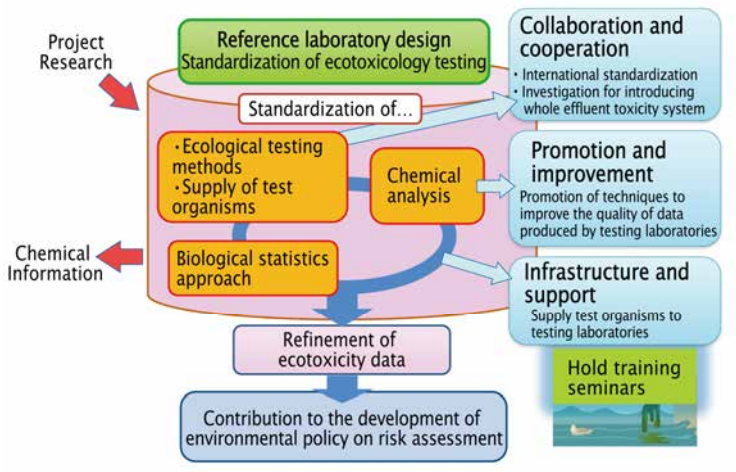
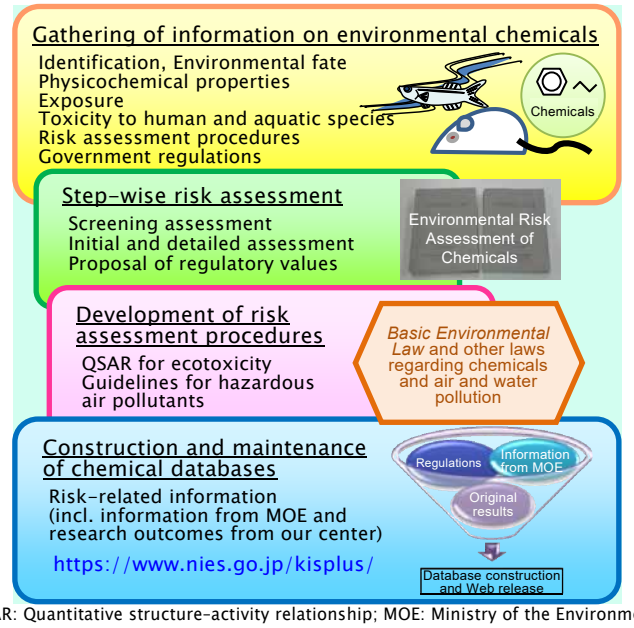


Fig. 2 The Ecotoxicity Reference Laboratory functions as a core organization for the standardization of ecotoxicity testing, both domestically and internationally.

2. Environmental Risk Assessment Task Office

The Environmental Risk Assessment Task Office promotes research to support assessment and management of the risks posed by environmentally released anthropogenic chemicals. It also provides risk-related information to the government and the public. The Office collects a variety of information on the chemicals and assesses their environmental risks to help with the risk assessment activities conducted under the laws enacted by MOE. Our activities are outlined in Figure 3.



QSAR: Quantitative structure-activity relationship; MOE: Ministry of the Environment

Fig. 3 Activities and research projects of the Environmental Risk Assessment Task Office

Under the revised Chemical Substances Control Act, all chemical substances, which include existing chemicals but exclude chemicals subject to other laws (such as medicines and agrochemicals), must be screened to determine whether they need more detailed risk assessment (such as Risk Assessment I, II, and III under the Act). The Task Office supports the implementation of both the screening assessments and the detailed assessments. In FY 2019, as part of the screening assessments, we evaluated the credibility of hazard-ranking classification of 52 chemicals in terms of the hazards to the aquatic environment. We also collected and evaluated information on hazards to the aquatic environment of 18 chemicals under Risk Assessments I and II as part of the detailed assessments. Every year, MOE publishes an “Initial Environmental Risk Assessment of Chemicals.” In FY 2019, the Task Office supported the initial ecological risk assessment of 15 chemicals. To support the standards for registration of agricultural chemicals on the basis of the Agricultural Chemicals Regulation Law, information on the toxicity to the aquatic environment of 15 substances was collected, and the credibility of the toxicity information was evaluated.

We have been improving the Kashinhou Tool for Ecotoxicity (KATE) system for use in quantitative structure–activity relationship (QSAR) models. In February 2020, we released KATE 2020 (https://kate.nies.go.jp/), which is the updated version of KATE 2017 on NET. We have been continually updating our chemical substance databases and have renovated the related website, Webkis-Plus, in Japanese. Webkis-Plus contains information on about 10,000 substances, including their physicochemical properties; laws and regulations related to environmental pollution; environmental concentrations from surveys performed by MOE; amounts of chemical substances manufactured and imported; volumes of agricultural chemicals shipped into each prefecture; Pollutant Release and Transfer Register information; the results of risk assessments performed by several organizations; and details about the analytical methods developed by MOE for environmental surveys in Japan.

Environmental Emergency Management Office

Through research collaboration with the relevant organizations in Japan, this office implements projects aimed at supporting effective and efficient environmental emergency management by emergency response personnel. This includes building and operating institutional and information network systems that serve as a foundation for developing environmental emergency management strategies; training personnel to develop practical expertise in environmental emergency management; providing on-site support for disaster responses; setting up research hubs for environmental emergency management; and training researchers.

More specifically, this office is establishing a new platform for enabling domestic institutions to cooperate in collecting and organizing the experiences and lessons gained from tackling environmental issues caused by past disasters, and in efficiently and effectively organizing new knowledge derived from environmental emergency management research. The office will focus in particular on the smooth management and operation of the central government's Disaster Waste Treatment Support Network (D.Waste-Net), and on building emergency environment monitoring systems centered on regional environmental research institutions.

This year, we have especially made a great effort to establish a system of contributing to efficient and effective disaster waste management. Below are the main results of our efforts.

1. Provision of on-site support for disaster responses in the 2019 East Japan Typhoon disaster

Typhoon Hagibis, which hit parts of Eastern Japan in October 2019, caused extensive damage in areas of Nagano, Fukushima, and Miyagi prefectures. The amount of disaster waste in Nagano prefecture alone was estimated at nearly 266,000 t. An example of the support given by the office was advice on:

a) how to separate many kinds of waste at temporary storage sites (Fig. 1), and
b) estimating disaster waste amounts and planning for implementing disaster waste management.

Fig. 1 Onsite support at a temporary storage site in Nagano after typhoon Hagibis

2. Supporting the capacity-development projects of local governments

Human resources are key to properly enhancing our potential to manage disaster waste in real, unexpected disaster situations. Our office provides practical support to local governments when they design training programs aimed at developing practical expertise for disaster waste management. This year we provided support to Miyazaki, Mie, Shizuoka, Aichi, and Niigata prefectures, Tokyo metropolitan government, and Sakai city. In addition, we held a training program in the city of Kurashiki, where the treatment and disposal of disaster wastes from the July 2018 heavy rain disaster is still ongoing. The aim of this training program was to help officers from the prefectural government to i) gain knowledge and a mental picture of disaster waste management operations and b) revise their disaster waste management plan. The results of the questionnaire survey undertaken after the training program showed that the program was effective in terms of gaining knowledge and mental pictures, but improvement is needed to link this knowledge to the revision of disaster waste management plans.

3. Data collection and implementation of a disaster waste information platform

Data on the operations of temporary storage sites after two heavy rain disasters in 2018 were collected. These data were uses as references for the onsite support provided after the 2019 East Japan Typhoon.

We also improved our online information platform on disaster waste management to help local authorities further enhance their disaster waste management skills. A short video clip explaining the importance of resource management in disaster waste management projects was made and released (Fig. 2). In addition, we updated our online database of the disaster waste management plans prepared by local governments. Other information updated on the platform included:

a) lessons and strategies learned from central and local government responses to past disasters,
b) technical and managerial notes for disaster waste management projects, and
c) reports of experiences and methods regarding preparedness planning and capacity development for disaster waste management.

Fig. 2 Screen shots from a video clip about the importance of resource management in disaster waste management projects

Social Dialogue and Co-production Office

1. About

The Social Dialogue and Co-Production Office (DaC) is an organization serving all departments of NIES (Fig.1). It facilitates communication between various stakeholders in society and our institute to promote dialogue and co-production on environmental issues and environmental research.

Our mission statement is as follows:

We will engage in dialogue and co-production in order to protect the environment and realize a sustainable society.

- We will respect diverse views and opinions in society and will learn from the public's voices to tackle environmental issues with them.
- We will disseminate the value of dialogue and co-production and support such activities by sharing the experience and the joy gained through them.
- We will create a relationship of mutual trust between NIES and society.

For example, we provide feedback from the voices of society to our research activities by providing opportunities for dialogue, such as stakeholder meetings and science cafés. We also provide opportunities for dialogue via social media and online contents according the needs of society. Furthermore, we organize and run in-house interview sessions and workshops to collect and analyze the existing experiences of members of NIES. The outcomes are published internally as guidelines.

Through these activities, we aim to improve our ability to engage in dialogue, to help build a relationship of mutual trust with society, and to receive more approval from society for the research we undertake.

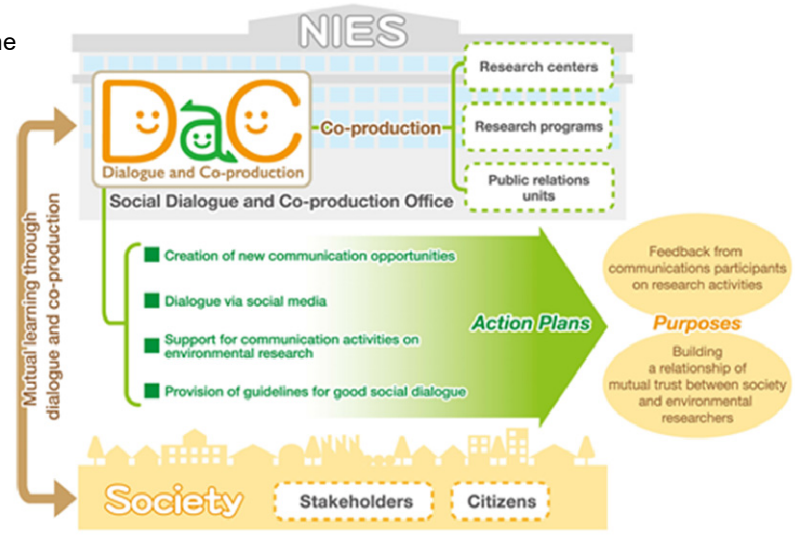


Fig. 1 DaC and its action plans within the NIES structure

2. Highlights of our activities in FY 2019

2.1 Creating opportunities for dialogue

Some of our new challenges have included producing and supporting online dialogue events by using social media platforms such as YouTube, Twitter Live, and Niconico Live (a Japanese video-sharing platform) (Fig.2). Early in FY 2019, in response to public interest, we hosted a variety of face-to-face dialogue events, including a seminar about global warming and a science café discussing plastic waste problems.

Fig. 2 DaC broadcasted three YouTube Live videos on global warming.

2.2 Social media and web site

The number of our followers on Twitter has been steadily increasing since we opened the account in 2017. Through social listening utilizing social media, we

have been able to publish information and content answering the needs of the public. For instance, our scientific tweet responding to rising public interest in the 2019 Amazon rainforest wildfires received a great response. Also, DaC's website has been updated to accommodate users of smartphones (Fig.3).

Fig. 3 DaC's new websites for PCs (left) and smartphones (right)

2.3 Supporting dialogue within NIES

DaC supported other sections within NIES to organize dialogue events, such as a stakeholder meeting and a discussion session about the climate crisis. We also invited an environmental cartoonist as a lecturer and held a lecture for NIES staff members in regard to dialogue on environmental issues.

3. Future outlook

We intend to consider how the voices of society obtained through dialogue can be fed back to our research activities. We will continue to use social media because it is an effective tool for reaching out to younger generations and those who are not necessarily interested in environmental problems. It is also important to enforce our work on co-production. We will try to gather existing experiences on co-production within NIES's research activities and will continue examining the roles that DaC can take in these co-production activities.

Center for Climate Change Adaptation

Center for Climate Change Adaptation

Under the Climate Change Adaptation Act enforced in December 2018, NIES is the core information platform for climate change adaptation in Japan. NIES established the Center for Climate Change Adaptation in the same month. It is tasked with collecting, organizing, analyzing, and providing information on the impacts of climate change and climate change adaptation, as well as supporting local governments and Local Climate Change Adaptation Centers (LCCACs) by providing technical advice for efforts on climate change adaptation (Fig. 1). Some of the activities of the Center in FY 2019 are described below.

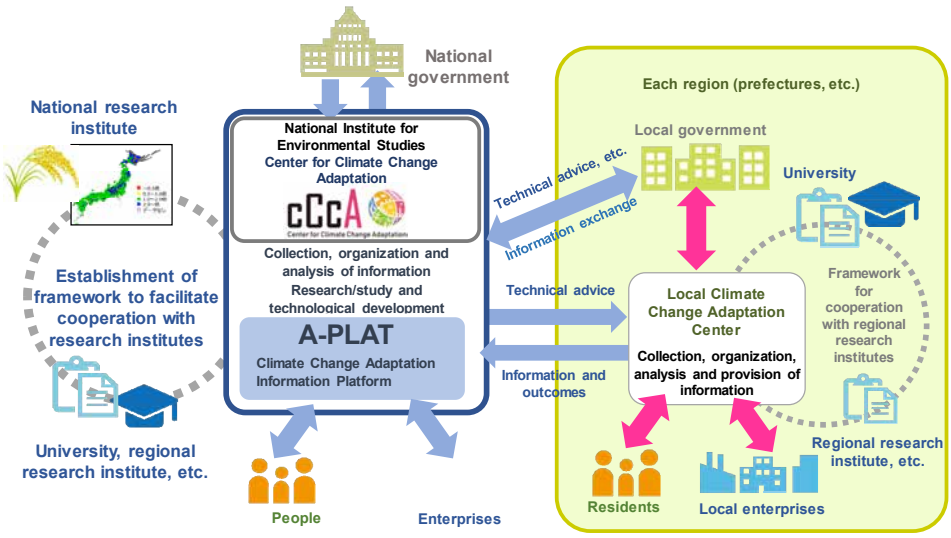


Fig. 1 Role of the Center for Climate Change Adaptation

1. Promotion of climate change adaptation

1.1 Technical support for local public bodies

Questionnaires were distributed and discussion meetings were held with staff of local governments and LCCACs to identify their needs for technical help. On the basis of the needs that were identified, we considered our support strategies and expressed them as NIES support measures. They include providing technical advice, sending experts, building regional capacity, enhancing regional scientific knowledge, and constructing networks among regions; any of these measures can be applied, depending on the specific circumstances.

As support measures, we:

- gave lectures to about 2300 local government staff, regional company employees, and local residents at regional meetings and study sessions to provide information on climate change adaptation
- participated in meetings of examination committees of LCCACs and other regional groups to provide scientific advice

- helped promote regional climate change adaptation policies by providing scientific advice, figures, and tables to be used in Local Climate Change Adaptation Plans, brochures, and websites developed by local public bodies
- participated as advisors to the seven Climate Change Adaptation Regional Councils organized by the Regional Environment Office of the Ministry of the Environment (MOE) under the Climate Change Adaptation Act, and contributed to inter-regional cooperation with local governments.

In addition, the following projects were implemented to contribute to regional capacity building related to climate change:

- A workshop was held in August 2019 and a discussion meeting was held in November 2019 (Fig. 2) with the aim of sharing knowledge with local administrators to formulate regional climate change adaptation policies.
- The All-Japan Environmental Research Institutions Symposium was held in February 2020 with the theme of climate change adaptation, and related research was shared with regional environmental research institutes.
- In August 2019, NIES, with MOE, organized the "Second Workshop on Promoting Climate Change Adaptation by the Private Sector." Companies, local administrators, and researchers attended the workshop to deepen their understanding and accelerate the private sector's adaptation activities.

Fig. 2 At the workshop in August 2019 and discussion meeting in December 2019

1.2 Collecting, organizing, analyzing, and providing information related to climate change adaptation

NIES operates the Climate Change Adaptation Information Platform (A-PLAT), a portal site for disseminating information on adaptation to the impacts of climate change. To disseminate more useful information on climate change adaptation to stakeholders such as governments, local public bodies, researchers, private companies, and individuals, we revised A-PLAT to improve user accessibility and expand the contents (Fig. 3).

To improve A-PLAT, we implemented the following:

- By collaborating with the Japan Meteorological Agency, we included the outcomes of "Global Warming Projection Vol. 9" in the WebGIS (https://a-plat.nies.go.jp/webgis/index.html), and we created graphs of weather observation data that can be viewed by region.
- In line with the enforcement of the Climate Change Adaptation Act, in addition to posting related provisions such as the Climate Change Adaptation Plan and the Local Climate Change Adaptation Planning Manual, we established a new web page on Local Climate Change Adaptation Plans and LCCACs.
- Articles were added to introduce the topic of adaptation planning efforts and highlight examples of adaptation measures.
- An Adaptation Measures Database was created to introduce examples of adaptation measures for reference use by local governments.
- We added cases reports on Adaptation Business and Climate Risk Management to introduce adaptation efforts by private companies.
- To educate the general public about adaptation, we created a webpage on the current and future impacts of climate change and various adaptation measures.

The number of views of the Japanese pages of A-PLAT reached approximately 630,000 in 2019; the number of annual visitors has increased each year since the platform was launched. In addition, information on A-PLAT is being utilized in regional climate change policy-making. For example, information provided in A-PLAT is quoted in many Local Climate Change Adaptation Plans, brochures, and websites formulated by local public bodies.

Fig. 3 Home page of the A-PLAT website (https://www.adaptation-platform.nies.go.jp/)

1.3 International contributions to the development of an information platform for the Asia-Pacific region

In accordance with the Paris Agreement, to support adaptation planning for developing countries, we developed a prototype version of the "Asia-Pacific Adaptation Information Platform" (AP-PLAT). The platform was introduced at COP23 (the 23rd annual Conference of the Parties to the 1992 UN Framework Convention on Climate Change) and included impact assessment data and information related to adaptation (Fig. 4). Having the opportunity to hold the G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth, in Karuizawa, Nagano, MOE officially launched AP-PLAT and held the AP-PLAT Launching Ceremony on 16 June 2019.

We presented an update of our activities to the UN Adaptation Committee at COP25 in Madrid on 11 December 2019 and at the Asia Pacific Climate Week in Bangkok on 5 September 2019.

To support the establishment of a platform that summarizes climate risk information in Asia-Pacific countries, we visited Thailand in October 2019 to conduct Web-GIS technical training for T-PLAT (the Thailand Adaptation Information Platform). In addition, we exchanged information with relevant global platform organizations, including those from Asian countries, in November 2019.

Fig. 4 Home page of the AP-PLAT website (https://ap-plat.nies.go.jp/index.html)

1.4 Contribution to climate change policy

We managed a Study Team to Promote Climate Change Impact Observation and Monitoring and a Study Team to Collaborate and Promote Climate Change Projection and Impact Assessment, each of which comprises a group of experts contracted by MOE for relevant projects. The first study team produced a report

titled “Direction of Strategic Observations and Monitoring for Climate Change Impacts,” which described the direction of sectoral issues and solutions for climate change impacts, and the second produced “Future Approaches to the Link Between Climate Change Projections and Impact Assessment,” which organized issues and approaches to impact assessment. These two reports were presented to the 19th Climate Change Impact Assessment Subcommittee under a meeting of the Global Environment Committee of the Central Environment Council, held in March 2020. The reports were used as references for climate change policy-making.

Center staff members participated in deliberative councils and investigative conferences, such as Assessment Subcommittees of the Central Environment Council, noted above, and helped to promote climate change policy.

2. Climate change impact and adaptation research

We consolidated research into climate change impacts and adaptation. We also organized research programs to advance climate change adaptation research and development in an integrated manner and support climate change adaptation activities by national and regional governments. The program consists of the three research projects; these are outlined in Figure 5 and discussed below.

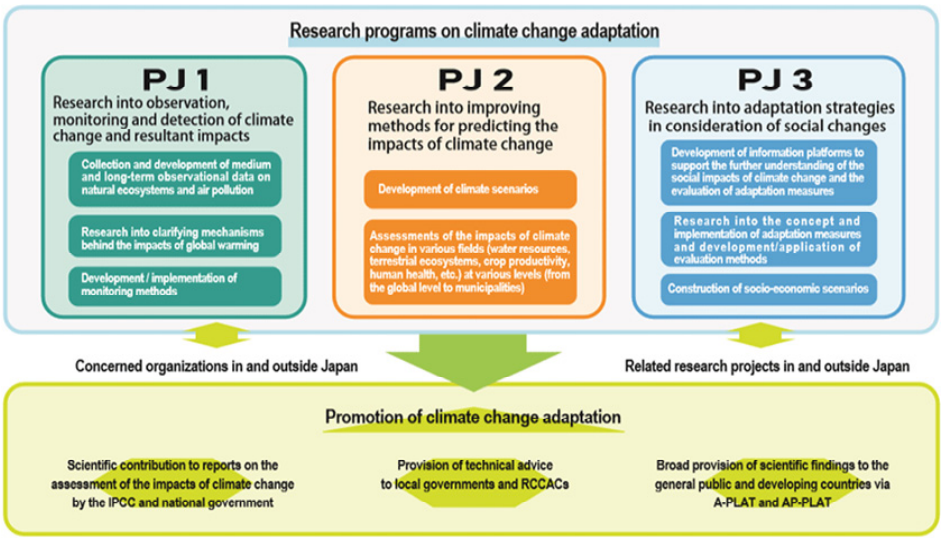


Fig. 5 Structure of our research projects

2.1 Observation, monitoring, and detection of climate change and resultant impacts (PJ1)

Project 1 has started collecting long-term monitoring data on ecosystems (terrestrial ecosystems, coastal-area/enclosed-sea ecosystems, marine ecosystems, coastal ecosystems, and lake/watershed ecosystems), as well as data on associated meteorological factors (e.g., air temperature, precipitation, wind velocity, and

humidity). The aim is to detect and clarify the effects of climate change on ecosystems.

For example, in the case of terrestrial and coastal ecosystems, surveys of published reports were conducted to list global warming impacts on ecosystems and to collect and digitize previously collected information on the distribution of plants and corals.

2.2 Enhancing methods for predicting the impacts of climate change (PJ2)

We worked on seven sub-projects to conduct climate change impact assessments at multiple scales (e.g. global, Asia-Pacific region, Japan, and local government) and across multiple sectors (e.g. water resources, ecosystems, crop yields, and human heath). To conduct cross-sectoral climate change impact assessments, we need reliable climate scenarios. We developed a set of new climate scenarios covering all of Japan at a spatial resolution of 1 km by statistically downscaling six global climate models with the aid of the latest technique termed Cumulative Distribution Function-based Downscaling Method (CDFDM). We also launched a new server to distribute various climate scenarios to a wider range of users.

2.3 Adaptation strategies in consideration of social changes (PJ3)

Project 3 consists of eight research themes with common ultimate objectives, namely (1) understanding the gaps that exist among adaptation planning, scientific knowledge, and adaptation implementation; and (2) exploring effective adaptation strategies for filling the gaps.

For example, in the research theme called “Development of indicators of a regional cycle symbiotic zone to support adaptation planning,” we developed a method for integrated assessment of the impact of climate change on communities from the perspective of residents. The questionnaire survey results revealed the preferences of individuals for certain indices. For example, agriculture, forestry, and fisheries workers placed high weightings on the natural environment, heavy rains, and other climate-related factors. We used these weightings to estimate the integrated value for quality of life (QOL) in municipalities nationwide. We built a basic framework to assess the impacts of climate change, the effects of adaptation measures, and resident-level outcomes considering impact chains and QOL indicators. By using this framework and interactive tools such as workshops with local stakeholders, we can support local government to establish and implement new local adaptation plans.

Basis for Environmental Research

Center for Global Environmental Research

Global environmental change is an essential threat to a sustainable society and human life. Climate change, including global warming caused by increasing atmospheric greenhouse gas (GHG) concentrations, together with changes in the stratospheric ozone, is having serious impacts on all ecosystems and on humans. Considering the predicted impacts, it is urgent that we take measures to conserve the global environment so as to establish a sustainable society with lower emissions of GHGs. We must adopt a long-term perspective and recognize the importance of mid- and long-term continuous research, because a lot of time is needed for the effects of climate change mitigation options to manifest.

The Center for Global Environmental Research (CGER) conducts strategic environmental monitoring across the atmospheric, oceanic, and terrestrial domains and distributes the resulting data through environmental databases to assess climate change and its impacts on society. CGER also implements proactive and predictive research on the global environment, develops new technologies, and conducts pioneering and fundamental research, especially in the field of climate change. CGER supports collaborative studies among domestic and international organizations, disseminates the scientific findings, and facilitates mutual understanding to raise public awareness of global environmental problems.

1. NIES Voluntary Observing Ships program and contribution to the Global Carbon Project

The ocean plays an important role as one of the largest sinks of CO_2 from the atmosphere, where CO_2 concentrations have been increasing. Because the ocean-surface CO_2 partial pressure (pCO_2) changes dramatically in time and space, an understanding of the temporal and spatial variations of pCO_2 and air–sea CO_2 exchange is important for estimating future natural sinks of CO_2; these sinks could be important in the mitigation needed to ensure safe levels of stabilization of atmospheric CO_2.

As pCO_2 can be measured only by direct observations (e.g. from buoys or ships), global observation has been encouraged by the international research community. As part of its contribution to the international oceanic research network, NIES has been observing the pCO_2 for over 20 years in the North Pacific and

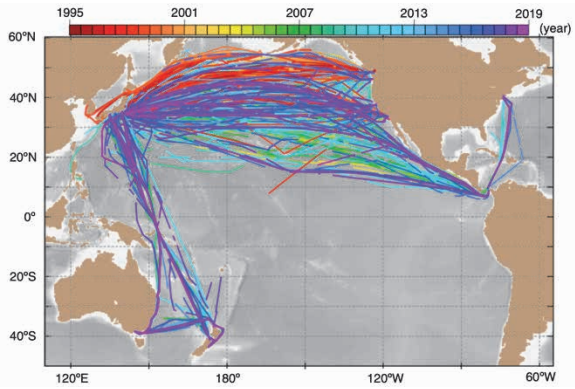


Fig. 1 Composite cruise tracks of NIES Voluntary Observing Ships. The color of each track represents the year of observation.

Western Pacific by using several commercial cargo ships. The ships have sailed regularly at intervals of about 4 to 8 weeks between Japan and North America or Oceania throughout the year (Fig. 1), and observation data have been collected successfully.

By sharing these data with the international research community through a pCO_2 database named Surface Ocean CO_2 Atlas (SOCAT; https://socat.info), NIES has helped to evaluate global air–sea CO_2 exchange as part of annual reports of the Global Carbon Budget (e.g. Friedlingstein et al. 2019). A plot of temporal variations in CO_2 uptake in the Global Ocean clearly shows that oceanic CO_2 uptake gradually increased from less than 1 GtC year^{-1} in the 1960s to approximately 2.5 GtC year^{-1} in 2010s (Fig. 2). Moreover, the figure shows that the difference between the mean ocean CO_2 uptake among all the estimates, including those from ocean biogeochemical models (black line), and the pCO_2-observation-based estimates (light blue lines) has gradually increased since 2010. This suggests the need to improve oceanic biogeochemical models and the importance of monitoring oceanic carbon cycles in the future.

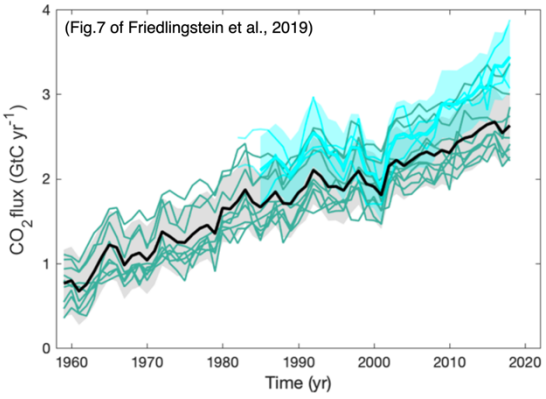


Fig. 2
Temporal variations in the estimated ocean CO_2 uptake, showing the mean budget values (black; with ±1σ uncertainty in gray shading), individual ocean models (teal), and three pCO_2 observation-based flux products (light blue; with ±1σ uncertainty in light blue shading.

Reference

Friedlingstein et al. (2019) Global Carbon Budget 2019, *Earth Syst Sci Data.* 11, 1783–1838 (doi: 10.5194/essd-11-1783-2019)

2. Impact of inland water on the global carbon cycle

The advanced process-based model, National Integrated Catchment-based Ecohydrology (NICE)–Biogeochemical Cycle (BGC), which incorporates the whole process of carbon cycling in land, was modified to include the feedback between soil organic content and overland carbon fluxes. Robustly evaluating the balance of the terrestrial carbon budget, including the effect of inland water, is a crucial and difficult task. To perform this task, NICE-BGC was used to quantify the global biogeochemical carbon cycle closely associated with the complex hydrological cycle during the 36 years from 1980 to 2015. The model demonstrated that inter-annual variations in the carbon cycle have been greatly affected by extreme weather patterns. We analyzed the spatial distribution of temporal trends in riverine carbon fluxes and their relationship to soil organic carbon (SOC) between different biomes and major river basins. Although there was a positive relationship between SOC and the riverine flux of dissolved organic carbon and particulate organic carbon in the northern boreal region, it was difficult to see this relationship in other regions. Furthermore, our evaluation of

the factors potentially controlling temporal trends in SOC and fluvial carbon exports helped to quantify the inter-annual variations or temporal trends caused by the various factors, such as CO_2 concentration, temperature, and precipitation. SOC was influenced more by temperature variations, whereas riverine carbon exports were determined mainly by precipitation variations. Finally, the net ecosystem exchange (NEE) calculated by including inland water (−1.49 ± 0.50 PgC year^{-1}) revealed a slight decrease in the carbon sink in comparison with previous values (−2.33 ± 0.50 PgC year^{-1}) (Fig. 3). These results help us to distinguish the carbon cycles in different river basins and to reevaluate carbon cycle changes explicitly including the effect of inland water, because this effect has been so far implicitly included within the range of uncertainty in the Earth's global carbon cycle comprising land, oceans, and the atmosphere.

Reference:

Nakayama T. (2020) Inter-annual simulation of global carbon cycle variations in a terrestrial-aquatic continuum. *Hydrol Process.* 34(3): 662–678 (doi:10.1002/hyp.13616)

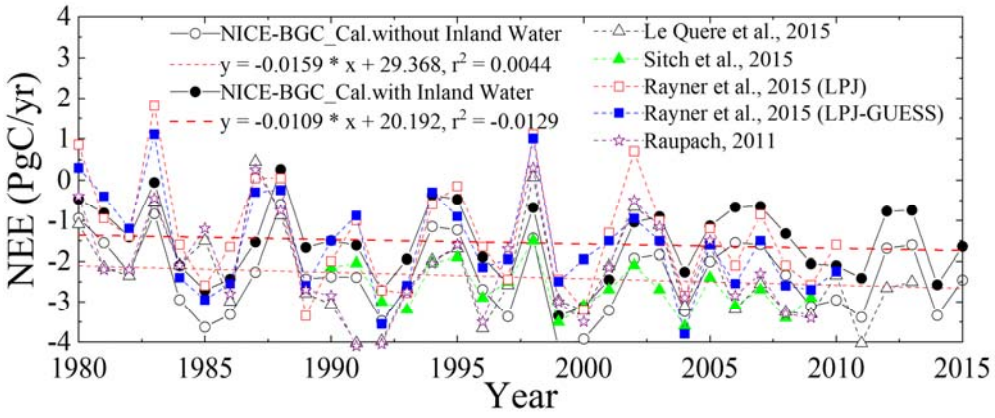


Fig. 3 Global trends in annual-averaged net ecosystem exchange (NEE) in terrestrial ecosystems, as estimated by NICE-BGC. Red dotted lines show linear regressions of the simulated values (clear and solid circles). A positive value means a carbon source, and a negative value means a carbon sink. NEEs simulated by NICE-BGC both with and without consideration of the effects of inland water bodies are plotted (reprinted from Nakayama 2020).

Center for Material Cycles and Waste Management Research

The Center for Material Cycles and Waste Management Research conducts a variety of studies to establish a political and academic base in the fields of materials cycling and waste (Fig. 1). Currently our focus is the present state of, and mechanisms behind, the structure of material flows and the associated environmental burdens imposed by socioeconomic activities at local to international scales.

We intend to propose assessment methods and strategies for shifting to a sustainable, sound material-cycle society. We are also evaluating technologies and systems for treating and recycling waste and recyclable materials in Japan and other countries, and we are developing fundamental technologies for materials recycling and substance control in waste treatment and recycling processes.

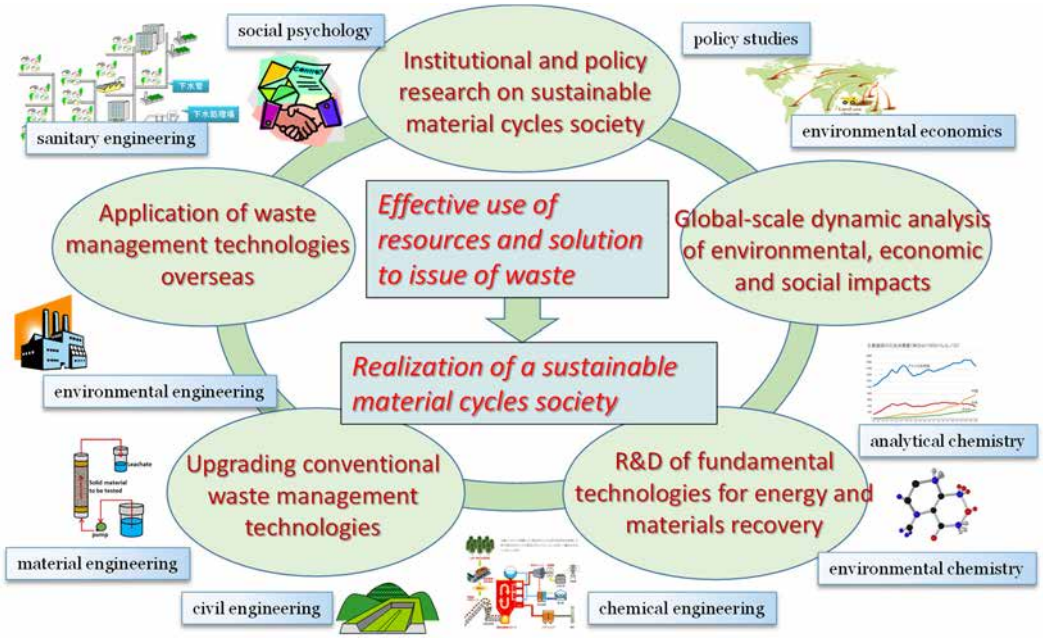


Fig. 1 Outline of fundamental research into material cycles and waste management

1. Institutional and policy research on systems and measures for shaping a sound material-cycle society

In our research on extended producer responsibility (EPR) this year, we analyzed the discourses of EPR experts and practitioners in Japan. Our categorization of the discourses by using two axes— final goal ambition and policy intervention preference—indicated that there were at least six positions for EPR policy. In our previous study using a questionnaire, we found that there were various perceptions of the concept of EPR, and this caused miscommunication of EPR policy. We now understand the origins of these various perceptions. In specific policy dialogues about EPR, the two axes will need to be clarified before concrete discussion begins.

In our research on pro-environmental behavior, we analyzed the influence of e-commerce reuse experience on consumers' clothing disposal behavior. The results revealed that e-commerce reuse experience promoted the utilization of conventional reuse routes such as second-hand stores. Interaction between online and offline could be a driver of change in people's behaviors, and such interactions are likely to occur more frequently in the near future. Attention should be placed on these interactions in behavioral studies. In another study, we analyzed the factors influencing collective pro-environmental behavior, targeting Japanese aged 20 to 69 years. We found that behavioral intention toward collective pro-environmental behavior was particularly low in people in their 20s and 30s. This might be a trait of the next, younger generations of Japanese, or it might be associated with the current social situation of this age group in Japan. More studies are needed.

We also furthered our studies of sustainable consumption and lifestyles in Asia. We held a stakeholder workshop in Bangkok to discuss energy-reduction policies in Thailand, because the energy consumption of air-conditioning in Thailand is projected to increase markedly this century. A variety of policies were suggested by Thai stakeholders; they were almost the same as those implemented in Japan and other developed countries and included energy labeling of air-conditioners and the education and provision of information to consumers. However, many Thai stakeholders emphasized the importance of policy implementation, and this was the most important message to non-Thai policy collaborators who engage in environmental policy in Thailand. In another study, we developed a co-design method to generate ideas on consumption and production patterns and policies together with external research collaborators.

2. Dynamic analysis of international material cycles and assessment of their environmental, economic, and social impacts

We examined the effects of product price increases on metal consumption, greenhouse gas (GHG) emissions, and product sales via changes in the product replacement decisions of consumers. A dynamic discrete choice model was applied to air-conditioners in Japan to determine these effects when product price was increased by between 5% and 30% in 5% increments. To illustrate, a 5% increase in the price of air-conditioners was shown to reduce the consumption of iron by 6000 t, copper by 1000 t, and aluminum by 2000 t, with an increase in GHG emissions of 506 kt-CO_2 eq and a decrease in product sales of 56 billion Japanese yen from 2005 to 2013. Thus, product price increases for air-conditioners led to a reduction in material consumption and a decrease in product sales, while the effect on GHG emissions depended on the level of the product price increase. These interactions suggest that consumers will use products longer, provided that the value of the product's enhanced durability and longevity matches the increased price of the product. Efforts to improve product durability and longevity, however, will require air-conditioning companies to explore new business models

in order to cope with the anticipated decrease in product sales as the transition to a circular economy continues.

We calculated the carbon footprint of Japanese healthcare services (i.e., the domestic GHG emissions caused by healthcare expenditure, including the associated fixed capital) by using an input–output analysis. In 2011 the total carbon footprint of these services was 62.5×10^6 $MtCO_2e$, representing 4.6% of total domestic GHG emissions. Medical services involving hospitalization accounted for the greatest share, at 15.7 $MtCO_2e$. The second-highest category, medical services without hospitalization, accounted for only slightly less, at 14.2 $MtCO_2e$. However, the difference in emissions per patient between these two categories was considerable. On average, emissions per patient for medical services (hospitalization) were 12 tCO_2e/patient, whereas for medical services (non-hospitalization) they were only 2.1 tCO_2e/patient, which is about 5.4 times less. In terms of the type of medical condition, the greatest annual emissions were associated with cardiovascular disease (6.2 $MtCO_2e$) and neoplasms (4.0 $MtCO_2e$). In terms of age, emissions attributed to patients aged 65 and over accounted for more than half of all healthcare emissions. By 2015, the total carbon footprint had increased to 72.0 $MtCO_2e$—a rise of over 15% in 4 years. Although medical care and pharmaceuticals are the main factors responsible for this increase, emissions associated with nursing services have also risen, suggesting that demographic aging may be having a marked impact on GHG emissions. As a countermeasure, the potential annual GHG mitigation achievable by avoiding the generation of unused prescribed medicines resulting in waste was estimated at 1.24 $MtCO_2e$—comparable with the total carbon footprint of home medicines. To safeguard planetary health, in addition to making technological improvements to the supply chains of healthcare services, we need to give the public additional options for improving their health and mitigating GHG emissions simultaneously.

3. Developmental and survey research on various types of fundamental technologies required for resource recycling and materials management

We have been using artificial sweat and sebum to develop a method of assessing dermal exposure to flame retardants, heavy metals, and dioxin-like compounds in indoor dust and recycled materials from e-waste.

To help promote environmentally sound management of waste containing new persistent organic pollutants (POPs), we performed an international inter-laboratory study to quantify the brominated flame retardants listed among the POPs in the Stockholm Convention (so-called POP-BFRs) in plastic waste. At the same time, we used public documents to survey the conditions of POP-BFR waste management in other countries.

We developed a practical mass spectrometric method to quantify short- (SCCPs)

and medium-chain chlorinated paraffins (MCCPs) and investigated SCCP and MCCP concentrations in polyvinyl-chloride-based consumer products on the Japanese market. In addition, we used both active and passive air-sampling methods to investigate the emissions of SCCPs, MCCPs, and organophosphorus flame retardants (OPFRs) from automobile shredder-residue-processing (ASR) facilities.

Moreover, we have been applying a factory-fate model that we developed last year to ASR facilities to gain an understanding of the behavior of SCCPs, MCCPs, and OPFRs in the facilities and suggest measures for reducing their emissions to the environment. This model requires data on the volatilization flux of these compounds from waste material. Therefore, we first measured the flux of SCCPs and MCCPs from a plastic sheet by using the microchamber method.

4. Advancement of testing and evaluation management systems related to landfill disposal and the use of waste as construction materials

During the development of a method for determining the sources of heavy metal pollutants in soil, we confirmed the method's applicability to marine sediments by using titanium as a reference element. We also examined the method's applicability to land-based sediments.

By applying a liquid-solid ratio-change test to waste incineration ash, we confirmed that parameters such as the partition coefficient could be derived more accurately by keeping the pH within a certain range.

A column percolation test method that we have been developing and upgrading was announced as an official ISO standard in September 2019.

To elucidate the water balance in an inland water pond, we performed a laboratory experiment—a tracer test using holmium chelate—and adapted the test for use in the field. The usefulness of holmium as a tracer was verified.

We also conducted a questionnaire survey on the problems experienced by waste landfill sites in the event of a heavy rain disaster, and we identified points to be noted in regard to structural standards at landfills.

5. Fundamental research into the application of waste management technologies in Japan and overseas

We are studying fundamental technological issues associated with the improvement of waste management systems in Japan and Asia. In FY 2019, our studies included the following.

We analyzed the relationship between disposal costs and transportation distances for several items of industrial waste. We showed that the geographic flow of industrial waste, by item, can be explained by the nature of the waste, the demand for it as a resource, and the locations of facilities such as treatment and disposal facilities.

In light of the downward trend in the number of household members, to promote the effective operation of *johkasou*—a household wastewater-treatment system—we constructed a bench-scale reactor and began experimental investigations using real sewage.

The effects of organic fractions on water retention and stickiness were evaluated and theorized, and the effects of organic fractions on the efficiency of waste treatments such as aeration and sorting were also evaluated.

For construction and demolition waste generated in Hanoi, we calculated the source units for each type of construction and floor area, by composition, to estimate waste generation. In addition, we optimized the waste composition evaluation method by using image analysis.

We confirmed that sulfur-oxidizing bacteria accelerated the deterioration of the products of sulfur polymer stabilization/solidification of elemental mercury and caused the volatilization of mercury.

We performed a continuous experimental anaerobic biofilm treatment of highly saline organic wastewater by using iron-modified biochar from agricultural residue to promote biofilm formation. The addition of iron-modified biochar resulted in a high methane production rate of about 20% and an increase in biofilm formation.

6. Waste management research collaboration and research into practice projects with Asian countries

We conducted a study of solid waste management in drains and waterways for flood prevention in urban Asia. Waste management in low-income communities along Bangkok's waterways was studied in collaboration with Thammasat University as an action research project. Factors that contribute to the unintentional dropping of waste into waterways such as canals were identified. Measures to counter problems with land-based waste collection systems and to encourage community engagement were proposed to local government (Fig. 2).

We participated in both ISO TC297 (Waste Collection and Transportation Management) and TC300 (Solid Recovered Fuels) technical committees. We chaired, and provided advice to, Japanese mirror committees based on our expertise, and we proposed new standards and led discussions on their

standardization processes at ISO committees. In addition, we shared our knowledge of standardization with emerging Asian countries.

A comparative analysis of decentralized wastewater management within the ASEAN region was initiated by examining the technology and institutional systems in each member country. The composition of construction and demolition waste in Vietnam was examined as a JICA (Japan International Cooperation Agency)/JST (Japan Science and Technology Agency) SATREPS (Science and Technology Research Partnership for Sustainable Development) study, and a paper on the laws, regulations, and systems for construction waste in Asian countries was published.

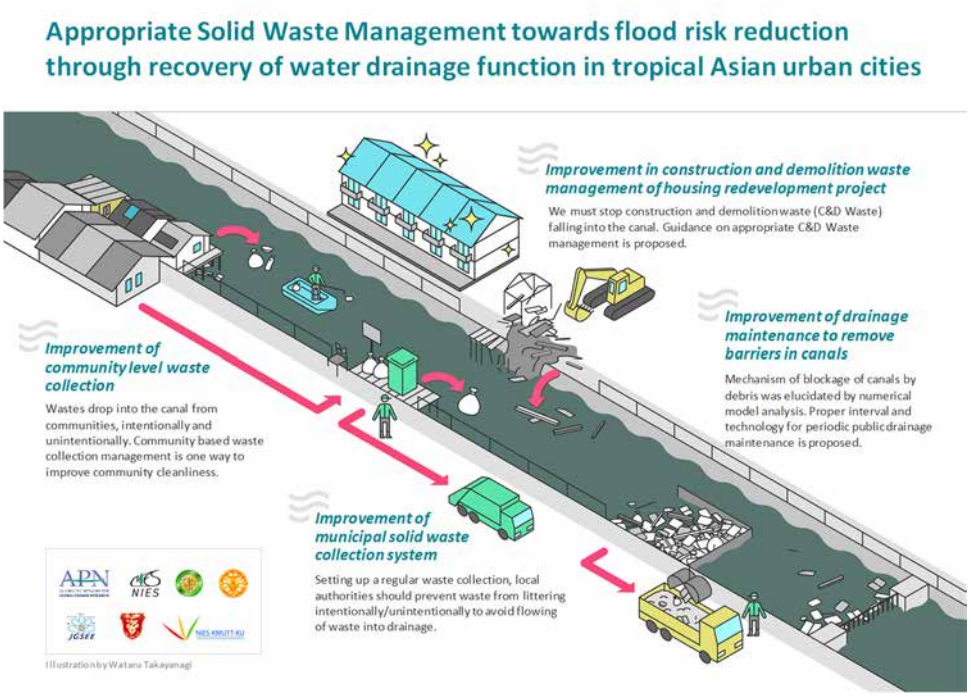


Fig. 2 Outline of policy recommendations to the Bangkok local government for the appropriate management of solid waste in drains and waterways in urban areas

Center for Health and Environmental Risk Research

The Center for Health and Environmental Risk Research conducts research in the Environmental Risk Research Field and Environmental Health Research Field. The two research fields form the basis of two projects administered by the Risk Assessment Science Collaboration Office (RASCO) and the Japan Environment and Children's Study (JECS). The Center leads the Health and Environmental Safety Research Program with other research centers. Here, we report the current outcomes of research in the environmental risk and environmental health research fields.

1. Upgrade of ecotoxicity testing and development of a novel system to evaluate the ecotoxicological effects of chemicals

In collaboration with the quantitative structure–activity relationship (QSAR) research team at the University of Gdansk, Poland, we continued to develop ecotoxicity prediction models by using a category approach with k-nearest neighbor (k-NN) algorithms and various quantum chemistry parameters. The causal relationship between the decline of dragonfly species and the increased application of systemic insecticides to nursery boxes was investigated in a paddy field in north–central Japan.

To improve the ecological risk assessment of pesticides, we conducted acute toxicity tests of two pesticides and their metabolites by using a green alga (*Raphidocelis subcapitata*), a daphnid (*Daphnia magna*), and Japanese medaka (*Oryzias latipes*). During the tests we monitored the concentrations of pesticide metabolites. We also conducted short-term chronic toxicity tests in green alga, daphnid (*Ceriodaphnia dubia*), and zebrafish (*Danio rerio*) embryos for seven selected human pharmaceuticals. The toxicity values were compared with the QSAR predictions in collaboration with National Institute of Health Sciences under the Ministry of Health, Labour, and Welfare.

2. Fundamental study of integrated approaches to assessing chemical exposure and environmental effects

We are comprehensively analyzing the relationship between chemical exposure and effects on humans and organisms by investigating PM2.5 (particles with a diameter of 2.5 μm or less) and their carcinogen-related activities (i.e., DNA damage). This fiscal year, we examined the additivity of DNA damage when various PM2.5 samples were mixed. The additivity was evaluated by mixing samples such as PM2.5 collected at various sampling points, diesel exhaust produced experimentally, and PM2.5 extract produced secondarily from volatile organic compounds. Moreover, we developed a small PM2.5 sensor as a tool for measuring personal exposure to PM2.5. More specifically, we modified a commercially available small sensor by adding a GPS receiver and a data logger

unit to it and created a device that does not require a smartphone and can be connected to a battery to take measurements for a long time. We conducted field measurements with this device in the city of Yangon and confirmed that the per-second PM2.5 exposure level could be measured continuously for 24 h. In addition to these ongoing research activities, we have initiated a study on the development of sediment toxicity assay methods. As a starting point, we have demonstrated in detail the mass distributions of hydrophobic organic chemicals in the assay system. We also started to evaluate the physicochemical properties of semi-volatile organic chemicals such as flame retardants to gain an understanding of their environmental fates.

3. Current status of the intertidal invertebrates in Fukushima Prefecture, Japan, in the wake of the Great East Japan Earthquake

Since December 2011—after the 2011 Tohoku earthquake, tsunami, and nuclear disaster—we have been surveying the intertidal zones along the coastline of eastern Japan. In 2012, we found that the number of intertidal species decreased significantly with decreasing distance from the Fukushima Daiichi Nuclear Power Plant (FDNPP). No rock shell (*Thais clavigera*) specimens were found near the plant, from Hirono to Futaba Beach (a distance of about 30 km), even though rock shell specimens were collected from many other sites struck by the tsunami. Quantitative surveys in 2013 showed that the species richness and population densities of sessile invertebrates—especially arthropod sp.—in the intertidal zones were much lower at sites near, or within several kilometers to the south of, the FDNPP than at other sites, and they were also lower than they were in 1995. In addition, from 2014 to 2019, we conducted quantitative quadrat surveys of sessile invertebrates at seven intertidal sites in Ibaraki, Fukushima, and Miyagi prefectures, including at sites near the FDNPP. We found no increases in species richness or population density in the intertidal zones near the FDNPP until 4 to 5 years had passed since the disaster. These findings strongly suggest that the intertidal biota around the FDNPP was affected by the nuclear accident.

In April, July, August, and September from 2012 to 2019, we also surveyed the population density and spawning behavior of rock shells in an area near the FDNPP. Although no areas devoid of rock shells around the FDNPP were observed in July 2016, the densities of *T. clavigera* populations near the FDNPP in 2018, and the reproductive performances of these populations in 2019, remained below the levels observed before the disaster. Although sessile invertebrate larval recruitment from remote areas to the intertidal zones near the FDNPP was expected, this was not clearly observed until 2016. Therefore, it is possible that environmental factors have inhibited invertebrate reproduction, recruitment, or both, in the intertidal zones near the FDNPP.

4. Basic study for strategic risk management

We are studying the factors that are important for modeling the environmental fate and emissions of chemicals; assessing exposure to, and risks posed by, environmental chemicals; assessing the ecological impacts of environmental disturbances; and systematically managing the risks to health and the environment posed by environmental chemicals, while taking into consideration the many risk factors.

This fiscal year we performed studies on modeling the global fate of mercury; the behavior of chemicals by using multimedia environmental fate models (G-CIEMS and FATE); the emission of additives from products; environmental monitoring and risk management during and after accidents and natural disasters; the bioaccumulation of chemicals in the aquatic environment; the impacts of chemicals on the community structures of benthic animals in the field; and the management of wild mammals in cooperation with local governments. We utilized the results as the basis for research projects in Issue-Oriented Research Programs and for projects related to the strategic management of risks. In our environmental fate study, we studied the emissions and multimedia behaviors of volatile methylsiloxanes in the Tokyo Bay catchment. In examining the relationship between the predicted and measured values of these compounds, we proposed a new method combining censored regression, multiple imputation, bootstrapping, and major axis.

5. Fundamental study of integrated health-risk evaluation

This fundamental study aims to develop advanced toxicity evaluation methods and biomarkers of neurotoxicity, immunotoxicity, reproductive and developmental toxicity, genotoxicity, and inhalation toxicity on the basis of the physicochemical characteristics of harmful environmental substances such as nanomaterials, PM2.5, metals, and microplastics.

We have made progress in developing an *in vitro* system for studying the inhalation toxicity of microplastics and nano-sized plastic particles. The three 3-dimensional culture system consists of alveolar epithelial cells–basement membrane–fibrillar collagen matrix, alveolar epithelial cells–basement membrane–endothelial cells, and alveolar epithelial cells on fibroblasts embedded in collagen gel. Notably, submicron plastic particles could not pass through the basement membrane. The accumulation of submicron particles beneath the basolateral side of the epithelial cells applied mechanical stress to the cells and stimulated the collagen production. These results suggest that inhaled microplastics induce thickening of the alveolar wall.

6. Association between gut microbiota and autism spectrum disorder

Autism spectrum disorder (ASD) is a serious neurodevelopmental condition. ASD patients often suffer from gastrointestinal problems and altered gut microbiotal profiles. To investigate the association between ASD symptoms and the gut microbiota, we investigated the intestinal microbial composition and its alteration in a valproic acid (VPA)-induced rat model of autism. Sprague-Dawley pregnant rats on gestation day 12.5 were intraperitoneally administered 500 mg/kg of VPA. We performed 16S rRNA sequencing of fecal samples to analyze the gut microbial composition and examined gene expression in the intestines (ileum, colon) of the male and female offspring at 12 weeks of age. We found altered gut microbiotal composition (Fig. 1a); the change was similar to that seen in human autism. In addition, VPA administration resulted in decreased mRNA levels of Muc2 (the major gel-forming colonic mucin) in the ileum (Fig. 1b) and IgA in the feces of the offspring. These results were more prominent in males than in females.

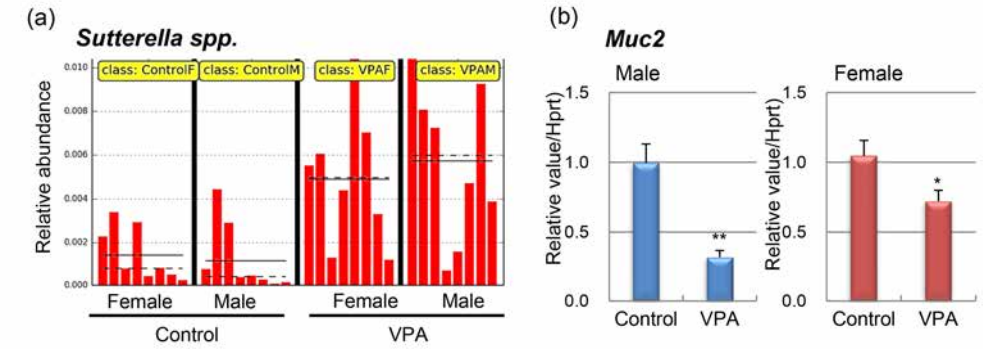


Fig. 1 Differences in relative abundances of bacterial taxa in feces and gene expression of *Muc2* in the ileum.
(a) Relative abundance of *Sutterella* spp. in feces. (b) mRNA level of Muc2 in the ileum. In (a), straight lines are mean abundance and dotted lines are median abundance.
Data are expressed as means ± SE for eight animals per group.
**P* < 0.05, ***P* < 0.01, vs. control.
VPA, valproic acid

7. Fundamental evaluation of the health impacts of environmental factors

This fundamental study aims to develop methodologies for evaluating the neuropathological and social behavioral effects of environmental factors. Its goal is to help identify health-threatening chemicals, reduce the adverse effects of environmental chemicals, and develop precautionary approaches to these threats.

The prevalence of autism is suspected to be related to environmental factors. Autism patients exhibit disabilities in sociality and communication. This fiscal year, we found aberrant ultrasonic vocalization and disability in adaptation to novel environments in mice, including gene-modified mice that have autism-like signs. Also, we developed a VPA-induced autism rat model and evaluated autism-like behaviors in rats after developmental exposure to diesel exhaust-derived secondary organic aerosol (DE-SOA). Developmental exposure to DE-SOA produced significant effects on social behaviors and social-behavior-related gene expression. Diphenylarsenic acid (DPAA) is a suspected cause of health problems in occupants of the city of Kamisu, in Ibaraki

Prefecture, Japan. The major signs and symptoms are neurological. We observed that DPAA exposure affected extracellular dopamine levels in the striatum of mice. Moreover, we investigated the effects of air samples and chemicals found in ambient air on immune cells such as monocytes and macrophages.

8. Biomarker investigation for large-scale human biomonitoring

Human biomonitoring is a technique that is used widely to characterize our exposure to chemical substances and to detect early signs of the resulting health effects. We developed a high-throughput analytical method for the quantification of steroid hormones in blood. The method was sensitive enough to detect sex hormones in children's blood; these hormones are, by nature, present only at trace levels and are thus difficult to measure by using existing methods. We employed automated sample preparation along with high-throughput liquid chromatography–tandem mass spectrometry. This enabled us to detect estrogens at sub-picogram levels per milliliter in children's blood samples. We also investigated protein adduct measurement methods to effectively analyze blood samples for important chemical adduct products such as acrylamides.

9. Adverse health effects of ambient air pollution

Few studies have examined the association between Asian dust and health effects. This fiscal year, we conducted a bi-directional, time-stratified case-crossover study to evaluate the association between exposure to Asian dust and placental abruption. From the Japan Perinatal Registry Network database, we identified 3014 patients who had had singleton deliveries in hospitals in nine Japanese prefectures from 2009 to 2014 and had been diagnosed with placental abruption. Asian dust levels were measured at lidar (light detection and ranging) monitoring stations, and these measurements were used to define Asian dust days. The adjusted odds ratio of placental abruption associated with exposure to Asian dust was 1.4 (95% confidence interval = 1.0, 2.0) for cumulative lags of 1-2 days. Even after adjustment for co-pollutant exposures, this association with abruption did not change substantially. This result supports our hypothesis that Asian dust is a potential trigger of this complication.

Center for Regional Environmental Research

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

The center consists of six sections (Regional Atmospheric Modeling Section, Regional Atmospheric Environment Section, Lake and River Environment Section, Marine Environment Section, Soil Environment Section, and Regional Environmental Systems Section) and has one Principal Researcher.

In FY 2019, we implemented many research projects covering a wide range of regional environmental issues. Our main research projects were as follows:

1.1 Type II joint researches on for photochemical oxidants and $PM_{2.5}$
1.2 Assessment of the climate change impacts on an enclosed sea environment
1.3 Dissolution and migration behavior in the soil environment of major and trace metals derived from electronic waste in soil environment
1.4 Decrease in bacterial production over the past three decades in the north basin of Lake Biwa, Japan.

Most of the projects are collaborations with other NIES centers. Additionally, there are two long-term monitoring programs: the Regional Atmospheric Monitoring Program and the GEMS (Global Environment Monitoring System)/Water Program, which is a collaboration with the Center for Environmental Biology and Ecosystem Studies.

Below, we briefly describe some of the important results of the Center's research in FY 2019.

1. Basic research

1.1 Type II joint research on photochemical oxidants and $PM_{2.5}$

In past type II joint research by NIES and the environmental research institutes of local government, we have investigated the causes of $PM_{2.5}$ levels exceeding environmental standards; to do this, we have used analysis of high-concentration episodes, high time-resolved observation, and a variety of model analyses. The rate of achievement of environmental standards has improved in the past few

years, and the number of high-concentration episodes has tended to decrease, although the rate of achievement of the standards is still low in some areas, such as the Kanto district and some parts of Western Japan. The reason for this has not yet been clarified.

Although measures have been implemented to control the emission of pollutants such as NOx (nitrogen oxides) and VOCs (volatile organic compounds), no marked improvements have been seen in atmospheric levels of the products of these pollutants, namely photochemical oxidants (Ox); Ox warnings are still issued every year in the Kanto and Kinki districts. In addition, there is a need to consider Ox and $PM_{2.5}$ at the same time, because Ox participates in the secondary generation of $PM_{2.5}$.

This study, which started in 2019, aims to yield basic information on the stocktaking of Ox and the influence of precursors on Ox generation. It also aims to elucidate the factors behind the high concentrations of $PM_{2.5}$ by source contribution analysis or weather analysis, and to clarify the behavior of air pollutant materials and the factors driving the generation of high concentrations of these materials by using simulations. We plan to accumulate this information to improve public health and climate change adaptation.

In 2019, a kickoff meeting was held to decide on, and discuss, the rules for managing research in this field. We formed a total of seven research groups: two for photochemical oxidants, four for $PM_{2.5}$, and one for simulations. In each group, implementation plans appropriate to each purpose are discussed. Every person involved in this research needs to join at least one research group and to be involved in observation, analysis, simulation, or other tasks in accordance with the group's policy.

1.2 Assessment of climate change impacts on an enclosed sea environment

Our objectives are to evaluate and predict the effects of climate change on the Seto Inland Sea, which is the largest semi-enclosed sea in Japan. We conducted statistical analyses by using long-term monitoring data from the past four decades to clarify the long-term trends in water quality and the benthic ecosystem and the impacts of climate change on these trends. We performed laboratory experiments and created kinetic growth functions by using three influence variables (temperature, light intensity, and inorganic nitrogen concentration) and two phytoplankton species (*Skeletonema* and *Eucampia*), which were dominant in the Seto Inland Sea in the past. We used these analytical and experimental results to determine the causes of past environmental variations in the Sea and predict the potential influence of climate change on the future environment there. We performed a numerical simulation of the marine environment at the end of the 21st century under the Representative Concentration Pathway 8.5 (RCP8.5) scenario. For the simulation, we used an integrated hydro-environment

assessment model, which could simulate hydrological discharge from basins and the subsequent hydrodynamic–biogeochemical processes in the Seto Inland Sea.

The long-term trends in seawater temperature and water quality varied and depended on the geographic location within the Seto Inland Sea. The trends in two straits, namely the Bungo Suido and Kii Suido, which are both connected to the Pacific Ocean, indicate that they would be strongly affected by variations in the path of the Kuroshio. Bottom water temperature increased markedly, beginning in the 1980s, in most parts of the Seto Inland Sea, and macrobenthic invertebrate diversity and density sharply increased in the 1990s. The variations in the benthic ecosystem corresponded not to the increase in the bottom water temperature but to a decrease in sedimentary total organic carbon content. Increasing water temperature in the future may therefore not be fatal for most benthic invertebrates that are tolerant of temperature fluctuations. However, the macrozoobenthic community structure in the area would change dramatically if future climate warming induces changes in sediment characteristics such as organic content and grain size distribution, as well as changes in the frequency and intensity of bottom water hypoxia. The kinetic growth functions of the two dominant phytoplankton species suggested that the past species succession from *Skeletonema* to *Eucampia* was induced synergistically by increased seawater temperature and transparency, rather than by decreased nitrate concentration.

Our numerical simulation under the RCP8.5 scenario (Fig. 1) showed that sea surface temperature (SST) would rise by 3.2 to 4.2°C by the end of the 21st century; however, climatological changes in nutrient loads may not be substantial. Especially from summer to autumn, the SST increase would be marked and could cause a severe drop in primary production owing to the effects of high-temperature stress on phytoplankton. As a result, nutrients in the sea surface layer could remain until the end of autumn, when the SST would begin to drop; subsequently, the lower SST and the remaining nutrients could enhance primary production. In future, the enhanced primary production could be sustained until spring, but the nutrient concentration would remain low from winter to spring. Our simulation suggests that climate change would have severe impacts on primary production and nutrient dynamics in the Seto Inland Sea.

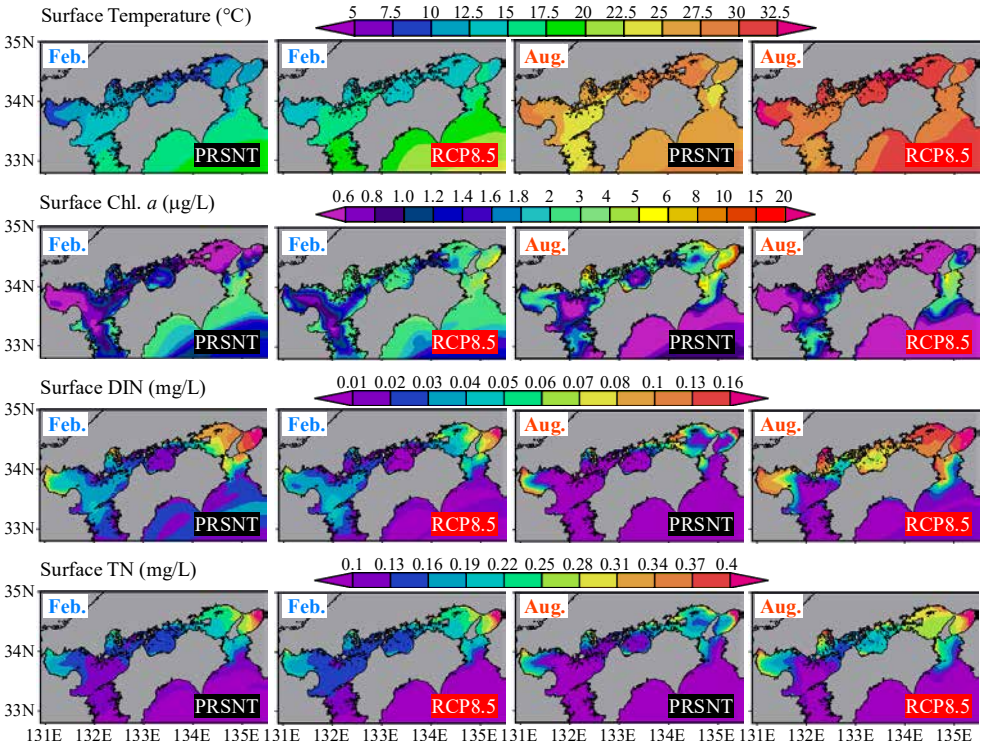


Fig. 1 Simulated sea surface temperature, chlorophyll-a (Chl. *a*), dissolved inorganic nitrogen (DIN), and total nitrogen (TN) in the Seto Inland Sea in February and August under the climate conditions of the present (PRSNT) and at the end of 21st century under the RCP8.5 scenario.

1.3 Dissolution and migration behavior in the soil environment of major and trace metals derived from electronic waste

In life cycle assessment, it is important to clarify the behaviors of metals eluted from electronic waste (e-waste) products. For this purpose, we conducted a rain exposure elution test and soil diffusion tests using various e-wastes.

Assuming outdoor dumping of e-waste, we examined the elution conditions, with exposure under precipitation, on turf located under cedar forest, red pine forest, or bamboo-leaf oak forest. E-wastes included printed circuit boards (PCBs), liquid-crystal displays (LCDs), and cathode-ray tube glass (CRTG). Furthermore, assuming the case of dumping in soil, we examined the elution characteristics of metals in PCB waste after being mixed with soil. We added 10 g of PCB to 50 g of different types of soil and adjusted the water content to 60% or 120% of the maximum water-holding capacity. We then incubated the mixtures at 25°C for 2 months. After the incubation, we applied a metal content test to the soil by using a 1-mol L^{-1} HCl extraction. We obtained the following results.

Rain exposure elution test: Because of the tree cover, the throughfall was less than the incident precipitation. Moreover, the pH differed between the throughfall and the incident precipitation and the pH of the throughfall differed across the different tree species. PCB eluted many types of elements, including large

amounts of Pb from solder. Pb and Zn were eluted from CRTG. Liquid crystals notably eluted only B. In general, the elution of metals was strongly influenced by the precipitation and rainfall pH.

Soil and waste mixture exposure test: The various metals eluted from PCB were Pb, Cu, Sn, Zn, Ni, In, and Sb. The amounts of these metals eluted were affected by the soil pH and moisture conditions. Metal elution from PCB (including Pb, Sn, Ni, In, and Sb) was lower at 120% of maximum water-holding capacity than at 60%. Similarly, metal elution was suppressed in environments with high soil pH (Table 1).

Table 1
Contents of metals extractable in 1 mol L^{-1} HCl from incubation of control soil or soil mixed with PCB.
Note that the 1-mol L^{-1} HCl extraction method is used as a content test method under the Soil Contamination Countermeasures Act.
tr., trace

Treatment		Soil	Cu	Ni	Pb	Zn	In	Sn	Sb
Mois.	Addition	pH	mg/kg-dried soil						
Cambisol (forest)									
60%	Control	5.7	11	0.7	22	10	0.02	0.3	0.07
	PCB	5.9	217	21.8	410	48	0.33	87.2	0.26
120%	Control	6.9	13	1.0	26	11	0.03	0.2	0.08
	PCB	6.7	67	6.5	175	36	0.11	22.2	0.16
Andosol (forest)									
60%	Control	5.5	38	tr.	14	13	0.05	0.6	0.11
	PCB	5.6	48	41.9	349	14	0.05	0.5	0.10
120%	Control	6.4	35	tr.	59	11	0.04	0.1	0.02
	PCB	6.5	59	6.6	169	16	0.06	3.4	0.13
Fluvisol (arable land)									
60%	Control	6.3	11	0.5	9	12	0.01	0.4	0.09
	PCB	6.5	77	6.9	282	24	0.22	64.6	0.34
120%	Control	7.4	14	0.7	11	13	0.02	0.4	0.04
	PCB	7.6	39	7.0	96	21	0.14	32.9	0.09

1.4 Decrease in bacterial production over the past three decades in the north basin of Lake Biwa, Japan

Lake Biwa is the largest lake in Japan, with a surface area of 674 km^2, a mean depth of 41 m (maximum depth, 104 m), a drainage basin of 3848 km^2, and a water residence time of 6 years. Lake Biwa was experiencing eutrophication until the 1970s, judging from total phosphorus (TP) concentrations. However, TP began to decrease in 1976, and the chlorophyll *a* concentration followed from 1981 onward owing to various efforts to reduce pollutant loads from the watershed. External pollutant loads have decreased since the 1980s, leading to improved water quality, such as a reduction in biochemical oxygen demand (BOD) and PO_4^{3-} concentrations.

Heterotrophic bacteria are important in the cycling of materials and energy in pelagic environments. Bacteria produce biomass (i.e., bacterial production: BP) by using dissolved organic matter (DOM), which most other organisms cannot utilize, and are linked to microbial and grazing food webs. Measurement of BP is therefore important to determine whether or not externally loaded DOM is assimilated into aquatic food webs.

In 2016 and 2017, we examined long-term variations in BP under the above-mentioned environmental changes in the north basin of Lake Biwa. BP was estimated by measuring the incorporation of stable isotope ^{15}N-labeled deoxyadenosine (^{15}N-dA) from June 2016 to December 2017 and compared with measurements made in 1986 and 1997–1998. In 1986, BP was measured by following ^{3}H-labeled thymidine (^{3}H-TdR) incorporation, and in 1997–1998, it was measured by tracking the bacterial abundance in incubations and calculating specific growth rates (μ). To allow direct comparison of the ^{15}N-dA and ^{3}H-TdR incorporation rates, we calculated a conversion factor. To estimate μ in 2016–2017, we determined a factor for converting ^{15}N-dA incorporation to cell number increase. In 2016–2017, the ^{15}N-dA incorporation rate ranged from 0.13 to 30.7 pmol l^{-1} h^{-1} and μ ranged from 0.016 to 0.70 day^{-1}. BP values from the ^{3}H-TdR incorporation rates in 1986 and from μ in 1997–1998 were 4.6 and 2.1 times the BP values in 2016–2017, respectively, confirming the decrease in BP over the past three decades in Lake Biwa (Fig. 2).

Water quality data showed only low rates of decrease for BOD and TP concentration from the 1980s onward, whereas the rate of decrease in PO_4^{3-} concentrations was equivalent to that of BP. BP and the decomposition of organic matter are known to be strongly phosphorus-limited in Lake Biwa. Our results suggest that the decrease in BP can be explained by the reduction in readily bioavailable PO_4^{3-}. Organic phosphorus can also be an important phosphorus source for BP in the presence of very low PO_4^{3-} concentrations (nM), and changes in the bioavailability of organic phosphorus might have also regulated BP dynamics.

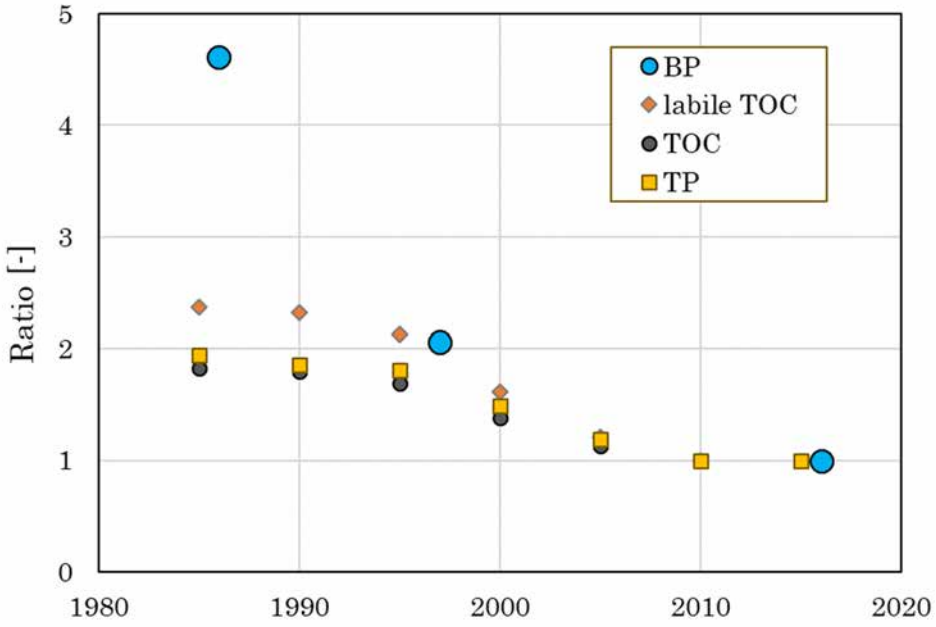


Fig. 2 Temporal variations in bacterial production (BP) and external loadings in the north basin of Lake Biwa, in comparison with the latest measured values set as 1. TOC, total organic carbon; TP, total phosphorus

2. Long-term monitoring

2.1 Long-term monitoring of atmospheric pollutants at Cape Hedo, Okinawa, and Fukuejima, Nagasaki, to monitor air quality in East Asia

Long-term monitoring of atmospheric pollutants, including aerosols and gaseous species, has been conducted by our Center at Cape Hedo Atmosphere and Aerosol Monitoring Station (CHAAMS) on Okinawa Island and at Fukuejima (Fukue Island) Observatory in Nagasaki Prefecture, Kyushu, to observe changes in the atmospheric environment of the East Asian region. Observations of optical, physical, and chemical characteristics, including the scattering coefficient, chemical composition, mass concentration, and vertical distribution of aerosols, have been conducted since spring 2004 at CHAAMS and since autumn 2008 at Fukuejima.

As an example of continuous aerosol measurements, the monthly averaged aerosol optical depth (AOD) at both observatories between April 2019 and March 2020 are shown in Figure 3. The AOD is a vertically integrated extinction coefficient measured by lidar (light detection and ranging), and two components (spherical particles and dust) indicate the vertically integrated loadings of spherical particles (e.g. sulfate, nitrate, organic carbon) and mineral dust (long-range transported Asian dust), respectively. At Cape Hedo, greater AOD(s) were detected in winter and spring of 2020, whereas AOD(d) remained low throughout the year. At Fukuejima, AOD(s) peaked in June and July in 2019, and AOD(d) peaked in February–March 2020, the typical Asian dust season in east Asia. Linking these results to the changes in human activities caused by COVID-19 will be one of the challenges in our understanding of the mechanism of long-range transportation of air pollutants.

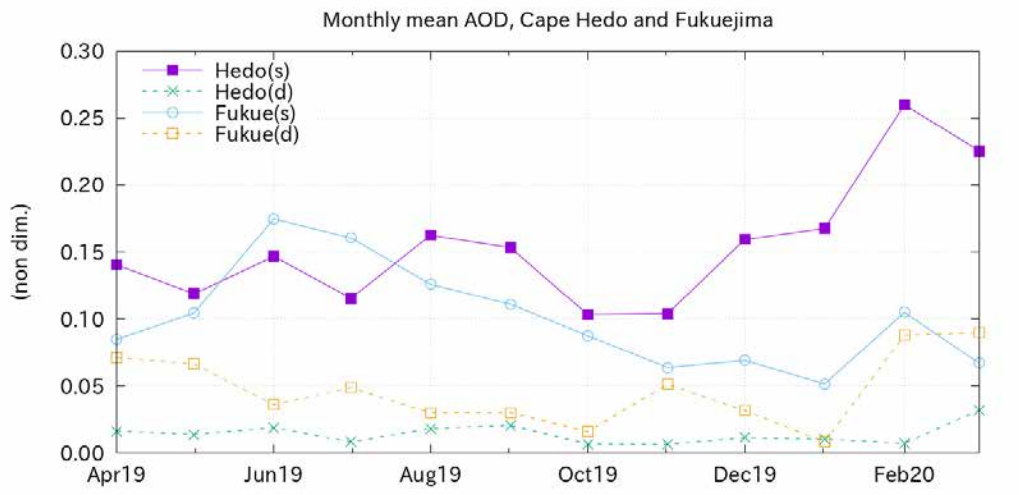


Fig. 3 Aerosol optical depth (AOD) observed at Cape Hedo and Fukuejima. (s) and (d) indicate the AOD components spherical particles and mineral dust, respectively.

These types of long-term monitoring data contribute to our understanding of the current status and trends of atmospheric pollutants in the East Asian region and of trans-boundary pollution entering Japan. Some of these measurement data and a list of peer-reviewed papers are available to the public on the NIES web pages (https://www.nies.go.jp/asia/hedomisaki/home-e.html)

2.2 Long-term monitoring at Lake Kasumigaura

We have been monitoring Lake Kasumigaura—the second-largest lake in Japan—monthly for nearly four decades in collaboration with the Center for Environmental Biology and Ecosystem Studies. This lake is registered as a trend-monitoring station of the United Nations Environment Programme's GEMS (Global Environment Monitoring System) Water Programme, a core site of JaLTER (the Japan Long-Term Ecological Research Network), and a GBIF (Global Biodiversity Information Facility).

We measure a wide range of environmental variables (e.g., water temperature, water depth, and transparency), water quality (e.g., electronic conductivity, chlorophyll *a*, nitrogen, and phosphorus), plankton (e.g., bacteria, phytoplankton, and zooplankton), benthos (chironomids and oligochaetes), and primary production. Detailed information and the database for this monitoring program have been released on the following website:
https://db.cger.nies.go.jp/gem/moni-e/inter/GEMS/database/kasumi/index.html.

Along with the monthly survey, preliminary measurements of methane and ammonia flux from the atmosphere *in situ* were started this fiscal year. Furthermore, data acquisition and logging of dissolved oxygen (DO) in the surface and bottom layers were performed every 15 min for the purpose of predicting hypolimnetic anoxia. Simultaneous with the DO acquisition, three-dimensional current velocity was also measured by employing an acoustic Doppler current profiler. With the cooperation of NIES Lake Biwa Branch Office, continuous DO data in the bottom layer were obtained at the sites for environmental quality standards in Lake Biwa (the south basin).

To improve the identification accuracy of phytoplankton and zooplankton, we cross-checked the morphologically based results by microscopic observation and the DNA-based results by DNA barcoding. By using convergent cross-mapping, we also showed the causal relationships between phytoplankton diversity and the efficiency of nutrient intake. Collaborative work with GLEON (Global Lake Ecological Observatory Network) is proceeding apace and has been associated with the outcomes of two collaborative papers.

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 composition and function and the relationships between these two factors, as well as the effects of human activity on biodiversity.

The center is responsible for leading the Biodiversity Research Program (one of the five Issue-Oriented Research Programs in the fourth NIES five-year plan), with the aim of helping to implement the Strategic Plan for Biodiversity 2011–2020, including the Aichi Biodiversity Targets of the Convention on Biological Diversity. Moreover, CEBES conducts long-term ecological monitoring, preserves biological resources, and establishes biodiversity databases. We have also studied the effects of the Great East Japan Earthquake on organisms and ecosystems. In 2017, we established the Lake Biwa Branch Office in cooperation with the Center for Regional Environmental Research.

CEBES considers commitment to national and international frameworks and policies to be an important task in the conservation of biodiversity and ecosystem services. During the third NIES five-year plan, some of the CEBES researchers were selected as experts and contributed as lead authors to the assessment reports of IPBES (the Inter-governmental Platform on Biodiversity and Ecosystem Services). We also responded to notifications from the Secretariat of the Convention on Biological Diversity, such as requests for peer review of documents. In addition, to lead and coordinate participation in these activities by the scientific community in Japan, CEBES set up the Secretariat of the Japanese Biodiversity Observation Network (J-BON) in 2014; its role is to act as an interface between the scientific community and other sectors.

1. Studies of the conservation and ecosystem management of Lake Biwa

The NIES Lake Biwa Branch Office aims to restore the ecosystem of Lake Biwa, the largest and oldest lake in Japan. The CEBES group at the branch office focuses on the recovery of native fishes that have dramatically decreased in abundance since the late 1980s. For their recovery, conservation and restoration of the lakeshore vegetation zone (Fig. 1) are indispensable, because the submerged part of this zone is used as a spawning site by many native fishes, including three endemic ones. Although the submerged-plant zone, which consists mainly of reed (*Phragmites australis*), had a total area of about 130 ha in 1976, 70% of the zones were no longer available as spawning grounds by the mid-1980s because of the construction of lake banks. The extent of the submerged reed zone depends on the water level of the lake. Thus, the artificially low summer water levels that began in 1992 also hinder spawning.

For effective conservation and management of the zone and the native fishes, the spawning-site performances of various reed zones need to be evaluated and monitored adequately. From the second year of opening of the branch office, we started to monitor five areas, including two natural and three artificially developed reed zones (Fig. 1). Fish eggs attached to plants (Fig. 2) were collected through the spawning season, with the collection point of each egg population sample recorded as GPS (global positioning system) data, and each egg was DNA identified in the laboratory. The results were then mapped to the vegetation map of each survey area. Monitoring for the past 2 years, including this year, is revealing differences in spawning habitat among fish species (subspecies). It is also demonstrating differences in the spawning inhibition effect of artificial water level control between the natural and artificially developed reed zones.

Fig. 1 Reed zones in the coastal area of Lake Biwa: natural reed zone (left) and artificially developed reed zone (right)

Fig. 2 Fish eggs attached to plants

2. Environmental genomics studies

NIES preserves highly endangered Japanese domestic species, such as the Okinawa rail and white stork. Some of these are protected and propagated by the national government. For efficient protection and propagation, we need to perform genome-wide analyses of these species and determine their genetic diversity. Because of the restrictions of the Washington Convention, it is difficult to conduct whole-genome analyses of such species at overseas research institutes. Therefore, the analyses must be conducted, and the genome data released, by NIES.

In this project, a draft analysis of the whole genome will be performed for highly endangered Japanese domestic species, species causing environmental problems, and indicator organisms widely distributed in Japan. By 2020, whole-genome draft analyses of 23 endangered avian species and seven mammals had been completed. These data were released on the NIES homepage (https://www.nies.go.jp/genome/index.html; in Japanese). Figure 3 shows representative species for which we have released data.

In addition, by using environmental DNA analysis methods, NIES plans to perform a detailed food-chain analysis and distribution survey in lakes Kasumigaura and Biwa, and on the Ogasawara Islands. To achieve more reliable results, highly accurate DNA barcode data for species identification are essential, and we are acquiring the DNA barcodes of those organisms in these areas that are targeted for environmental research. To date, more than 3,000 DNA barcode sequences have been identified, and these are being used in other NIES research projects. Moreover, as part of this project, we have consolidated a platform for bioinformatics analyses and support for our research collaborators (Fig. 4).

Fig. 3 Northern goshawk (*Accipiter gentilis*, left) and white-naped crane (*Grus vipio*, right)

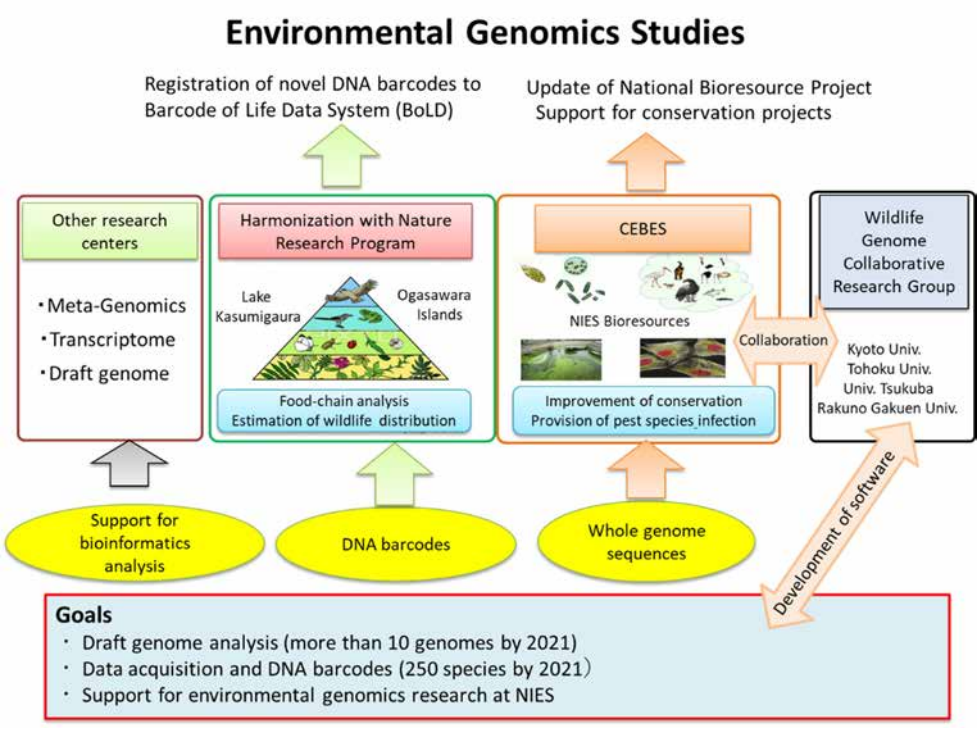


Fig. 4 Outline of the Project for Environmental Genomics Studies

3. Economic analysis of ecosystems

Given resource constraints, climate change adaptation policies require fine-scale monetary valuation of vulnerable ecosystem services at the national scale when policy priorities are being set. However, the prevailing evaluations have been

spatially and temporally limited by technical issues. This study adopts a traditional economic valuation approach. It uses mobile phone network data to reveal the current nationwide economic values of coastal recreation at Japanese beaches in summer and winter, and to project changes in recreational value under four climate change scenarios [Representative Concentration Pathway (RCP)2.6, RCP4.5, RCP6.0, and RCP8.5] (Fig. 5). The approach used in this study identified 274 current nationwide coastal recreational values (i.e., 202 in summer, and 72 in winter); the values ranged from JPY4,865 to JPY36,136,364 in summer and from JPY1,684 to JPY19,842,105 in winter. However, the projected economic values dropped to less than a quarter of the current values under the RCP2.6 scenario and decrease even more as the climate scenarios worsened, reaching less than one-tenth of current values in the case of RCP8.5 in both seasons. On a national scale, the value loss rates were substantially larger than the physical beach loss rates under the four climate change scenarios; this implies that the existing physical evaluations alone are insufficient to support policy-making. Furthermore, our geographical insights demonstrated regional differences in recreational values: most southern beaches with larger current values would disappear, whereas the current smaller values of the northern beaches would remain relatively the same. These changes imply that the ranking of beaches on the basis of economic value will enable policy-makers to discuss management priorities under climate change. For more details, see Kubo et al. (2020) in Tourism Management (https://doi.org/10.1016/j.tourman.2019. 104010).

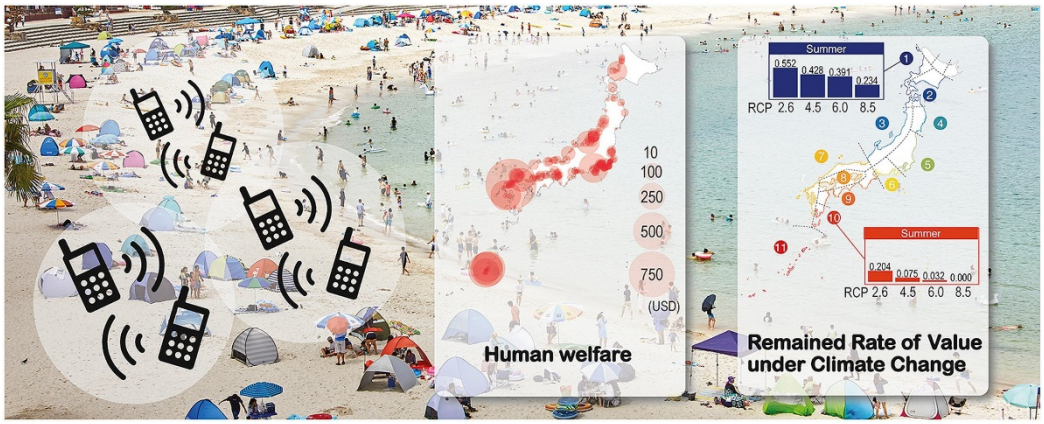


Fig. 5 Mobile phone big data reveal the economic value of coastal recreation across Japan and predict changes in that value under climate change.

Center for Social and Environmental Systems Research

The Center for Social and Environmental Systems Research targets linkages between human activities and the natural environment to identify the relationships among socioeconomic systems and environmental issues. The work of the Center results in important academic findings as well as policy recommendations for environmental issues, covering a broad area, from global environmental issues to local sustainable cities and regions.

The Center consists of five research sections:

1. The **Integrated Environment and Economy Section** analyzes the structure of causes and effects of various environmental problems, considering the inter-relationships among multiple sectors (such as household, government, and enterprise) and multiple scales (including world, country, and city), and explores solutions to these problems.
2. The **Trans-boundary Impacts and Mitigation Modeling Section** develops and utilizes analytical models to quantify the impacts of various environmental changes at transboundary and national scales—including the impact of climate change—and to examine measures for mitigating these changes.
3. The **Regional Environmental Impact Assessment Section** investigates solutions for environmental problems by developing methods and models to assess various environmental impacts at country, local, and city levels.
4. Through social transition research for innovative technological and social systems, the **Eco-society Innovation Section** conducts system design, evaluation, and support for the implementation of environmentally friendly technologies and policies to foster the transition to a sustainable environmental society.
5. The **Environmental Policy Section** aims to elucidate pathways to sustainable social systems by assessing the effectiveness of environmental policies and analyzing the roles and activities of multiple stakeholders.

Researchers at the Center are involved in at least one of two major research programs, namely the Environment-Economy-Society Integration Research Program and the Low-Carbon Research Program. Basic research that supports these project-oriented programs, together with any other research activities, is categorized as part of our Center's research sections. In FY 2019—the fourth year of the fourth mid-term plan of NIES—our goal was to coordinate various research activities to be able to arrive at tangible outputs by March 2021. Another goal was to start discussing what research agenda should be set under the Center in the fifth mid-term plan, which will start in April 2021. The future activities need to cover a variety of research projects regarded as "seeds" for future large-scale projects. Included are those related to data collection for model development, development of new methodologies to assess resource management, and outreach-related activities. Some of our outputs are described below.

1. Development of an integrated assessment model to assess ICT (information and communications technology) services in Japan

This NIES Center collaborates with NTT (Nippon Telegraph and Telephone Corporation) to assess the economic and environmental impacts of disemination of ICT services on socio-economic activites in Japan. The Network Technology Laboratories of NTT develop scenarios for future ICT services in Japan. NIES then assesses the impacts of these scenarios on greenhouse gas (GHG) emissions and gross domestic product (GDP) by using AIM (Asia-Pacific Integrated Model)/computable general equilibrium (CGE) [Japan], which is a dynamic recursive CGE model for Japan. In FY 2019, a total of 36 ICT services were selected for assessment. In AIM/CGE [Japan], parameters for energy efficiency and other inputs were revised in proportion to the projected increase in future ICT services. Figure 1 shows the results for GHG emissions and GDP. In 2030, under an accelerated ICT scenario, GHG emissions would decrease by 34 $MtCO_2eq$ (2.7%) and GDP would increase by 33 trillion JPY (4.7%) compared with the baseline scenario. These results suggest that ICT services can contribute to both GHG mitigation and economic development through, for example, increased efficiency of transport service inputs and avoidance of unnecessary production. On the other hand, in the household sector, rebound effects on GHG emissions were observed because of the projected income surplus. For ICT services to have further effects, behavioural change will need to be taken into consideration in the future.

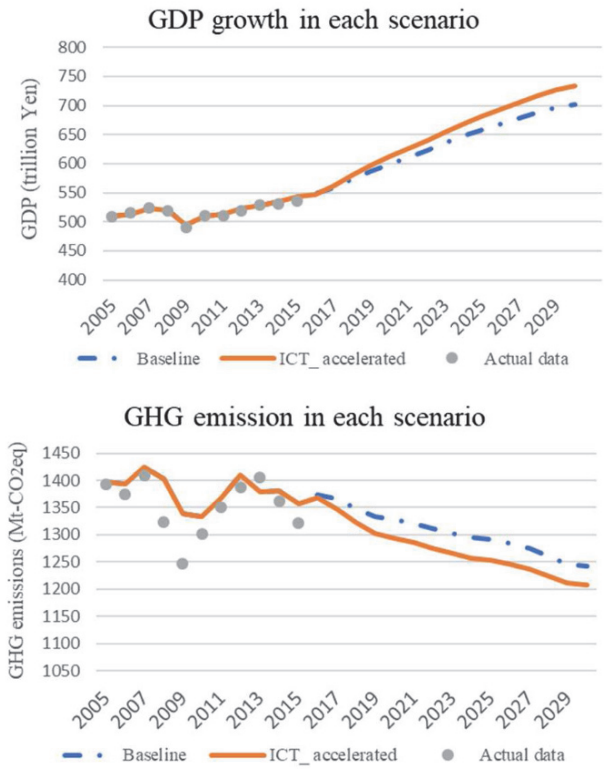


Fig. 1 Changes in GDP (above) and GHG emissions (below) with the introduction of ICT services in Japan

2. Life-cycle assessment of resources to provide information on their allocation

Because there are many means of recovering energy from waste, guidance is needed to select the most appropriate means for a given situation. Resource life cycle assessment (LCA) provides information on the optimum allocation of resources. Resource LCA falls within the scope of International Organization for Standardization (ISO)-LCA. However, in addition to equalizing functions between scenarios for comparison, the unique point of resource LCA is to include the process in which the resource (fossil fuels) that is substituted by waste is used in a typical application of the resource; this approach reflects the value to society of the substituted resource. This is rarely considered in conventional LCA. Unlike in conventional LCA, we include the original use of the substituted resource in the system boundary. We examined how steam supply from a waste incinerator to a nearby factory reduced CO_2 emissions compared with conventional waste power generation. We also examined the CO_2 emission reduction that occurred when natural gas was used to heat the boiler (Fig. 2). Because natural gas can be used in combined-cycle thermal power generation (with a power-generation efficiency of approximately 60%), electricity production is likely to be greater than when heavy oil is used. In this situation, steam supply from a waste incinerator produced a CO_2 emission reduction of 0.39 kg-CO_2/kg-waste; this was greater than the CO_2 reduction when heavy oil was used to heat the boiler (0.19 kg-CO_2/kg-waste; data is not shown in Fig. 2). The difference in CO_2 reduction between the two situations is attributable to the fact that natural gas has a better physical property than heavy oil as a low-carbon electricity fuel; this property is reflected in the framework of the resource LCA.

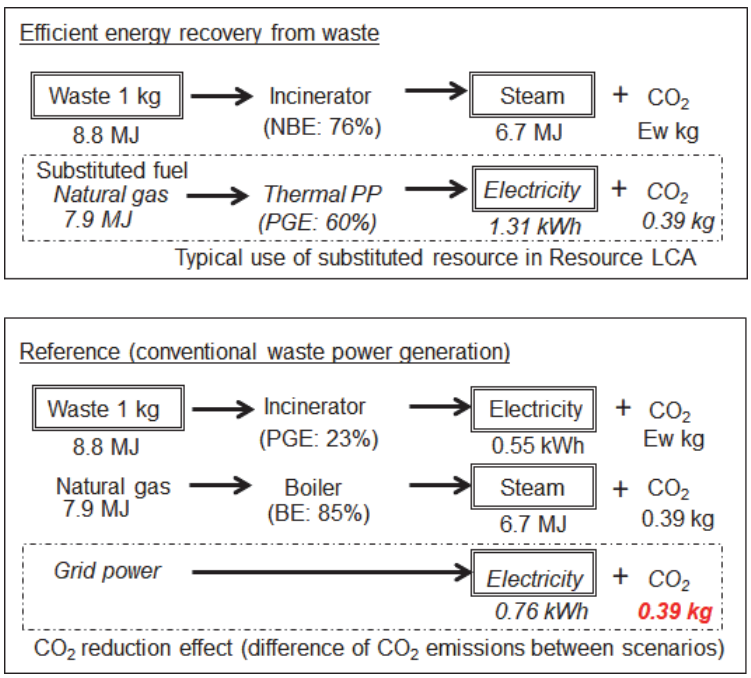


Fig. 2 Estimated CO_2 reduction due to steam supply from a waste incineration plant, as determined from resource LCA
NBE denotes net boiler efficiency, PP denotes power plant, PGE denotes power generation efficiency and BE denotes boiler efficiency.

3. Development of educational materials on urban heat island countermeasures for awareness-raising in schools

We have been promoting many types of environmental science education as a mission of Tsukuba “Science” City; we have developed educational materials, such as short movies, to raise the awareness of elementary school children about the importance of urban heat island counteraction. We studied the effect of clothing color choice in outdoor space to reduce the risk of summer heat stroke; this strategy is considered one of the most important for personal climate change adaptation. The reflectivity (i.e., the luminance) of the visible electromagnetic radiation bands (400 to 750nm) was one of the dominant determinants of the surface temperature of clothing. However, our survey of the effect of the near-infrared bands (750 to 1400nm), which cover only part of the spectrum of solar radiation, was insufficient. We therefore analyzed the spectrum of reflectance (350 to 1050nm) on the surface of clothes. The reflectance of each color, when we considered the near-infrared bands as well as the visible bands, was 87% for dark green, 86% for black, 84% for blue, 84% for green, 82% for purple, 78% for red, 75% for gray, 70% for yellow, and 63% for white (Fig. 3). A difference of 25% in reflectance resulted in a 15 °C temperature difference at the surface of the clothing. The correspondence of surface temperature with the reflectivity in each color became closer than when we focused on the visible bands only. These results were shared with elementary school students and they have begun to change their choices of clothing color in summer. This kind of knowledge needs to be widely shared among the younger generations.

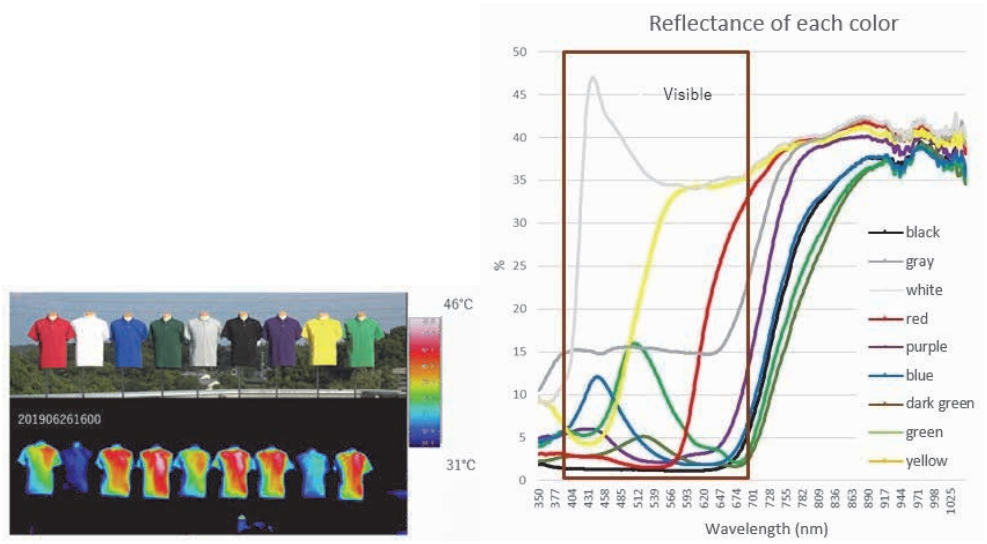


Fig. 3 Surface temperature and reflectance of clothes exposed to solar radiation. Each color has a specific reflectance.

4. Contributions to national or local governmental environmental committees

Many of the researchers at the Center for Social and Environmental Systems Research are involved in the environmental policy-making processes of national and local governments. As members of environmental committees and councils of national or local governments such as Tokyo Metropolitan Government and Ibaraki prefecture, they are often asked by government officials to give input to discussions from a scientific perspective. Our research outcomes—especially in regard to climate change mitigation and adaptation actions and urban planning system design utilizing notion of SDGs—are often utilized by governments to facilitate discussions aimed at establishing sound environmental policies.

5. Activities led by the Environmental Economics Assessment Cooperation Group

Four or five NIES research staff members with backgrounds in economics, although they belonged to different Centers, sought a way to interact with each other and to have other staff members with a variety of backgrounds join in the conversation. In this context, the Environmental Economics Assessment Cooperation Group was set up under our Center in collaboration with other Centers in 2016 for these staff members to gather together and develop their own joint research proposals. This fiscal year we held several workshops on "evidence-based policy-making" (EBPM), a methodology that has been attracting the attention of governmental officials in Japan. The role of NIES economists in EBPM is to perform quantitative assessments of the effectiveness of environmental policies.

Center for Environmental Measurement and Analysis

The goals of the Center for Environmental Measurement and Analysis (CEMA) are to help develop better scientific methodologies that will enable the early detection of environmental issues and changes, give us a deeper understanding of environmental issues, and improve the assessment of current and future environmental concerns. CEMA also helps manage the quality of chemical analyses of environmental samples. Furthermore, we have continued our environmental specimen banking as important work that complements the archiving of environmental changes.

To achieve these goals, the six research sections of CEMA have been conducting a variety of studies. The **Fundamental Analytical Chemistry Section** has been in charge of an environmental specimen banking program; it collects bivalve specimens annually to complete a round of sampling from many sites along the Japanese coast. The section has also been preparing and distributing environmental Certified Reference Materials to meet the demand for environmental chemical analysis. The **Advanced Analytical Chemistry Section** has been developing techniques for the comprehensive analysis of organic pollutants; for example, they have coupled a two-dimensional gas chromatograph to a high-resolution time-of-flight mass spectrometer. The **Environmental Chemodynamics Section** has been monitoring the temporal and spatial variation of chemical species in the atmosphere to gain an understanding of the sources and sinks of anthropogenic and natural substances. A microscale radiocarbon (^{14}C) analysis has also been conducted by this section to distinguish the fossil fuel and biogenic sources of carbon-containing materials such as airborne particulate matter. The **Advanced Remote Sensing Section** has been developing advanced techniques for remote sensing, such as lidar (laser radar), to monitor the temporal and spatial distribution of the main aerosol components (e.g., mineral dust, sea salt, and black carbon) in the atmosphere. The **Environmental Reaction Chemistry Section** has been tackling the development of methods to help us understand the mechanisms and efficiency of the production and chemical conversion of atmospheric fine particles—especially organic particles. The **Environmental Imaging and Spectrum Measurement Section** has been involved in the development of non-invasive and non-destructive techniques for monitoring the human brain by using a magnetic resonance (MR) imaging system. The possibility of utilizing measured MR images as *in vivo* biomarkers has been assessed by this section.

Below are brief accounts of some of the important results of our research in FY 2019.

1. Recent increase in CFC-11 emissions from China revealed by atmospheric observations

Trichlorofluoromethane (CFC-11), a widely used agent (mainly in foam manufacturing), was globally banned in 2010 under the Montreal Protocol on Substances that Deplete the Ozone Layer owing to its harmful impacts on stratospheric ozone. In response to such regulations, the atmospheric mole fraction began to decline in the mid-1990s. However, the rate of decline has recently slowed, and an emission increase somewhere in east Asia is suspected to be the cause for the unexpected slowdown.

To find the area and magnitude of this regional source, high-frequency atmospheric observations in east Asia are crucial. Since 2004, we have been conducting *in situ* high-frequency atmospheric monitoring of halocarbons, including CFC-11, at Hateruma station on Hateruma Island in Okinawa, as part of global environmental monitoring conducted by our CGER (Center for Global Environmental Research). Figure 1 shows atmospheric observations of CFC-11 in east Asia, made at Gosan (South Korea) and Hateruma. At both sites, we observed frequent enhancements of the mole fractions of CFC-11, indicating that CFC-11 is emitted from nearby sources and transported to the measurement sites downwind. We analyzed the atmospheric observations by using atmospheric chemical transport model simulations. The results indicated that the derived emission increase for eastern mainland China accounts for a substantial fraction of the global emission increase. Most of this rise is estimated to have come from provinces in north-eastern China (Shandong and Hebei). Multiple considerations suggest that the increased emissions are likely the result of new, unreported production after the global ban in 2010.

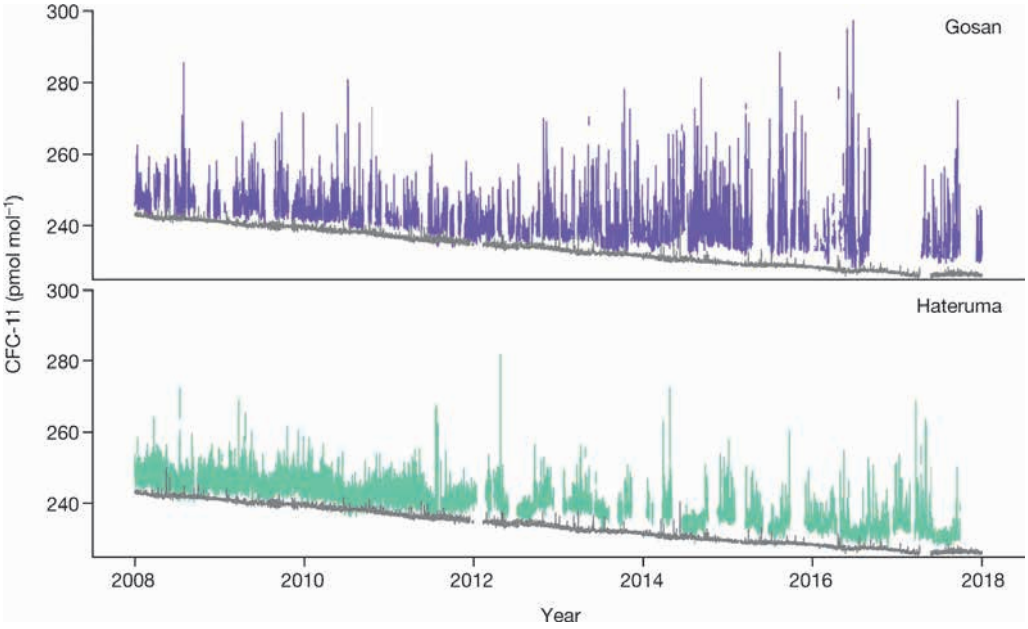


Fig. 1 Dry-air mole fractions of CFC-11 measured at Gosan, Jeju Island, South Korea (33.3°N, 126.2°E) and Hateruma, Japan (24.1°N, 123.8°E). The gray lines show the mole fraction observations at Cape Grim, Tasmania, Australia (40.7°S, 144.7°E) for comparison. (adapted from Rigby et al. (2019))

2. Accurate identification of dimers from α-pinene oxidation by using high-resolution collision-induced dissociation mass spectrometry

Owing to the recent advances in mass spectrometry technology, many kinds of species causing air pollution can be measured with high sensitivity. In particular, online chemical ionization mass spectrometry (online CIMS) makes it possible to perform real-time analyses of volatile and semi-volatile organic compounds involved in the formation of secondary organic aerosols (SOAs) in the atmosphere. Because the oxidation of α-pinene (which is largely emitted from forests) is well known to be a major SOA source, attention has been given to the formation of dimers from α-pinene oxidation, from the perspective of the formation of low volatile organic compounds. Two formation mechanisms have been proposed: (i) self- and cross-reactions of peroxy radicals (RO_2) to form organic peroxides (R–OO–R′); and (ii) gas-phase reactions of a stabilized Criegee intermediate (sCI) with acids, hydroperoxides, and alcohols to form hydroperoxides (R"–OOH). Online CIMS has been used to perform mechanistic and kinetic studies of α-pinene-derived dimer formation. To determine the properties of the abovementioned dimers accurately, we need to know the fractions of ion signal that originate from mechanisms (i) and (ii). Furthermore, the formation of hydrogen-bonded dimers as instrumental artifacts needs to be taken into consideration because of adiabatic expansion caused by the pressure difference between the ionization area and the vacuum region in the mass spectrometer. The fractions of these artifacts must be subtracted from the detected ion signals. In this work, we used collision-induced dissociation (CID) and high-resolution tandem mass spectrometry (HR-CID-MS) to specify the origin of dimers and quantify their fractions.

α-Pinene ($C_{10}H_{16}$) in gas phase was oxidized by O_3–OH–NO_x, and the oxidized products were negatively ionized by using an atmospheric pressure corona discharge technique. We focused on the ion signals at *m/z* 369 observed in a full-scan spectrum. The CID spectrum at *m/z* 369.2 ± 0.4 is shown in Figure 2a. This *m/z* range includes two precursor ions, $C_{19}H_{29}O_7^-$ (*m/z* 369.1911) and $C_{20}H_{33}O_6^-$ (*m/z* 369.2276) (Fig. 2b, VIII). The fragmentation pattern has three features. First, the major product ions at *m/z* 167, 169, 183, 185, 199, and 201 correspond to various deprotonated monomers, and several pairs of these monomers can describe the precursor ions. For example, the $C_{20}H_{33}O_6^-$ ion consists of a complex of two monomers, $C_{10}H_{16}O_3$ and $C_{10}H_{18}O_3$, either of which is deprotonated. Secondly, most product ions with a lower *m/z* value (<*m/z* 165) are identical to the ones from CID for deprotonated monomers. Thirdly, although CID was performed under the lowest collision energy conditions (E_{lab} = 10 eV), many precursor ions were dissociated (i.e., only 1.3% of $C_{20}H_{33}O_6^-$ and 0.2% of $C_{19}H_{29}O_7^-$ remained). By taking these three features into consideration, we found that most precursor ions ($C_{20}H_{33}O_6^-$ and $C_{19}H_{29}O_7^-$) could be identified as deprotonated dimers consisting of two hydrogen-bonded monomers (denoted as “deprotonated HB dimers”). Their fraction was estimated to be 96.4%.

The CID spectrum in Figure 2a suggested that precursor ions included dimers with a hydroperoxide functional group formed from sCI (mechanism (ii)) because loss of H_2O_2

from the precursor ions $C_{20}H_{33}O_6^-$ and $C_{19}H_{29}O_7^-$ was observed (see Fig. 2b, VIII). The fraction of hydroperoxide-type dimers at *m/z* 369 was estimated to be in the range of 0.8% to 3.6%. In contrast, the fractions of organic peroxides (mechanism (i)) in the precursor ions was estimated at 0% to 5.7%.

Recently, rate constants for the R–OO–R′ formation reaction from the abovementioned mechanism (i) were evaluated by using online CIMS. In those studies, the rate constants were determined by using the ion intensities of R─OO─R', RO_2, and R′O_2 and were directly proportional to the R─OO─R' ion intensity. If the measurements were to be performed by using the same type of online CIMS as used here, the reported rate constants of R─OO─R' formation could be overestimated by one or two orders of magnitude.

This work was performed in collaboration with Prof. Kanako Sekimoto of Yokohama City University.

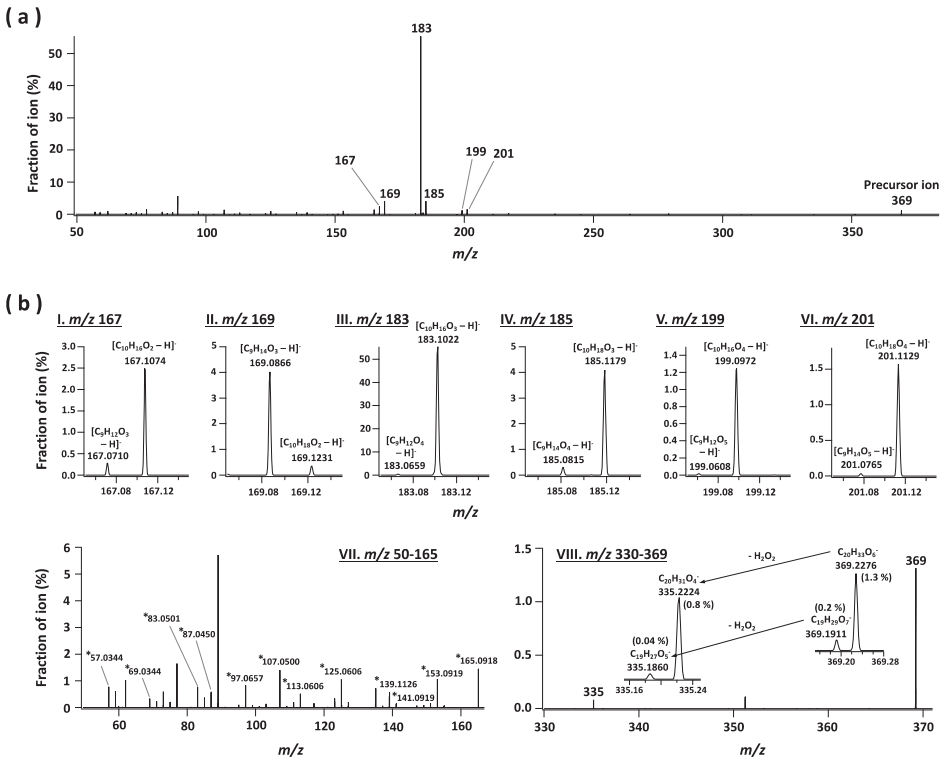


Fig. 2 (a) CID spectrum of negative ions at *m/z* 369.2 ± 0.4; (b) Magnified view of panel (a) at the selected *m/z* range. The ion fraction (%) was calculated by using the formula $AI_{ion}/\Sigma AI_{ion}$, where AI_{ion} represents the absolute intensity (arb.) of the precursor and product ions observed in the present CID spectrum.

3. A new system for measuring the stable carbon isotope ratio of atmospheric methane

Methane (CH_4) is an important greenhouse gas emitted from various anthropogenic and natural sources to the atmosphere. Despite determined efforts in many studies to understand the global CH_4 budget, estimates of individual CH_4 sources remain quantitatively uncertain. Measurement of the stable carbon isotope ratio ($\delta^{13}C$) of CH_4 is useful for evaluating the relative contributions of different CH_4 emission

sectors because individual CH_4 sources have their own characteristic $\delta^{13}C$ signatures. However, $\delta^{13}C$ measurements of atmospheric CH_4 have been limited because of the complex and laborious nature of the analysis. Here, we describe a new system that we set up to measure the $\delta^{13}C$ of CH_4.

Figure 3 is a schematic overview of the system. The measurement process is as follows: (1) Sample air flows through a preconcentration trap (T1) filled with an adsorbent (HayeSep D) maintained at −130 °C. This step collects CH_4 in the sample air, and many other gases are flushed out. (2) T1 is heated to liberate the CH_4 and transfer it to a cryofocusing trap (T2) maintained at −140 °C. (3) The CH_4 released from T2 passes through a separation column (GS-CarbonPLOT) to achieve chromatographic separation from some of the remaining gases. (4) The CH_4 is combusted to CO_2 (and water) in a high-temperature combustion furnace at 940 °C. (5) The CH_4-derived CO_2 is further separated from co-eluted atmospheric krypton by using a post-combustion separation column (PoraBOND Q). (6) The CH_4-derived CO_2 is then introduced to an isotope ratio mass spectrometer (IRMS).

We examined various settings at every measurement step and identified their optimum combination to achieve measurement reproducibility sufficient for atmospheric monitoring purposes. Repeated measurements of a working standard air showed a standard deviation of 0.12‰ (N = 158). We also performed automated outside-air measurements for 2 months at an institute building; the results were a good example of how our system could provide useful online data. In the course of the 2 months of measurements, we observed diurnal and day-to-day variations of $\delta^{13}C$ that were well correlated with variations in the CH_4 concentration. The relationships between $\delta^{13}C$ and the CH_4 concentration indicated that several types of possible sources contributed to the observed atmospheric variations.

Importantly, our system requires no cryogen (e.g., liquid nitrogen), in contrast to many previously reported systems. This is highly advantageous in automated and unattended measurement operation. Because the system is well optimized for measuring various flask air samples collected by existing air-sampling networks, future measurement operations will be able to provide a number of atmospheric CH_4 $\delta^{13}C$ data to the atmospheric science community.

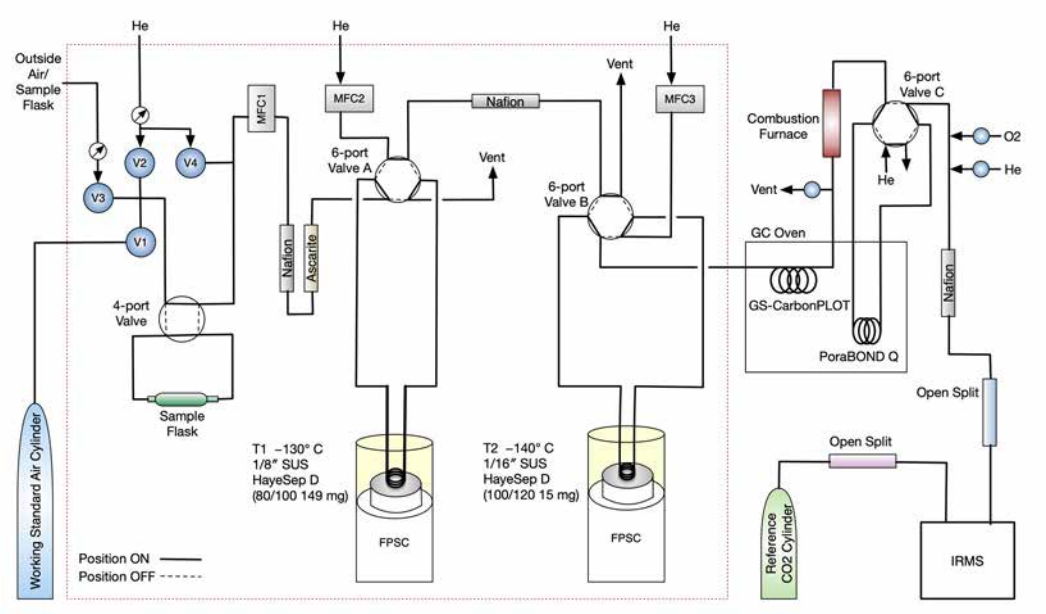


Fig. 3 Schematic overview of the system for measuring $\delta^{13}C$ of CH_4. MFC: mass flow controller; FPSC: free piston Stirling cooler; IRMS: isotope ratio mass spectrometer.

4. Development of an aerosol retrieval method by using space-borne lidar and a spectral radiometer

We have developed an algorithm to estimate the optical properties of mineral dust, sea salt, black carbon, and water-soluble particles, which are the main aerosol components in the atmosphere, by combining data measured by NASA's space lidar CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) and its satellite-borne spectral imager MODIS (MODerate resolution Imaging Spectroradiometer). Water-soluble particles are defined as a mixture of sulfate, nitrate, and organic compounds. Our algorithm eventually estimates a vertical profile of the extinction coefficient at a wavelength of 532 nm for each aerosol component, as well as air-column mean mode radii for each aerosol component. Figure 4 is an example of application of the algorithm to the measured data to estimate the global distribution of each aerosol component. In this figure, the optica depth (OD) which is a vertically integrated extinction coefficient is depicted. The OD of mineral dust was higher in the desert areas that were their emission source; the OD of water-soluble particles and black carbon were higher in urban, forest, or agricultural areas, indicating that these aerosols were due to air pollution and biomass burning. A comparison of the vertical distribution and global horizontal distribution of the aerosols estimated by this algorithm with the global aerosol standard products of CALIOP and MODIS provided by NASA showed the ODs of all the aerosols we examined were lower than those of the NASA standard products. To overcome these issues, we improved peripheral techniques, such as our cloud mask scheme and the signal noise removal required for the data analysis, as well as the algorithm itself. This improvement resulted in a better match with the NASA standard product. Furthermore, we performed some comparisons with ground-based

observations. In our preliminary results, the ODs of all the aerosols in this study were consistent with those observed by using ground-based sun photometers. These results suggest that the algorithm we developed in this study is valid. We will also proceed with the comparison on the mode radius as well as OD in the future.

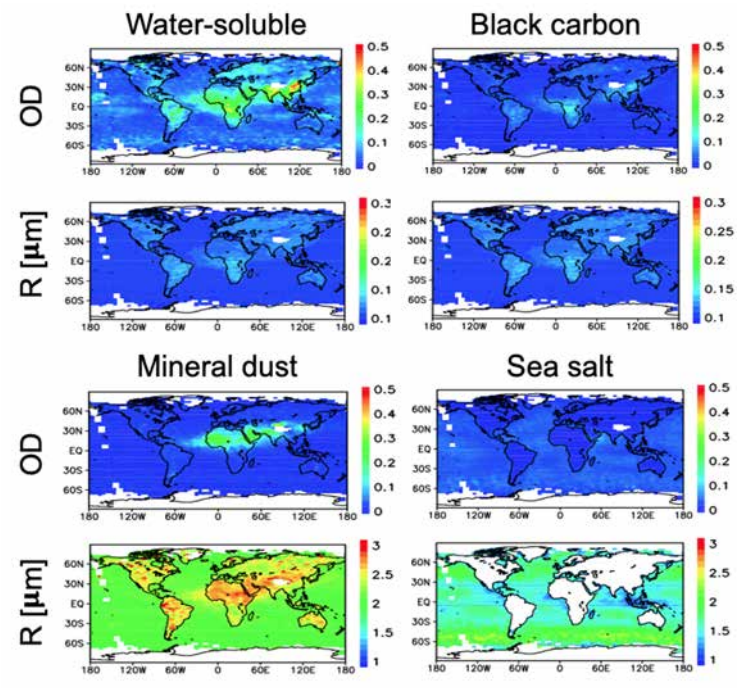


Fig. 4 Global distribution of optical depth(OD) at 532 nm and mode radius (R) for water-soluble particles, black carbon, mineral dust, and sea-salt aerosols. Values are annual averages for 2010.

Reference

Rigby, M., et al. (2019), Increase in CFC-11 emissions from eastern China based on atmospheric observations, *Nature, 569* (7757), 546-550.

Fukushima Branch

In April 2016, NIES opened its Fukushima Branch in the research building of the Fukushima Prefectural Centre for Environmental Creation (Fukushima CEC), located in the town of Miharu in Fukushima Prefecture. The Institute's objective is to promote and maintain rigorous scientific research focused on disaster-affected areas. NIES uses its Fukushima Branch as a collaboration hub to conduct environmental emergency research aimed at environmental recovery and renovation in disaster-affected areas. The collaborating partners include various relevant organizations, including the government of Fukushima Prefecture and JAEA (the Japan Atomic Energy Agency). NIES, by providing its environmental emergency research expertise, also extends support to Fukushima CEC's efforts to collect and disseminate environmental information and to prepare educational, training, and exchange programs (Fig. 1).

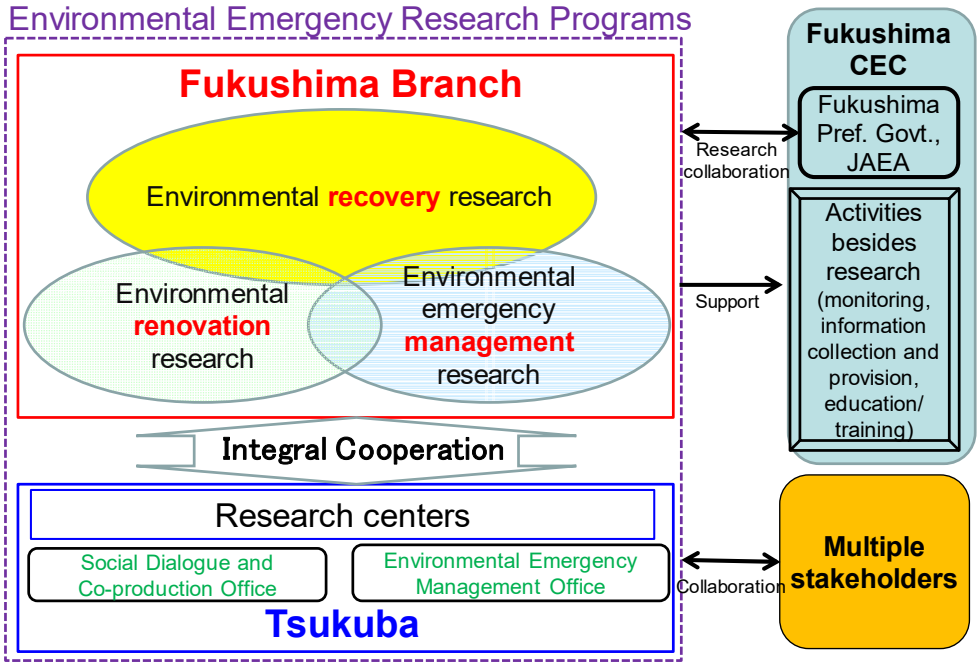


Fig. 1 Outline of environmental emergency research conducted at NIES's Fukushima Branch

In FY 2019, Fukushima Branch continued to conduct many kinds of research (laboratory work, field measurement, model simulation, and field studies) in the field of environmental emergency research, in collaboration with researchers in the research centers at Tsukuba. Research staff at Fukushima Branch also took part in the Environmental Emergency Research Program (see "Environmental Emergency Research Programs" in this report). Fukushima Branch led efforts to build a structure for collaboration among government, industry, and academia in the field of environmental emergency research. It held discussions and cooperated with local governments, non-profit organizations, and local people in Fukushima Prefecture. In particular, collaboration with many local governments has continued to advance in FY 2019. In addition, Fukushima Branch circulated

research outcomes and conveyed information to the public through public lectures, publications, and our website.

Environmental Information Department

Environmental Information Department

The Environmental Information Department provides information technology (IT) support for research and related functions at NIES; supports public relations initiatives (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

The first NIES supercomputer, an NEC SX-3, was installed in 1991 to elucidate phenomena related to global environmental change and to project such future phenomena. The NIES computer system has been updated several times, and in March 2020, computing performance and storage capacity were vastly improved by the installation of a new system consisting of the following three main elements:

- a vector-processing computer (NEC SX-Aurora TSUBASA A511-64; 256-vector engine, total 2048 CPU, peak performance 622.8 TFLOPS) (Fig. 1)
- a scalar-processing computer (HPE Apollo 2000; 28 nodes, total 1120 cores, peak performance 86.0 TFLOPS)
- a large-capacity file system (Data Direct Networks [DDN] SS9012 etc., total about 22 PB).

A local-area network called NIESNET was established at NIES in 1992. NIESNET was upgraded in March 2019. 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-Aurora TSUBASA supercomputer

1.2 Use of IT to improve work efficiency at NIES

The Department provides IT support to the administration and planning divisions 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 2019, 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 staff member at the Institute.

1.3 Library services

As of March 2020, the NIES library (Fig. 2) held 69,550 books, 897 journals (including electronic resources), and various other technical reports and reference materials. These materials can be searched by using OPAC (Online Public Access Catalog) and a link resolver via the Intranet.

In addition to these resources, researchers at NIES can use abstracts and full-text articles through scientific and technical information databases such as Web of Science (including Essential Science Indicators and Journal Citation Reports).

Library facilities include separate rooms for reading books, journals, and reports and are equipped with two PCs for accessing electronic materials.

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 publicly accessible information on its research activities and results via the Internet (https://www.nies.go.jp/; Fig. 3) in March 1996. In April 2001, the website was completely revamped and improved in step with the restructuring of NIES as an Independent Administrative Institution. The website was again revamped in July 2013. It also provides information on NIES initiatives related to the Great East Japan Earthquake.

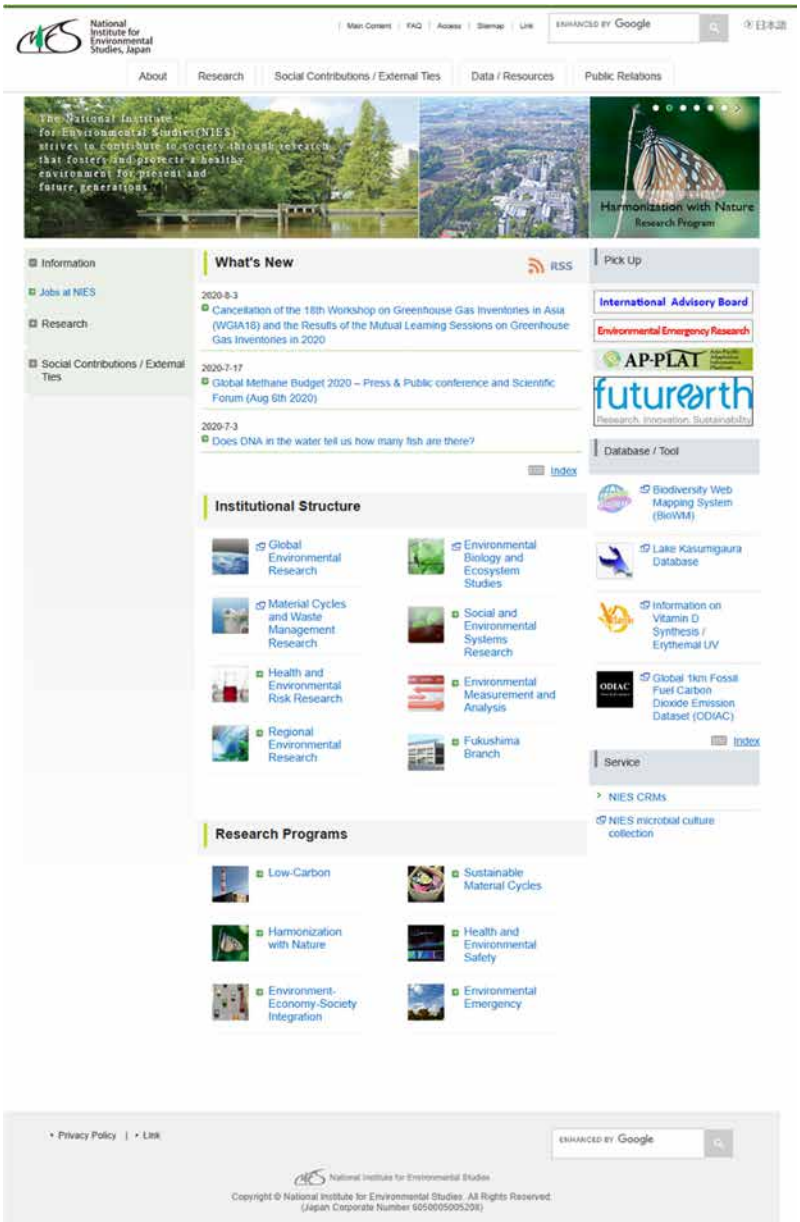


Fig. 3 The NIES website

2.2 Editing and publication of NIES reports

Reports on NIES research activities and outcomes, 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.

2.3 Promoting Open Science

To facilitate the use and application of research resources, prevent the loss of research results, and assure permanent accessibility, we have started attaching digital object identifiers (DOIs) to research data. Accordingly, we have set up a system for publishing URLs (metadata) associated with DOIs on the NIES website.

In response to calls for the establishment of a system for promoting open science, we have also started exploring an archive system (an institutional repository) to be created and operated by NIES. In addition, to estimate the costs of APCs (article processing charges) each year, we conducted a survey of open access activities at NIES and monitor publicly funded research published by using the CHORUS Institution Dashboard Service.

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. It also processes and manages environmental information databases and provides environmental information via GIS (Geographic Information Systems).

3.1.1 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 of the public and relevant institutions 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 to access news updates on such things as environmental issues in Japan and throughout the globe; descriptions of key environmental technologies; information on policies and laws in environmental fields; environmental information via GIS; and other content to aid environmental learning.

3.1.2 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 MOE. These processed data can be accessed through the database on the NIES website. Duplication and lending services are also available.

3.1.3 Provision of environmental information via GIS

The Department, with the cooperation of MOE, has been using GIS to develop an environmental data provision system. By displaying data on environmental quality and other information on maps, this system helps users to understand the status of the environment easily. 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 2019, the Department performed the following task, as commissioned by MOE:

- conversion of hourly values of regular air-monitoring data to standard format.

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