

NIES Annual Report

2024

AE - 30 - 2024



National Institute for Environmental Studies

<https://www.nies.go.jp/>

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Foreword



It is our pleasure to present the Annual Report of the National Institute for Environmental Studies (NIES). Since its establishment in 1974, NIES is the unique research institute in Japan conducting a broad range of interdisciplinary, integrated environmental research closely related to society, social change, and the people of Japan. This Annual Report is the official record of activities at NIES in Fiscal Year 2023 (FY2023: April 2023 to March 2024) which marked the third year of our Fifth Five-Year Plan (FY2021-FY2025).

Under the Fifth Five-Year Plan, NIES has been steadily engaged in basic and fundamental work to create scientific knowledge that should serve as a source to solve environmental issues by establishing six fields (Earth System; Material Cycles; Health and Environmental Risk; Regional Environment Conservation; Biodiversity; Social Systems) to form the pillars of environmental research and two fields (Environmental Emergency and Resilience; Climate Change Adaptation) which we aim to systemize over the long term. In addition to promotion of *Foresight and Advanced Basic Research* based on creative and cutting-edge science exploration, we are also steadily developing *Intellectual Research Infrastructure* to support academic and policy work through *Policy-Oriented Research* for practical research responding to policy needs, and global environmental monitoring which has been ongoing for long years.

Eight Strategic Research Programs are set across research fields to solve urgent issues. These research programs are climate change and air quality, material flow innovation, comprehensive environmental risk, harmonization with nature, decarbonized and sustainable society, co-design approach for local sustainability, environmental emergency and resilience, and climate change adaptation. The programs are being conducted in a focused and comprehensive manner with awareness to achieve goals within the Fifth Five-Year Plan. The climate crisis issues are particularly promoted in an integrated manner under *Climate Crisis Research Initiative*, which coordinates four related programs.

Based on national plans, NIES continues to conduct the satellite-based global observation of greenhouse gases (GOSAT) and the nationwide birth cohort study of 100,000 pairs of parents and children on children's health and the environment as projects to be implemented beyond the Mid-and-Long Term Plan period. Preparations for data processing for the third GOSAT to be launched, as well as continuation of the birth cohort study to children 13 years of age and onward has been approved. As for climate change adaptation, we are conducting research and providing technical assistance to local governments to promote adaptation.

As a core institute for environmental research in Japan, NIES will continue to cooperate with related organizations and contribute to the society. This year, NIES cooperated with organizations in City of Tsukuba, where NIES is based, to co-host a citizens' conference on climate change. Citizens who were selected by lottery from among many applicants participated in six conferences, and they handed 74 proposals for zero carbon in City of Tsukuba to the Mayor.

The pandemic has subsided and our overseas research activities have resumed their previous vigor. We will steadily achieve our goals for the current Mid-and-Long Term Plan period.

This Annual Report aims to inform the public of our research activities. We would appreciate any forthright opinions on our status and future activities.



Masahide KIMOTO

President

December 2024

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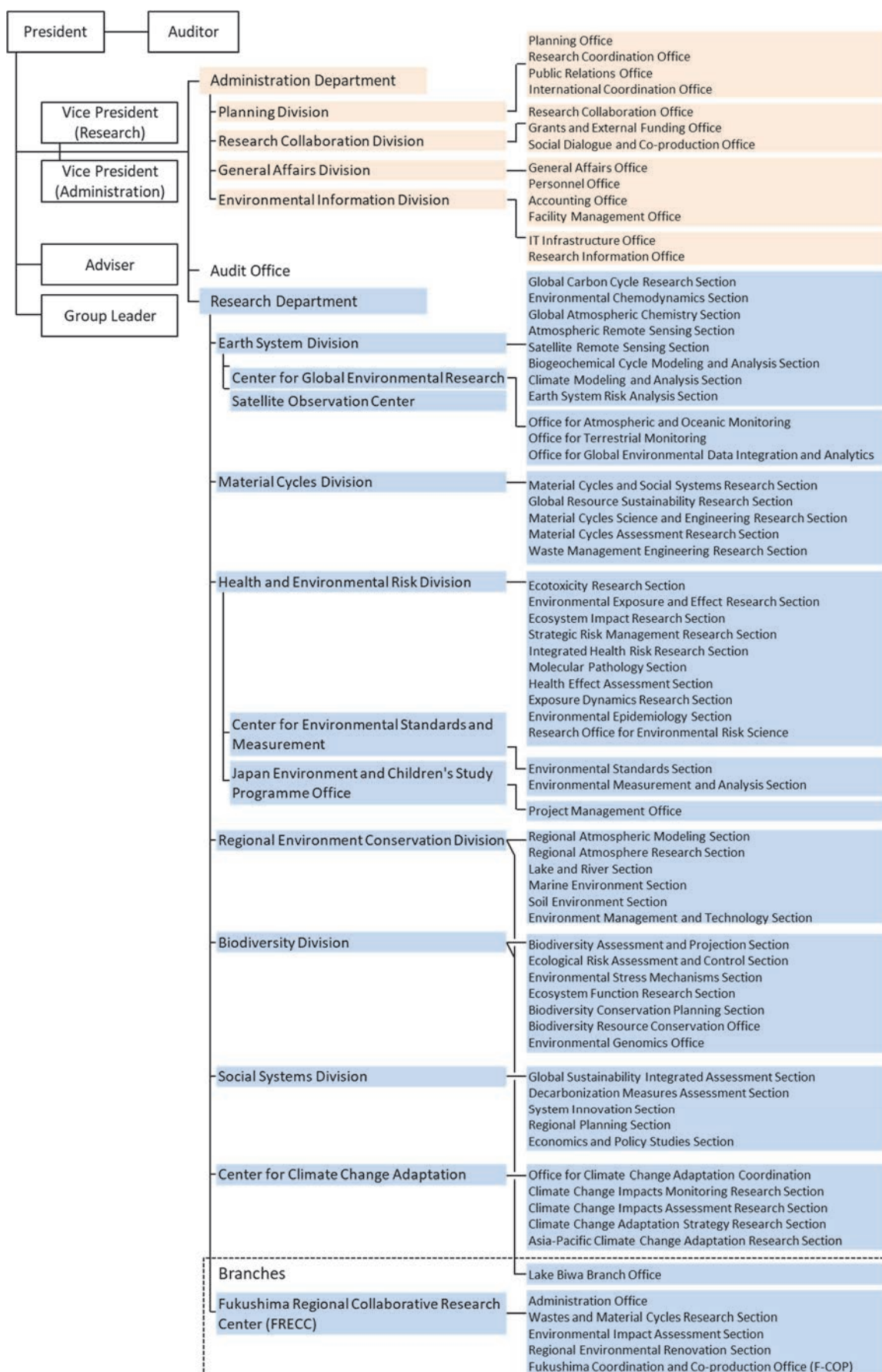
During the 1950s and 1960s, Japan experienced serious environmental pollution problems accompanying rapid economic growth. The Environment Agency was established in 1971 as part of the Japanese government to develop measures to counteract serious problems associated with environmental pollution, such 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. 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. In the Fourth Five-Year Plan (2016-2020), NIES established Fukushima Branch in April 2016 and Lake Biwa Branch Office in April 2017. In December 2018, we also established the Center for Climate Change Adaptation in line with the enactment and enforcement of the Climate Change Adaptation Act to research and promote adaptation to climate change. Our latest organization chart is shown in Fig. 1.

Fig. 1 Organization



April 2021 marked the beginning of the Fifth Five-Year Plan (2021-2025). NIES established 8 Strategic Research Programs such as environmental emergency and resilience research and climate change adaptation research, and pursuing them in an integrated manner that transcends individual fields.

Furthermore, to produce scientific findings on environmental protection, NIES has been carrying 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 an important work 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, 2023, there are 297 NIES permanent staff and 595 contract staff (Table 1; Figs. 2 to 5). The total budget for FY2023 was 21,064 million yen (Table 2).

Table 1
Numbers of permanent staff

Administration Department	67	
Research Department	224	(4)
Audit Office	1	
Executives and Advisers	5	
Total	297	(4)

(As of April 1, 2023)

Table 2
Budget for the Fifth Five-Year Plan

		(Unit: million yen)	
	Category	2021-2025 Budget (5 years)	Fiscal Year 2023 Budget
Revenue	Grants for Operating Costs	85,277	16,575
	Subsidies for Facilities	2,003	854
	Commissioned Work	18,428	3,636
	Total	105,708	21,064
Expenditure	Project Costs	66,315	12,748
	Facility Improvements	2,003	854
	Expenses for Commissioned Work	18,179	3,636
	Personnel Expenses	17,069	3,399
	General Administrative Expenses	2,141	428
	Total	105,708	21,064

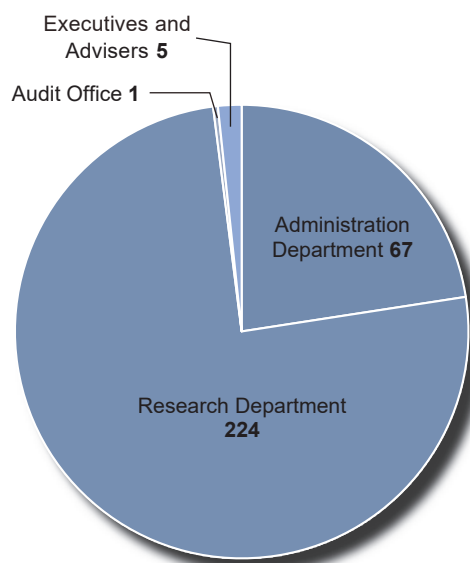
Note: The budget for each annual work plan will be requested and decided for each fiscal year, based on the Mid-and-Long Term Plan.

Administration Department	:	67	
Research Department	:	224	(4)
Audit Office	:	1	
Executives and Advisers	:	5	
Total		297	(4)

Notes:

1. Data is as of April 1, 2023.
2. Figures in parentheses indicate number of foreign nationals.

Fig. 2 Permanent staff breakdown



Basic Sciences	:	97	44.91%
Engineering	:	66	30.56%
Agricultural Sciences	:	32	14.81%
Medical Sciences	:	9	4.17%
Pharmaceutical Sciences	:	3	1.39%
Veterinary Medicine	:	2	0.93%
Social Sciences	:	7	3.23%
Total		216	

Note: Data is as of April 1, 2023.

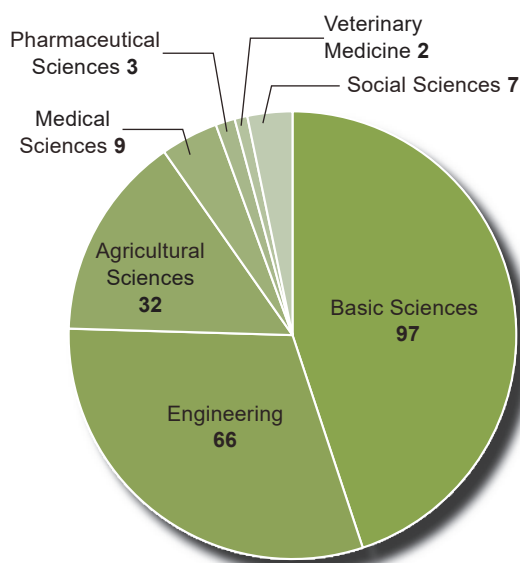
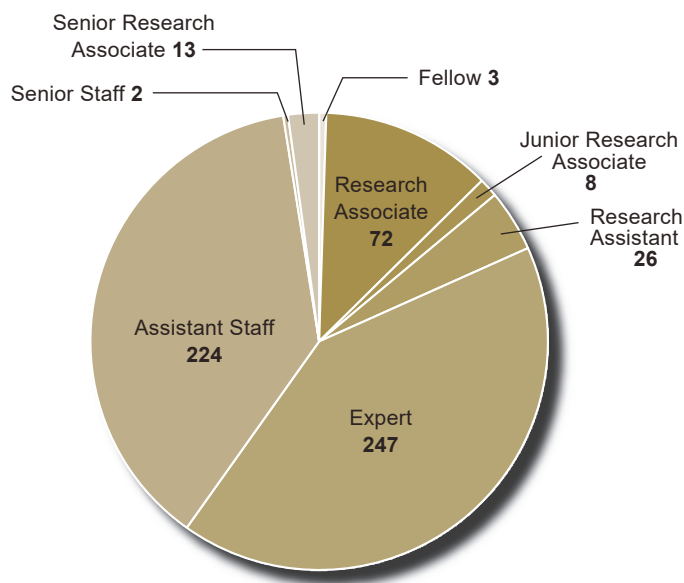


Fig. 3 Fields of expertise (Researchers holding doctorates (96.4%))

Fellow	:	3	
Research Associate	:	72	(36)
Junior Research Associate	:	8	(3)
Research Assistant	:	26	(6)
Senior Research Associate	:	13	(2)
Expert	:	247	(9)
Assistant Staff	:	224	
Senior Staff	:	2	
Total		595	(56)

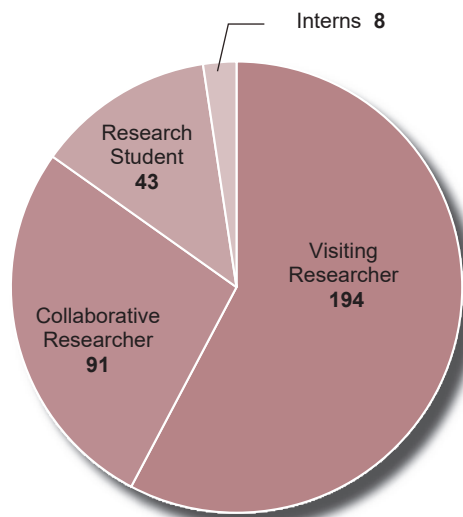


Notes:

1. Data is as of April 1, 2023.
2. Figures in parentheses indicate number of foreign nationals.

Fig. 4 Contract Staff Breakdown

Visiting Researcher	194	(19)
Collaborative Researcher	91	(10)
Research Student	43	(17)
Interns	8	(4)
Total	336	(50)



Notes:

1. Data is the total number accepted in FY2023.
2. Figures in parentheses indicate number of foreign nationals.

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

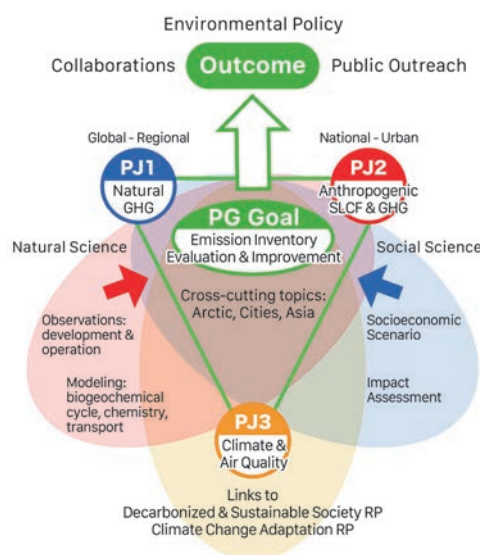
Strategic

Research Program

Climate Change and Air Quality Research Program

By making the best combined use of the Earth observation data from ground-based, ship-based, aircraft, and satellite platforms, we intend to meet the challenge to establish an operational system to estimate greenhouse gas (GHG) emissions and uptake on a global scale. We will also develop a new methodology to estimate GHG and SLCF (short-lived climate forcer) emissions on national and city scales. In addition, by using the latest emission estimates and evaluations, we will improve the accuracy of hindcast and forecast of the changes and variability in climate and air quality. To do this, we will use state-of-the-art modeling that takes into account the latest emission estimates and the latest knowledge of the fundamental processes of microphysics and chemical reactions and of the interactions of Earth systems. Overall, we will provide the scientific basis needed to make policy decisions to achieve the long-term goal of global stabilization of climate and air quality (Fig. 1).

Fig.1 Conceptual schematic of the Climate Change and Air Quality Research Program. PG, Program; PJ, Project, RP, Research Program.



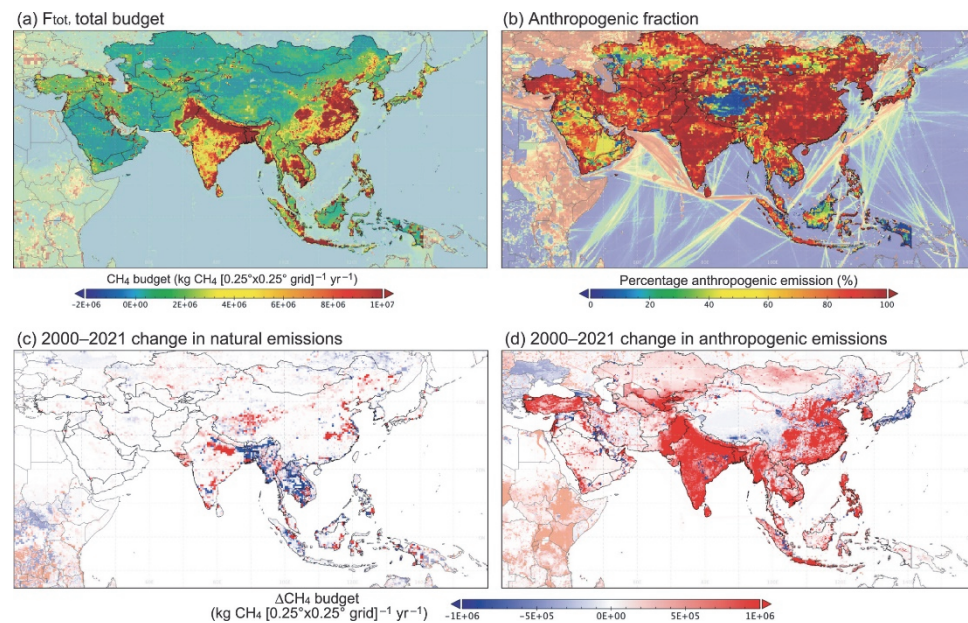
Project 1. Quantitative evaluation of natural/anthropogenic GHG sources and sinks on the global scale

This project aims to develop unified, neutral, and objective methods for estimating global GHG sources and sinks, from developed to developing countries, that are associated with different technical levels of preparation and compilation of emission inventories. To do this, we are making the best use of the data obtained from ground-based, ship-based, aircraft, and satellite observations. The project comprises three sub-themes: (1) GHG exchange over land and ocean, based on highly precise observations; (2) GHG budgeting over an extensive regional scale by atmospheric observation and modeling; and (3) GHG emissions and carbon (C) and nitrogen (N) dynamics associated with human activities.

A comprehensive methane (CH₄) budget, including spatial and temporal patterns of sources and sinks, is pivotal for effective climatic mitigation and prediction. To

elucidate the Asian CH₄ budget during the period 1970–2021, natural sources and sinks were evaluated by using a process-based biogeochemical model, complemented with ground and satellite observations (Fig. 2). Anthropogenic sources were evaluated by using emission inventories produced by socioeconomic studies. During 2001–2021, Central, East, South, Southeast, and West Asia accounted for 3.3%, 35.1%, 25.6%, 23.1%, and 13.0%, respectively, of Asian emissions. Sectoral compositions and temporal variations differed among subregions. Emissions from paddy field soils in Asia were smaller in 2021 (33.6 Tg CH₄ year⁻¹) than in 1970 (39.2 Tg CH₄ year⁻¹) because of changes in agricultural production. Among natural sources, wetlands accounted for 63% of total emissions in East Asia, but geological emissions predominated in Central and West Asia. Interannual variability of the net CH₄ budget was due mainly to wetland and biomass burning emissions, whereas decadal variability was due to emissions from the anthropogenic sector. Bottom-up evaluations of regional budgets can provide information critical to the Global Stocktake of the Paris Agreement, the Global Methane Pledge, and other related actions.

Fig. 2
Distribution maps of the total CH₄ budget. (a) Total flux; (b) the anthropogenic contribution; and changes in (c) natural and (d) anthropogenic emissions from 2000 to 2021.¹⁾



Reference:

Ito, A., Patra, P. K., Umezawa, T. (2023) Bottom-up evaluation of the methane budget in Asia and its subregions, *Global Biogeochemical Cycles*, 37, e2023GB007723

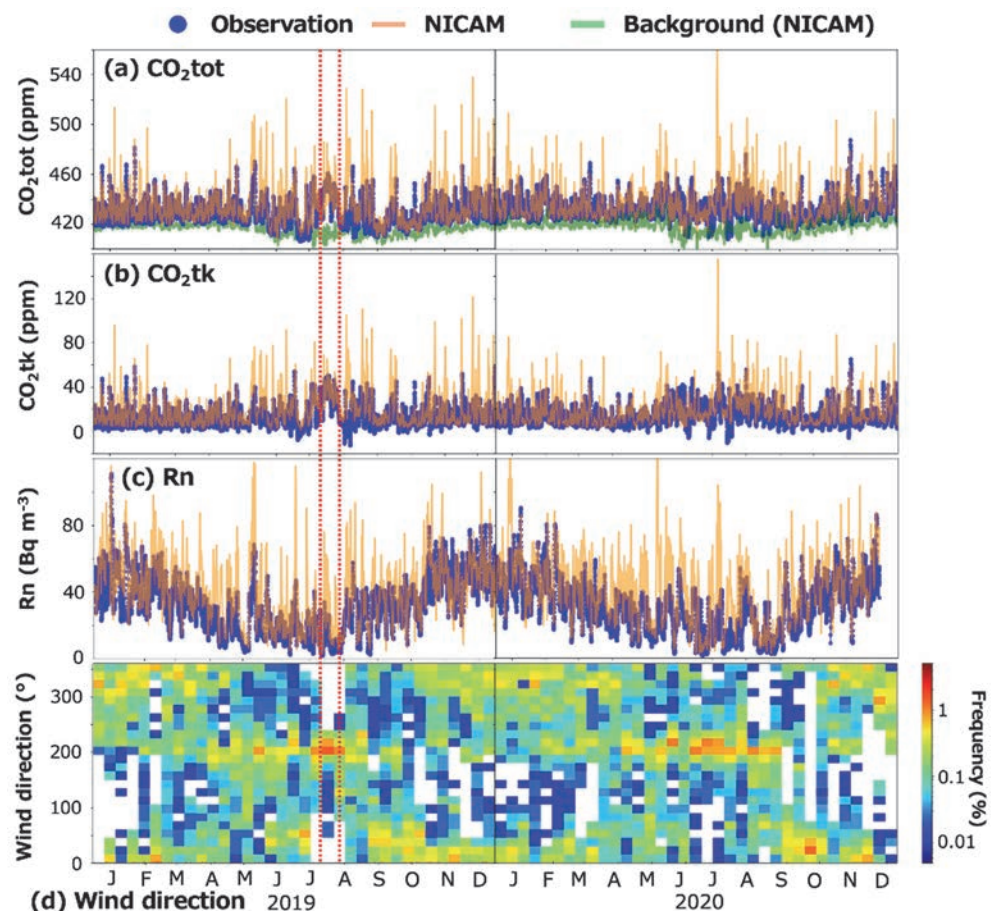
Project 2. Quantitative evaluation of anthropogenic SLCF and GHG emissions on regional, national, and city scales

This project aims to reduce the uncertainties in anthropogenic emission inventories for SLCF and GHG. These inventories are based on international assessment reports and are used in modeling studies of both climate and air quality. We perform four main activities: (1) expansion of our network of observations from the ground and

from ships and aircraft; (2) development of new analysis and observation methods; (3) development of a method of estimating emissions at a high spatial resolution; and (4) building of high-resolution inventories.

Quantifying emissions from megacities is important for reducing GHG emissions. To estimate net carbon dioxide (CO₂) fluxes from Tokyo, a global, high-resolution CO₂ simulation was made with carbon flux data from a global inverse analysis, constrained by the CO₂ concentration data obtained at an altitude of around 250 m above the ground at TOKYO SKYTREE (TST; a 634-m-high freestanding broadcasting tower; 35.71°N, 139.81°E) in central Tokyo, Japan (Fig. 3). Simulated variations of atmospheric CO₂ concentrations were reproduced well at remote sites around Japan. Tag-tracer simulations revealed that the variations of CO₂ concentrations at TST were driven largely by fluxes in the southwest region of Tokyo, including the western Tokyo Bay area, where large power plants are located. A regression analysis of modeled and observed CO₂ concentrations of Tokyo origin was made, and the impacts of the local wind speed were identified. Removing the data associated with wind speeds below 7 m s⁻¹ improved the model-vs.-observation agreement. We estimate that the annual net CO₂ emission from Tokyo is 79.5 ± 6.6 Tg-C year⁻¹. This demonstrates the usefulness of tag-tracer simulations with a global high-resolution model in monitoring the CO₂ emission changes in a megacity.

Fig. 3 Observed and Nonhydrostatic ICosahedral Atmospheric Model (NICAM)-calculated (a) total CO₂; (b) CO₂ originated from Tokyo; and (c) radon at TST for the period 2019–2020. Also shown are (d) the frequencies of wind direction at TST for 2019–2020. Red dotted lines indicate high-emission events caused by the continuous southern wind.²⁾



Reference:

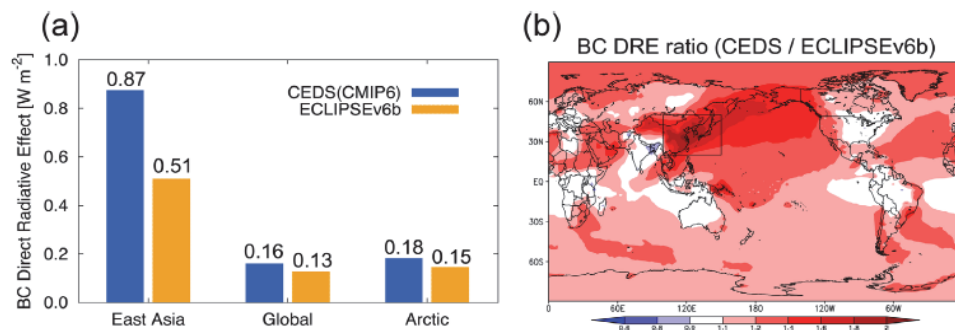
Yamada, K., Niwa, Y., Terao, Y., Tohjima, Y., Tsuboi, K., Ishijima, K., Murayama, S. (2025) Estimation of CO₂ fluxes from Tokyo using a global model and tower observation, *Journal of the Meteorological Society of Japan*, doi:10.2151/jmsj.2025-004

Project 3. Simulation and projection of climate air quality with enhanced numerical modeling capabilities

In this project, we are studying historical and future changes in climate and air quality by numerical simulation by using global climate models (GCMs) that include aerosol and chemistry modules. Output data from the numerical simulations are useful for discussing measures for the mitigation of, and adaptation to, climate and air quality changes. By producing these output data, we intend to help to achieve the temperature goals in the Paris Agreement.

We evaluated the mass concentration levels and long-term trends of black carbon (BC) in the historical and future scenario simulations by using 12 climate models from the Coupled Model Intercomparison Project Phase 6 (CMIP6) for East Asia, the region with the largest anthropogenic emissions (Fig. 4). By comparing the results with surface observations at two regionally representative sites, Fukue and Noto, for the period 2009–2020, we found that the CMIP6 multi-model mean was approximately double the observed BC concentrations and did not reproduce the observed decreasing trend before 2014. Sensitivity simulations of emission inventories performed by using a chemical transport model, GEOS-Chem, suggested that the overestimation and increasing trend of Chinese BC emissions in the CMIP6 historical inventory (CEDSV2017-05-18) were responsible for the higher concentrations and opposite trends in the CMIP6 BC simulations. The direct radiative effect of BC for CEDSV in East Asia was estimated to be 72% larger than that for the ECLIPSEv6b inventory, which reproduced the observed BC concentrations reasonably well.

Fig. 4
 Comparison of black carbon (BC) direct radiative effect (DRE) at the top of the atmosphere in 2014 over East Asia (20°N to 50°N; 100°E to 150°E), the global area, and the Arctic (> 66°N) between CEDSV for CMIP6 and ECLIPSEv6b. (b) Spatial distribution of the ratio of BC DRE between CEDSV for CMIP6 and ECLIPSEv6b. The black rectangle represents the East Asian region.³⁾



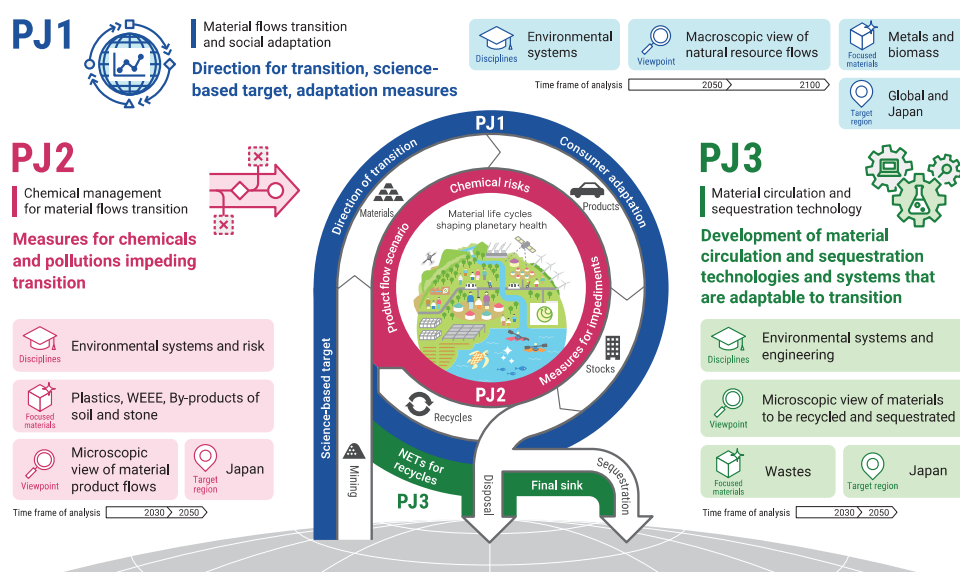
Reference:

Ikeda, K., Tanimoto, H., Kanaya, Y., Taketani, F., Matsuki, A. (2023) Evaluation of black carbon concentration levels and trends in East Asia from CMIP6 climate models: Comparison to long-term observations in Japan and biases due to Chinese emissions, *SOLA*, 19, 239–245, doi:10.2151/sola.2023-031

Overview of Material Flow Innovation Research Program

The Material Flow Innovation Research Program is focused on the assessment and enhancement of material flows over entire product life cycles to achieve the sustainable utilization of resources. We have been implementing three research projects with the goal of qualitatively and quantitatively demonstrating the future changes required in material flows (Fig. 1). The projects are: Project 1, Material flows transition and social adaptation (PJ1); Project 2, Chemical management for material flows transition (PJ2); and Project 3, Material circulation and sequestration technology (PJ3).

Fig. 1 Overall diagram of the project structure of the Material Flow Innovation Research Program. NETs, for Negative Emission Technologies; WEEE, waste electrical and electronic equipment.



In 2023, we continued to implement the yearly plans for each project and to circulate press releases regarding papers. Owing to the relaxation of COVID-19 restrictions, we were also able to actively communicate our achievements to domestic and international conferences and symposiums. We also continued to exchange opinions with private companies and organizations, mainly from manufacturing industries. To increase the number of users of an open-source personal carbon-footprint estimation app that we released last fiscal year (11,820 users as of 21 October 2023), we provided support for the app.

As cross-project results, by applying a pyrolysis system from PJ3, we identified the release characteristics of per- and polyfluoroalkyl substances (PFAS) that originated from water repellents in refuse-derived paper and plastics densified fuels (RPFs) and that had been detected in PJ2. Also, we conducted a cost assessment that was based on the effectiveness of PJ1's mercury-reduction scenario for artisanal and small-scale gold mining (ASGM) and PJ3's mercury management technologies, and we contributed to the accumulation of comprehensive knowledge on ASGM solutions under the Minamata Convention.

Highlighted research findings

Project 1: Material flows transition and social adaptation

The large-scale consumption of natural resources has historically been accepted as the cost of economic growth and personal well-being. However, consuming natural resources at the current pace is unsustainable, and the need to reduce resource consumption through more efficient use has become increasingly apparent. We have tracked the status of material utilization in a particular country, including inflow, outflow, and cyclical use, by using EW-MFA (economy-wide material flow accounting). We also used raw material consumption and material footprint (MF), two consumption-based indicators, to estimate the direct and indirect material use by a country through international trade. For instance, the countries with the largest per capita material footprints are Australia, Japan, and the United States, each of which exceeded 25 t per person as of 2008. The MF of the world increased substantially until 2014, driven by emerging economies in the Asia-Pacific region, including China, but it has since plateaued. Among the countries with the largest per-capita MFs, Japan is the only one that has seen a downward trend in total material flows: they fell from 2.1 billion tonnes in 2000 to 1.6 billion tonnes in 2015.

In the Japanese government's Fundamental Plan for Establishing a Sound Material-Cycle Society, progress toward a sound material-cycle society is assessed by using four material flow indicators (a, resource productivity; b, final disposal; c, cyclical use rate of inflow; d, cyclical use rate of outflow). In addition, if we are to create a carbon-neutral society, we need to achieve virtually zero emissions of greenhouse gases (GHGs). To integrally achieve a society that is both sound in material-cycling and low in GHG emissions, it would be helpful if improvements in material flow indicators were to contribute to reductions in GHG emissions. From 2011 to 2015, all four of the material flow indicators improved, and GHG emissions were reduced from 1353 MtCO₂ to 1320 MtCO₂. However, it was unclear how these changes were affected by economic factors, and this lack of clarity prompted the next stage of our research.

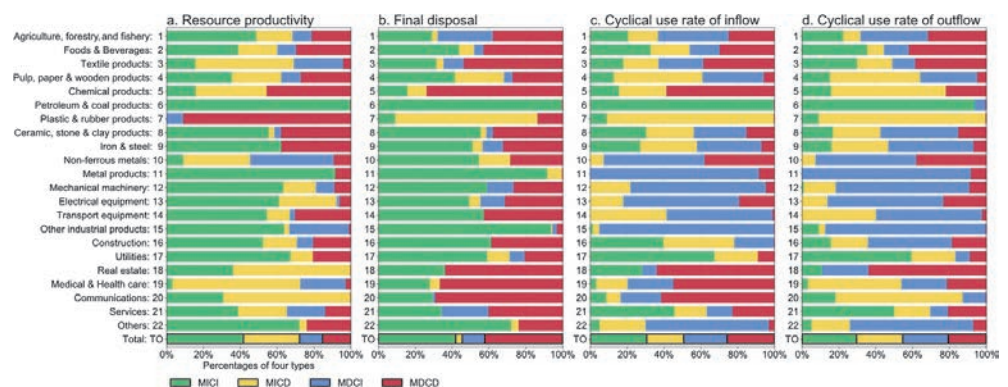
In this research¹⁾, we applied a structural decomposition method based on an input–output model, with the classification of 397 industrial sectors to identify those industrial sectors that contributed to improvements in both material flow indicators and GHG emissions [Both Improved]; those that contributed to either of them [Either Improved]; and those that led to a deterioration in both of them [Both Deteriorated]. We grouped the 397 industrial sectors into 22 segments and examined the ratios of the above contribution types by industry on the basis of production value. For the material flow indicators a (resource productivity) and b (final disposal), [Both Improved] had the highest ratios in many industries (green in Fig. 2). For the indicators c (cyclical use rate of inflow) and d (cyclical use rate of outflow), there were a few industries with [Both Improved], but those with [Either Improved] (yellow: material flow indicators improved and GHG emissions deteriorated; blue: material flow indicators deteriorated and GHG emissions

improved) were dominant. This suggests that, although improvements in cyclical use rates and reductions in GHG emissions were both achieved in the country as a whole, some industries have a structural relationship that makes it difficult to achieve both of them at the same time.

In our analysis of the industrial segments, all of the material flow indicators improved along with GHG reductions in petroleum and coal products (no. 6 in Fig. 2). However, in the plastic and rubber products segment (no. 7 in Fig. 2), for example, the contributions consistent with GHG reductions were on a very limited scale for any of the material flow indicators. Improving consistency between the two at the industry level on the basis of the respective features of the industries will drive progress toward a sound material-cycle society and a decarbonized society.

The above results show the need for a structural understanding of the relationship between material use and GHG emissions. For this purpose, a mechanism to manage both simultaneously, along with motivation for its implementation, would be helpful. For example, new rulemaking by the TCFD (Task Force on Climate-related Financial Disclosures) to raise financial motivation will likely incorporate a perspective on material flow management in the corporate management or disclosure of carbon emissions.

Fig. 2 Contribution to changes in four material flow indicators (M) and GHG emissions (C), by industrial segment. (green: both M and C improved [MICI]; red: both M and C deteriorated [MDCD]; yellow: M improved and C deteriorated [MICD]; blue: M deteriorated and C improved [MDCI]). ¹⁾



Reference:

- 1) Hata S. et al. (2023), Supply chain factors contributing to improved material flow indicators but increased carbon footprint, *Environmental Science & Technology*, 57 (34), 12713–12721

Project 2: Chemical management for material flows transition

Although there is an urgent need to identify how microplastics (MPs) pollute the environment, the mechanism of MP formation through the degradation and fragmentation of plastics released into the environment is still unknown. We developed a method for preparing cross-sections of degraded plastic samples by using ion-beam milling. The aim was to observe changes in the microstructures of these cross-sections, such as the changes in the growth or depth of cracks in plastics, which is the starting point for MP formation. By using scanning electron microscopy to examine the microstructures of cross-sections prepared from the

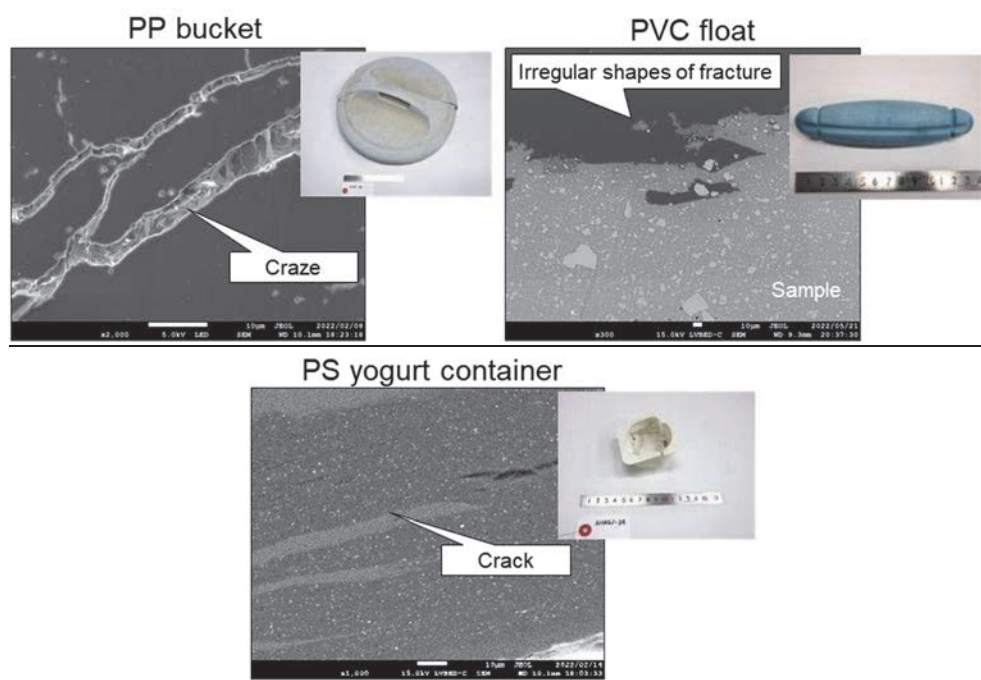
2. Material Flow Innovation Research Program

fragments of 15 different plastic product samples collected from beaches, we found that the cracks grew to a maximum depth of 300 μm in polypropylene products, for example, whereas crack growth in the polystyrene products was less than 100 μm , indicating that their degradation was limited. Polyvinyl chloride products had almost no crack growth, but irregularly shaped MP particles in the order of 10 μm were formed on the surface, confirming that MP release was in progress (Fig. 3).

In addition, we conducted tests to examine regional differences in the speed and degree of plastics degradation. By using the abovementioned preparation method with a cross-section polisher, we observed the cross-sections of polypropylene samples exposed outdoors at 10 locations throughout Japan. Cracks grew deeper in the samples exposed outdoors in warmer regions (e.g., Okinawa), indicating that degradation tended to progress more quickly in warmer regions. Furthermore, as a result of an analysis of plastic melting peaks by using differential scanning calorimetry, we found that the melting peak shifted to lower temperatures and the melting heat increased in heavily degraded samples. This means that the crystallinity increases as plastics degrade, indicating that it may be possible to quantitatively evaluate the degradation level of plastics by using the melting peak position and melting heat as indices. We also measured the two indices in samples subjected to accelerated exposure to ultraviolet light from xenon lamps. The samples with 2 weeks of accelerated exposure to the ultraviolet light had similar values to those with 3 months of outdoor exposure in a warm region, providing some insight into the relationship between accelerated exposure and outdoor exposure.

These results will help to establish a methodology for estimating the speed and degree of plastics degradation on the basis of the types of plastics and the period of their outdoor exposure, by region. They will also help us to refine the behavior parameters for plastics degradation and fragmentation in the environment. Through dynamic environmental modeling approaches, this will ultimately improve the accuracy of prediction and evaluation of the amounts of MPs released.

Fig. 3 Observed microstructures of cross-sections of degraded plastics prepared by the ion-beam milling method. PP, polypropylene; PVC, polyvinyl chloride; PS, polystyrene.



In addition, we analyzed the homolog compositions of 36 chlorinated paraffins (CPs) products distributed in various countries since the 1970s. The analysis showed that 10 of them contained short-chain CPs (SCCPs) as major components, but the SCCP content would have been unrecognized by producers or importers. We also analyzed the PFAS content of 22 refuse-derived fuel (RDF) and RPF samples. PFAS were detected in all samples, and the main sources were considered to be waste textiles and papers. Furthermore, we demonstrated that, even under Japan's strengthened soil environmental standard for hexavalent chromium, it would be possible to maintain the use of recycled crushed concrete with the necessary environmental safety quality controls by evaluating the leaching concentration of hexavalent chromium. This would be done by using a stirring-type leaching test of uncrushed samples, in accordance with the actual use situation of recycled crushed concrete.

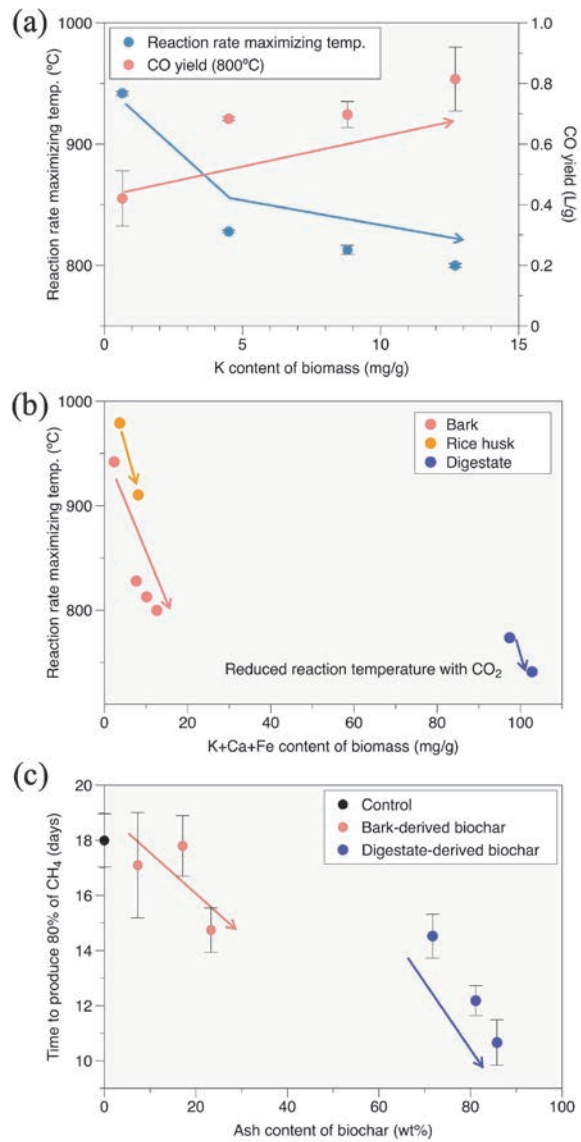
Project 3: Material circulation and sequestration technology

In the field of carbon-cycle waste treatment for decarbonization, we worked on an alternative technological system for waste biomass conversion. Specifically, we examined the conversion of the carbon content to CO gas in dry waste pyrolysis and the acceleration of fermentative methane generation treatment of wet waste by using ash-rich residue. In the pyrolysis of woody biomass with CO₂ gas supplied, we found that the temperature at the peak of the reaction speed of CO gas formation (CO₂ + C → 2CO) with CO₂ gas reduction tended to decrease as the K concentration in the material increased, whereas the peak reaction speed tended to increase. In the range of K concentration in the material from 0.65 to 13 mg/g, the peak temperature

decreased from a maximum of 942 °C to 800 °C, and the amount of CO gas formed by pyrolysis at 800 °C approximately doubled from 0.4 L/g to 0.8 L/g (Fig. 4a). These changes in reactivity with CO₂ were more prominent with different types of biomass, and the reactivity was found to increase with the concentrations of Ca, K, and Fe in the biomass. In particular, the reactivity of the anaerobic digestate was high, with the peak temperature dropping to 741 °C (Fig. 4b). As the conversion to CO consumes carbon in biochar, the residue after the reaction becomes an ash-rich solid. Although it is not suitable for carbon storage, it has proved to be an excellent anaerobic methane-production accelerator. An anaerobic digestion experiment, in which biochar with different ash contents ranging from 5% to 86% was input, showed that methane formation progressed most quickly under the conditions with the highest ash content (Fig. 4c).

These results suggest that there is a new pathway for the recycling of CO₂ generated from waste treatment. In the field of material cycles, separation and capture of CO₂ generated from waste treatment are being examined with the aim of achieving net-zero emissions by 2050. However, the direct use of captured CO₂ in agriculture and industry faces a supply–demand mismatch, whereas its conversion to raw materials and fuels faces the issue of hydrogen procurement. Pyrolysis and carbonization as post-treatment in the anaerobic digestion of wet wastes such as sludge and raw garbage are technologies that have already been introduced in some areas of Japan. According to our research, the use of separated and captured CO₂ in this treatment will lead to hydrogen-independent CO generation utilizing the high CO₂ reactivity of the digestion residue. This can contribute not only to energy savings with progress at low temperatures, but also to suppression of the formation of clinker derived from metal carbonates with low melting points, which hinders the practical application of CO₂-added pyrolysis. The residue after the reaction can also be used to improve the efficiency of wet-waste treatment upstream of the series of procedures. In general, this approach will provide support for the design of a new carbon-cycle waste treatment system that combines wet-waste treatment and CO₂-introduced pyrolysis.

Fig. 4 Reactivity with CO₂ in biomass pyrolysis (a, b) and acceleration of methane fermentation by using formed biochar as an additive (c).



Reference:

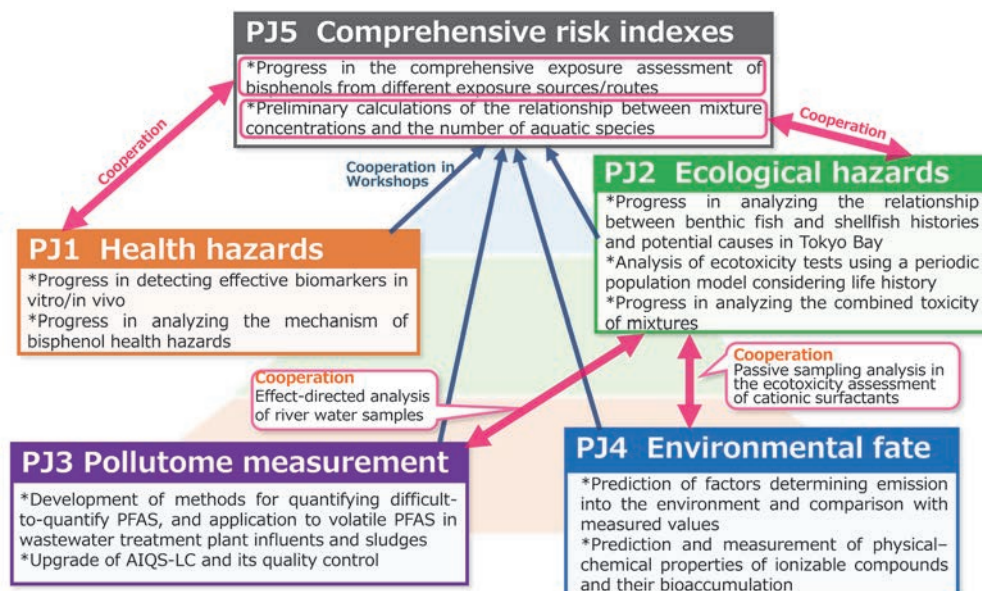
2) Kobayashi T., Kuramochi H. (2023) Catalytic pyrolysis of biomass using fly ash leachate to increase carbon monoxide production and improve biochar properties to accelerate anaerobic digestion. *Bioresource Technology*, 387, 129583

Comprehensive Environmental Risk Research Program

In this program, we conducted five projects to accomplish our annual goals. We aimed to more comprehensively investigate the environmental risks of all chemicals of concern and to consider vulnerable groups and life stages of humans (Project 1) and those of other organisms (Project 2). We also upgraded our comprehensive measurements of the pollutome (Project 3) and mathematical models of the environmental fate of chemicals (Project 4) to better assess the fate and transport of these chemicals, as well as the effects and risks that have been hard to quantify. As result of these efforts, we started to establish comprehensive health risk indexes and ecological risk indexes (Project 5).

In the third year of this Research Program we emphasized cooperation by holding periodic workshops under Project 5 with project leaders and key members of Projects 1 to 4. As a result, we made progress in the comprehensive exposure analysis of bisphenol-A and alternative bisphenols from difference sources with different methods of generation. In addition, the comprehensive ecological risk was preliminarily calculated for the relationship between the concentration of monitored substances in rivers and the decrease in the number of aquatic species. We also continued to emphasize inter-project cooperation by extending the cooperation between Projects 2 and 3 in an effect-directed analysis to identify the major toxicants in river water samples. Moreover, as a result of cooperation between Projects 2 and 4, we applied passive sampling analysis to ecotoxicity test methods by using invertebrates such as daphnia to test for cationic surfactants (Fig. 1).

Fig. 1 Overview of inter-project cooperation and major progress in the Comprehensive Environmental Risk Research Program in FY 2023. AIQS-LC, liquid chromatography with automated identification and quantification systems.



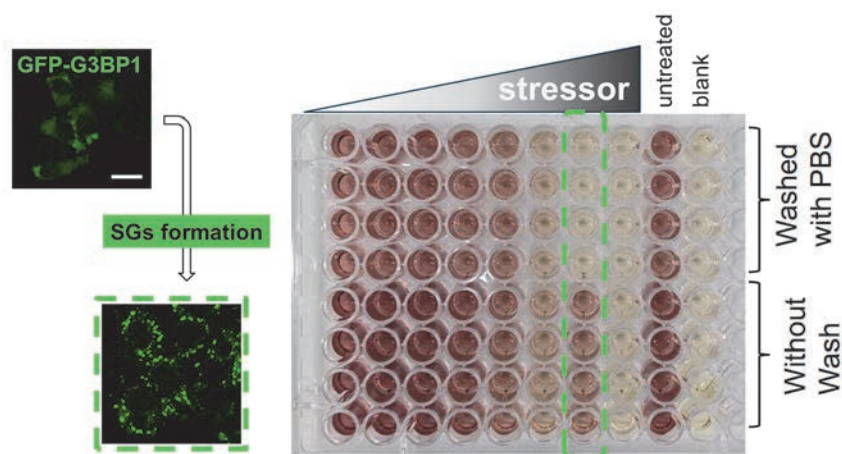
Project 1. Health hazard assessment considering the real-life environment and vulnerabilities

We established methods for assessing the human health hazards of chemicals, taking into account exposure in the general environment and vulnerable populations, and

we evaluated the effects of chemicals on disease, aging, and future generations. Our major research findings (including new *in vitro* evaluation systems and effects on neurodevelopmental disorders, allergic asthma, and aging) were as follows.

Ras GTPase-activating protein-binding protein 1 (G3BP1) is known to form stress granules (SGs) with, for example, the mRNA released when cells are exposed to stress, which halts translation. To visualize and monitor stress over time, we created cell lines that stably expressed GFP-G3BP1 (Hirano et al., 2024). Our findings indicated that the cell survival rate was not necessarily dose dependent; rather, it was higher when the SGs were well formed (Fig. 2). This suggests that a more accurate evaluation of environmental chemical toxicity could be achieved by considering the cellular resistance state until stress is relieved.

Fig. 2 Viability of cells at a concentration of SGs formation was unexpectedly higher. Washing-out the cells before routine evaluation often overlooks the cellular resistant state. (Hirano et al., licensed under CC BY 4.0; this figure is a partial modification of the original.)



In *in vivo* experiments, we analyzed a mouse model of hypothyroidism and detected a decrease in behavioral activity under specific conditions. In addition, we have developed automated home-cage monitoring systems to identify behavioral endpoints that persist into old age or are specific to old age in mice exposed to chemicals during their development. In an *in vitro* analysis using a human neuronal cell line, RNA-seq analysis revealed that exposure to some flame retardants reduced the expression of genes involved in neural development and axonal elongation.

We investigated the health hazards of bisphenols by using mouse models of allergy and senescence. We found that oral exposure to bisphenol F exacerbated allergic asthma. The mechanism of this may involve increased numbers of mediastinal lymph node cells, a trend toward increased Th2 cytokine production in allergen-restimulated splenocytes, and changes in the gut microbiota. Oral exposure to bisphenol S may induce anxiety-like behaviors in senescence-accelerated mice (SAMP8), accompanied by the altered expression of anxiety-associated genes (*BDNF*, *5HT1A*, *Drd2*) and apoptotic markers (*caspase-3*, *Bax*) in the hippocampus.

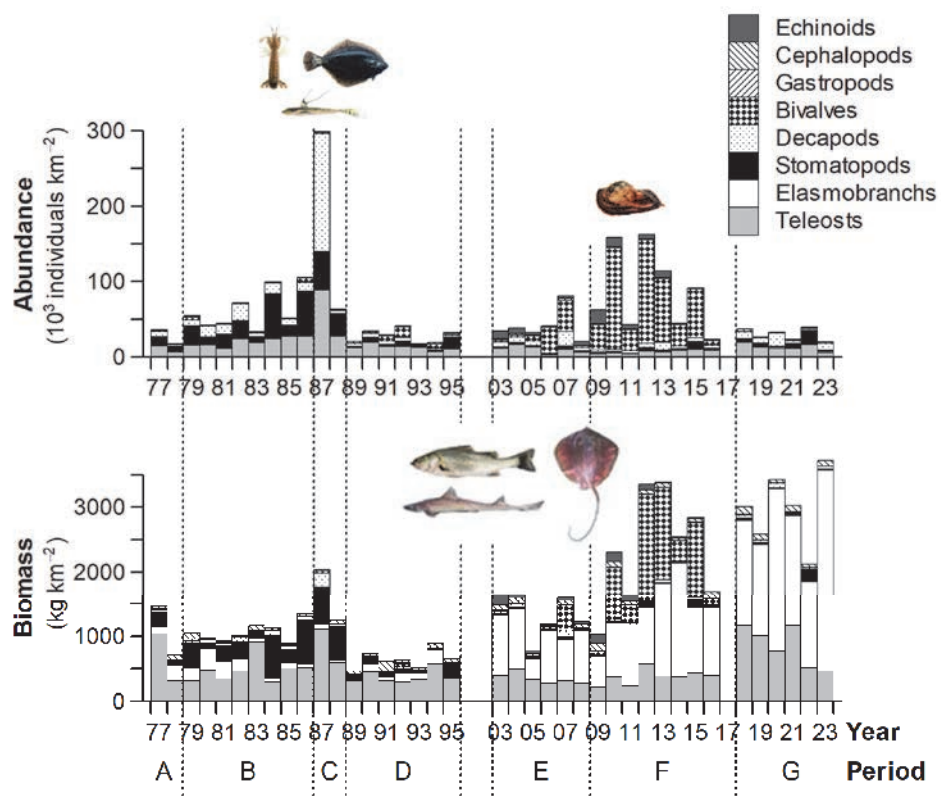
Reference:

Hirano S., Udagawa O., Kanno S. (2024) Formation of stress granules and non-canonical survival responses in arsenite-exposed cells. *bioRxiv*, 2024-07. doi: <https://doi.org/10.1101/2024.07.29.605725>

Project 2. Ecological hazards and factor analysis considering vulnerabilities

We investigated long-term changes in the megabenthic community in Tokyo Bay, Japan, by using data from fisheries-independent trawl surveys conducted from 1977 to 2023. In addition, we examined the potential relationship between changes in biotic communities and environmental conditions. The total abundance and biomass exhibited an increasing trend until 1987, followed by a substantial decline from the late 1980s to the 1990s due to a decrease in the abundance and biomass of small to medium-sized fish and crustacean species, such as mantis shrimp, dragonet, and marbled sole (Fig. 3). A marked increase in the biomass of large fishes such as Japanese sea bass and elasmobranchs, as well as Kobelt’s ark shell, was observed in the 2000s (Fig. 3). These shifts in the megabenthic community structure were correlated with an increase in water temperature and a decrease in nutrient concentrations and copepod densities. Cumulative evidence suggests that a marked shift in the megabenthic community structure occurred between the 1970s and the 2020s, possibly in association with variations in the environmental conditions in Tokyo Bay.

Fig. 3 Changes in the annual mean densities of major taxonomic groups within the megabenthic community of Tokyo Bay, Japan, in terms of abundance and biomass. Year groupings (periods A to G) were identified through cluster analysis of species biomass by year for the megabenthic community, coupled with a similarity profile test (SIMPROF; $P < 0.05$) (Kodama et al., permission from Elsevier).



We developed a mathematical model to assess population-level ecological effects by using ecotoxicity test data. Conventional methods for assessing population-level impacts include predicting population growth rates and conducting viability analyses by using matrix population models. However, conventional matrix population models often fail to account for the seasonal aspects of life history

observed in many organisms. To address this, we developed a method for population viability analysis that incorporates seasonality by using a periodic matrix population model, which represents the life history over 1 year at weekly intervals. In an ecotoxicological test using 4-nonylphenol (Medaka Extended One Generation Reproduction Test, MEOGRT), our results indicated that exposure to 4-nonylphenol from May to August—when the elasticity of the population growth rate to egg production is high—could substantially reduce the population growth rate compared with exposure to the same concentration in other seasons. The periodic matrix population model allows for a more detailed population-level ecological risk assessment by considering not only exposure concentrations but also the timing of exposure. Furthermore, lifetime survival and reproduction analyses that include life history stages that are typically not examined in standard ecotoxicological tests can enhance the accuracy of population-level risk assessments. We are currently developing matrix population models for *Oryzias latipes* and *Daphnia magna* on the basis of their full life cycles.

In mixture effects experiments, phthalic acid esters of alkyl chains with 1 (C1) to 11 (C11) carbons were assayed by using an algal growth inhibition test, daphnid reproduction test, and fish short-term test at the embryo and sac fry stages. We found a trend of increasing toxicity with increasing carbon chain from C1 to C6 (C5 for fish), whereas no significant toxicity was detected for C8 or longer with suspensions over the aqueous solubility limit. We combined these results with data from the ToxCast database of the US Environmental Protection Agency and investigated the (sub-)grouping of the series of phthalic acid esters. This resulted in a case study of the (sub-)grouping of chemical substances.

We also continued with our toxicity tests—an algal growth inhibition test and a daphnid reproduction test—of ambient water samples collected from six sites across Japan. These tests were performed three times. We also performed tests on samples from 10 additional sites. A comprehensive metal analysis was conducted on all 28 samples by using inductively coupled plasma-mass spectrometry (ICP-MS). Multi-target analysis by gas chromatography–mass spectrometry with automated identification and quantification systems (AIQS-GC) was conducted on 14 samples in cooperation with Project 3. The measured concentrations were compared with the toxicity data to calculate the toxic units and the contribution to the overall toxicity. Metals such as nickel (for daphnids) and zinc (for algae) were considered as major toxicants; the measured concentrations were corrected by using a bioavailability model, but the toxicity caused by the metals was overestimated. Toxicity was detected for a few solid-phase-extraction samples. This, combined with the measured concentrations suggested by AIQS-GC, indicated that a few insecticides, such as organophosphates and pyrethroids, could be major contributors to the daphnid toxicity of the water samples, whereas herbicides such as bromacil were considered to be major contributors to the algal toxicity.

Reference:

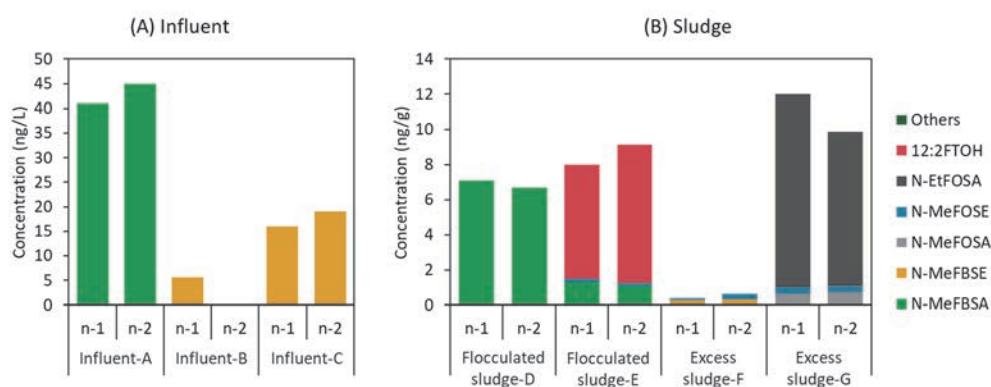
Kodama K., Kuroki M., Yamakawa T., Shimizu M., Kintsu H., Horiguchi T. (2024) Remarkable shifts in the megabenthic community structure over four decades in Tokyo Bay, Japan, in relation to environmental variations. *Marine Environmental Research* 200, 106640

Project 3. Comprehensive pollutome measurement

This project aims to develop methods to help us measure and understand exposure to all environmental chemical substances of concern. We also intend to develop new methods of analyzing chemical substances that have been hard to identify and quantify and establish a scheme that will help search for causative factors when new effects become apparent.

In proposing new analytical methods for difficult-to-measure substances, we developed a quantitative analytical method for 14 per- and polyfluoroalkyl substances (PFAS) that have a hydroxy group (fluorotelomer alcohols, FTOHs), an iodide (fluorotelomer iodides, FTIs), an acrylate group (fluorotelemer acrylates, FTACs), or a methacrylate group (fluorotelemer methacrylates, FTMACs) at the end of the polyfluoroalkyl moieties, as well as for six PFAS that have a sulfonamide group (perfluoroalkyl sulfonamides, FASAs) or a sulfonamidoethanol group (perfluoroalkane sulfonamido ethanols, FASEs) at the end of the perfluoroalkyl moieties. In addition, we used the new method to detect the targeted PFAS in samples of wastewater treatment plant influents and sludges. We detected 12:2 FTOH, three FASAs (N-MeFBSA, N-MeFOSA, N-EtFOSA), and two FASEs (N-MeFBSE, N-MeFOSE), with good chromatograms. Their concentrations ranged from 45 ng/L or less in the leachates and 11 ng/g or less in the sludges (Fig. 4). The results provided information about the current status of contamination of the influents and sludges in Japan by these PFAS. This new method should be useful for the comprehensive evaluation and management of PFAS.

Fig. 4 Concentrations of PFAS detected in samples of wastewater treatment plant influent and sludge.



As part of our expansion of the range of substances to be measured in a comprehensive analysis, we have started to upgrade our automatic identification and quantification system (AIQS-LC), which uses sequential window acquisition of all theoretical fragment-ion spectra (SWATH), a data-independent acquisition

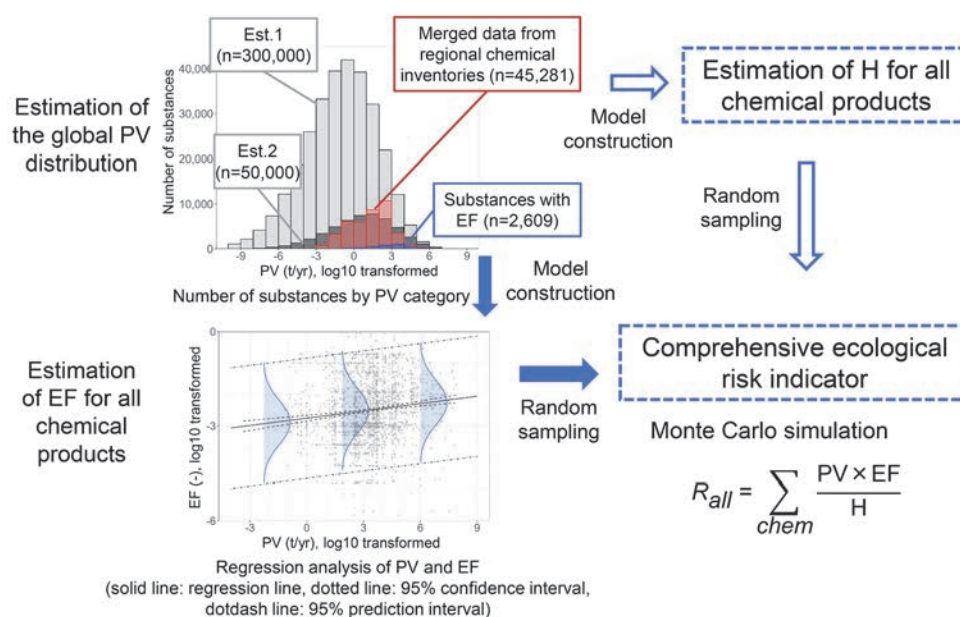
(DIA) method, for the simultaneous analysis of multiple components by using liquid chromatography with quadrupole time-of-flight mass spectrometry (LC-QToFMS). AIQS-LC is used to identify substances on the basis of such parameters as the retention time, the mass error between the accurate mass and exact mass of precursor ions, and the ion ratio of precursor and product (which are registered in advance from the DIA data), and to quantify them on the basis of the strength ratio of internal standards. This fiscal year, we improved our identification accuracy by calculating a method of correcting the predicted retention time by using six types of internal standards. Additionally, a round-robin test was performed across seven laboratories to determine the variability in quantitative values. We confirmed that the relative standard deviation for quantitative measurements of 90% of substances was less than 30%.

Project 4. Modeling the environmental fate of the pollutome

In this project, we are developing methods of deriving emission inventories, physicochemical parameters, and bioaccumulation properties to evaluate the environmental fates of all substances of concern for which we have only limited risk evaluation information. We are also improving environmental fate models to enable us to perform more reliable simulations and future predictions.

We estimated the global chemical production volume (PV) distribution, and we constructed a model for estimating the emission factor (EF) for all chemical products on the basis of limited data (Fig. 5). We collected ecotoxicity (H) data for 1253 substances and used them to construct a model to estimate the missing values of H on the basis of their relationship with PV.

Fig. 5 Conceptual diagram of estimation of the comprehensive ecological risk indicator for all chemical products



We evaluated the relationships between the natural variations determined for methyl-mercury (Hg) demethylation rates in North Pacific seawater and the properties of the water to find a proxy for estimating the concentrations of seawater Hg species. The vertical profiles of the demethylation rates obtained increased with decreasing water depth, in association with decreasing water temperature and increasing apparent oxygen utilization. These parameters can be obtained and calculated by sensor measurements, so that estimating some Hg species concentrations in seawater by modeling can be uncomplicated.

The hydrophobic sorption properties of 39 anionic PFAS were evaluated by measuring their liquid chromatography retention factors (k) on octadecyl (C₁₈)-coated silica particles. The k values were well correlated with the hydrophobicity-driven partition coefficients, such as those from water to phospholipid membranes, soil organic carbon, and the air–water interface, demonstrating that the measured k values are useful for predicting these properties. In addition, we examined methods for estimating the fish bioaccumulation kinetic parameters of alternative compounds of perfluoroalkyl acids, all of which are PFAS, by using the relationship with computationally predicted physical–chemical properties.

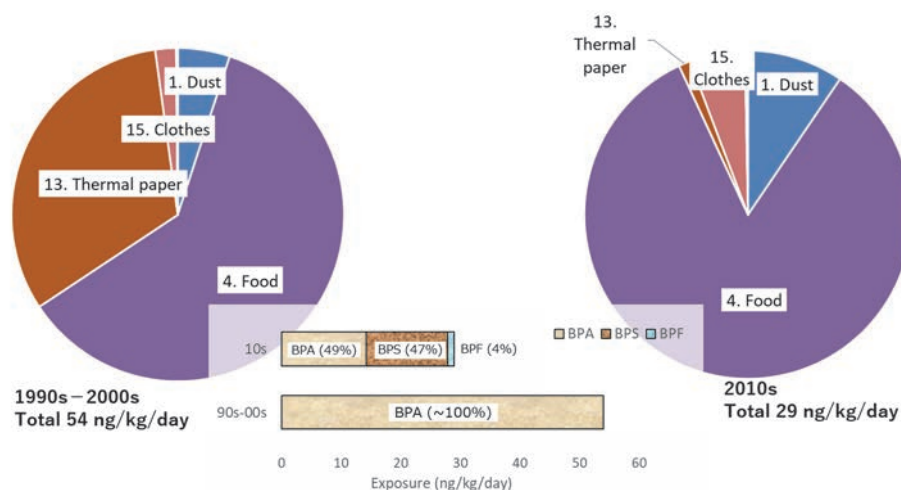
Project 5. Development of comprehensive health risk and ecological risk indexes

In this research project, we have continued to hold periodic workshops for the members including the leaders of other projects in the Comprehensive Environmental Risk Research Program. In these workshops, we have discussed the proposal of comprehensive environmental risk (i.e., health risk and ecological risk) assessment methods and assessment indicators for environmental risks. As an approach to the comprehensive environmental risk assessment of chemical substances, we are collaborating with other projects to achieve comprehensive risk assessments by dividing them into two dimensions: assessment by using comprehensive indicators for hazard assessment and simultaneous assessment of multiple chemical substances (grouping of similar chemicals).

In the field of comprehensive health risk assessment, we have focused on immunotoxicity related to social background, such as the recent increase in allergic diseases. We have selected chemicals to be assessed, namely bisphenol (BP) A and its substituted substances (e.g., BPS, BPF). The European Food Safety Authority reviewed the previous provisional tolerable daily intake (TDI) of 4000 ng/kg/day for BPA, and in April 2023 it proposed a revised TDI of 0.2 ng/kg/day, which is more than four orders of magnitude smaller than the previous value. This was based on the immunological effects (increase in Th17 cells) determined in animal experiments, and it remains controversial. In Project 1, animal experiments have shown that BPA and its alternative substances BPS and BPF have similar allergenic exacerbating effects. In Project 5, in a comprehensive exposure assessment, we examined the changes over time in exposure to BPs by gender and age group,

considering multiple sources of exposure and alternative substances. We considered a total of 16 combinations of exposure routes and sources, comprising 12 types of oral exposure (e.g., dust, toys, food), three types of dermal exposure (e.g., thermal paper), and inhalation exposure (indoor air). We found that, since the 1990s – 2000s, the exposure of the average adult human has been approximately halved. Exposure via food has been high in the past and was still high in the 2010s, but exposure from thermal paper has decreased. In addition, whereas almost 100% of the exposure of adults in the 1990s – 2000s was to BPA, the total exposure has almost halved, and it now consists of approximately equal exposures to BPA and BPS (Fig. 6). The exposure of infants to BPA from baby bottles, which was common in the past, has decreased, and in the 2010s, the contributions of breast milk and dust became large. In the future, we plan to analyze the results of the hazard assessment of BPA and alternative substances and the results of the exposure assessment and conduct comprehensive health risk assessments for multiple similar chemicals.

Fig. 6 Temporal changes in the exposure of the average adult human to bisphenol A and its alternative chemicals, considering 16 exposure sources, including food.



With the aim of developing an ecological risk index, we statistically estimated the number of species when the exposure concentrations of all target chemicals were small and compared it with the number of species at actual exposure concentrations to determine the reduction in the number of species due to chemical substance exposure. The concentrations of the 27 selected chemical substances, and the pH, were summarized into six variables by using principal component analysis. As a result of the statistical analysis, it was possible to estimate the impact of chemical substances on the number of species. For each location and month, the number of species reduced by chemical exposure was estimated, and this was used as a comprehensive ecological risk index. In this trial calculation, we estimated that the number of species had decreased at almost all locations and in almost all survey months. However, the above analysis focused on the number of species and did not include the population size of each species in the analysis. In future research, we plan to expand the analysis to a comprehensive ecological risk index based on species diversity, considering the population size of each species.

Harmonization with Nature Research Program

The Harmonization with Nature Research Program conducts research into, and technological development of, measures for biodiversity conservation, and the sustainable use of ecosystem services, which are essential for establishing a society in harmony with nature (Fig. 1). Our projects in FY 2023 were as follows:

Project 1: Sustainable ecosystem management strategies for a society with a declining population

Project 2: Management of ecological risk causative factors that threaten biodiversity and human society

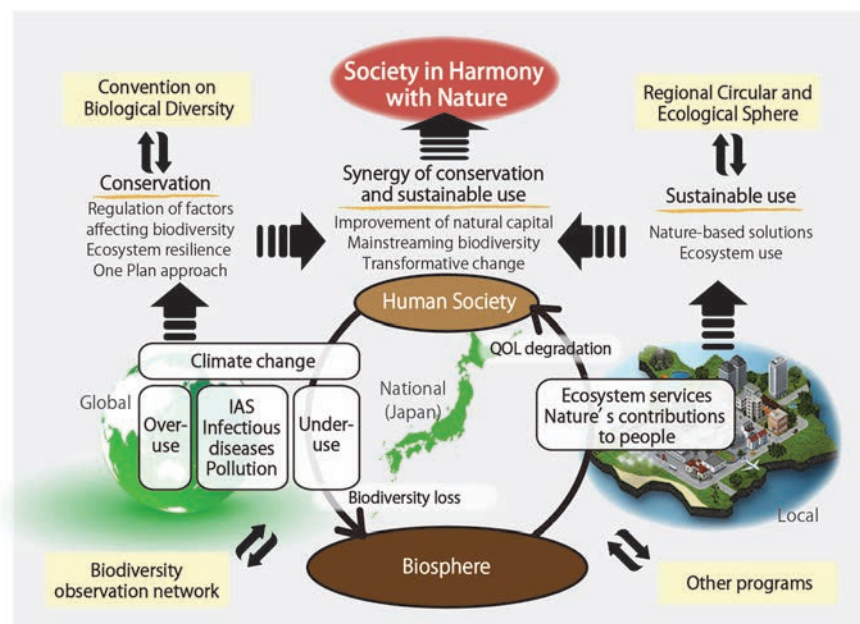
Project 3: Biological responses, acclimations, adaptations, and resiliencies to environmental changes

Project 4: Research on problem solving using ecosystem functions

Project 5: Integrated research for balancing conservation and utilization of biodiversity and behavioral change

Through these activities, we aim to mainstream biodiversity and promote transformative changes, such as behavioral change, as well as to improve natural capital by synergizing the conservation and sustainable use of biodiversity. We will also contribute to the Kunming-Montreal Global Biodiversity Framework of the Convention on Biological Diversity, the National Biodiversity Strategy and Action Plan 2023–2030, and the regional circular and ecological sphere from the perspective of sustainable use of regional resources.

Fig. 1 Overall structure of the Harmonization with Nature Research Program. IAS, invasive alien species; QOL, quality of life.



Project 1. Sustainable ecosystem management strategies for a society with a declining population

Sustainable agricultural development through enhancing biodiversity-friendly consumption by using wildlife-friendly labeling

Integration of agrobiodiversity benefits into market mechanisms attracts attention not only in conservation, but also in agriculture. A biodiversity-relevant food label (i.e., wildlife-friendly label) is a promising approach to overcoming the challenge of information asymmetry hindering mainstream wildlife-friendly farming and consumption. A key success factor of wildlife-friendly labels is whether the design attracts consumers.

To develop wildlife-friendly labels that consumers prefer, we conducted two choice experiment surveys of general Japanese consumers, focusing on wildlife-friendly rice. Our studies had two main purposes. The first research aim was to determine which certification label would attract consumers the most: outcome or input certification. The second aim was to determine which flagship species label would attract consumers the most: the daruma pond frog, the black-crowned night heron, or the Japanese pond loach.

For the first research aim, we confirmed that both input and outcome labels positively influenced consumer preferences. One interesting result was that consumer preferences for the certification requirements differed depending on the conservation target; our results showed that consumers preferred fish labels with outcome claims to those with input claims; in contrast, for bird labels, consumer utility was not increased by outcome claims but by input claims (Fig. 2).

Fig. 2 Summary of the main results of our first choice experiment survey.



Regarding the second research aim, our results showed that, on average, the black-crowned night heron label was the most attractive to consumers. However, there was preference heterogeneity associated with the flagship species. For example, a group may have had higher willingness to pay for fish than for a bird.

The differences in preferences for certification requirements and for flagship species highlight the importance of strategic certification and labeling in encouraging people to conserve biodiversity. The findings also highlight the role of the choice of flagship species on wildlife-friendly labels. Our empirical evidence provides insights to balance biodiversity conservation with food security through conservation marketing. We believe that our studies will aid in the development of well-designed wildlife-friendly labels to help balance biodiversity conservation and food security.

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Project 2. Management of ecological risk causative factors that threaten biodiversity and human society

Wing-slapping: A defensive behavior in which honey bees flick away ant intruders

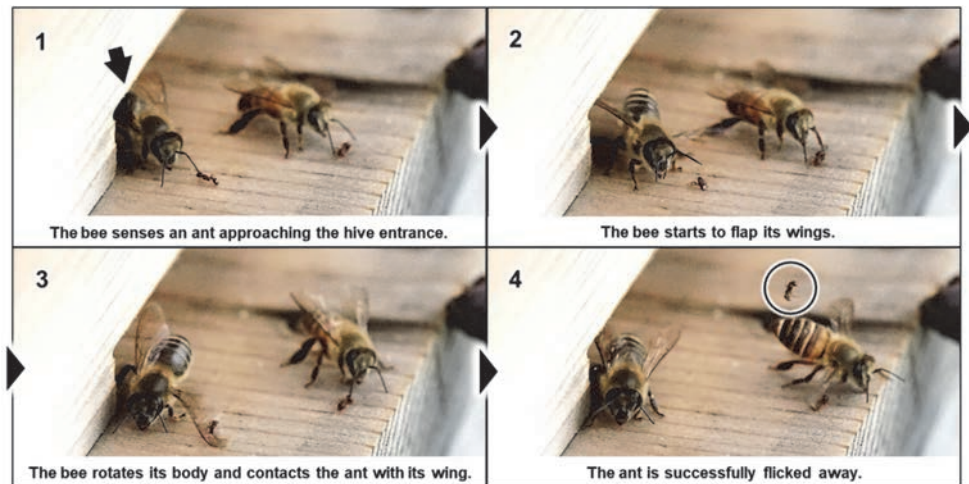
Beehives contain large stores of larvae, pupae, and honey, making them attractive food resources for natural enemies. Ants are one such enemy, and ant intrusions can sometimes cause devastating damage to honey bee colonies.

Studies in other countries have shown that honey bees prevent the entry of ants by facing away from the ants and flapping their wings to drive the ants away with wind pressure. This behavior is referred to as “fan-blowing” and has been observed among honey bee species and subspecies in various regions. On the other hand, the Japanese honey bee (a subspecies of the eastern honey bee), which is endemic to Japan, engages in a different defensive behavior in which the bees flick ants away through direct contact with their wings. Although this behavior was known anecdotally among some beekeepers, there do not appear to have been any academic studies that have examined the ecological significance of the behavior by using detailed observation.

To closely observe the defensive behavior of Japanese honey bees against intruding

ants, we trained a high-speed camera on worker bees as they responded to Japanese pavement ants approaching the hive entrance. The footage showed that the bees approached the ants and rotated their bodies while flapping their wings, thereby flicking the ants away (Fig. 3). We named this behavior “wing-slapping.”³⁾

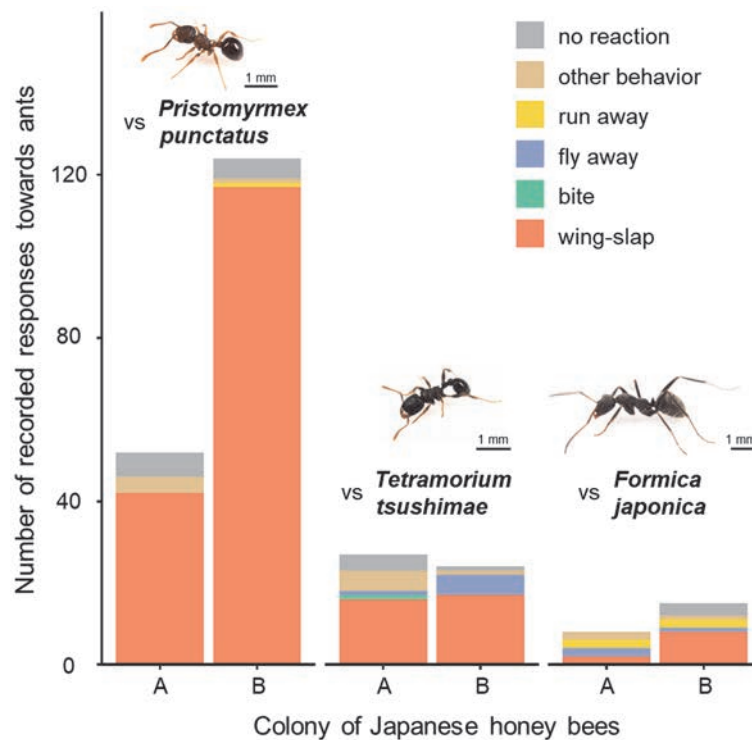
Fig. 3 The series of motions performed during wing-slapping by Japanese honey bees.



Next, to assess whether Japanese honey bees also perform wing-slapping on other ant species, we recorded the responses of Japanese honey bees to the introduction of three native ant species (Japanese queenless ant *Pristomyrmex punctatus*, Japanese pavement ant *Tetramorium tsushimae*, and Japanese wood ant *Formica japonica*) near the hive entrance. Wing-slapping was the behavior most frequently performed by Japanese honey bees in response to all three ant species (Fig. 4). This suggests that wing-slapping is the main behavior used by Japanese honey bees to defend against intruding ants.

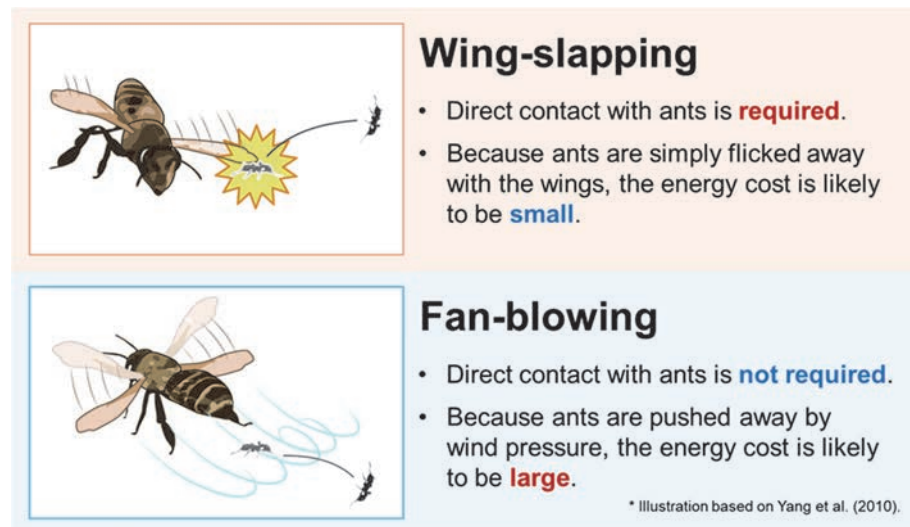
4. Harmonization with Nature Research Program

Fig. 4 Frequency of various behaviors by Japanese honey bees in the presence of each of three ant species.



It is unclear at this time whether other local populations of honey bees perform wing-slapping behavior. However, our results, in combination with previous reports from around the world, indicate that various honey bee species and subspecies employ different behaviors to defend against ant intrusion, and we speculate that this difference could be related to differences in the risk of predation by ants (Fig. 5). In regions where bees show fan-blowing behavior, the native ant species include so-called “aggressive ants” that approach hives to prey on adult bees. Therefore, fan blowing, in which the bee’s wings do not come into direct contact with the ants, is likely an effective means of reducing predation risk on the part of the bees, albeit at a high energy cost. On the other hand, in Japan, where wing-slapping behavior is prevalent, the risk of predation from ants is thought to be low because few native ant species actively prey on adult bees. We hypothesize that the more energy-efficient wing-slapping behavior evolved in this region as an adaptation to the lower predation risk from ants.

Fig. 5 Comparison of two behaviors used by honey bees to defend against intruding ants.⁴⁾



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This study was featured in *The New York Times*, *Scientific American*, *New Scientist*, and over 20 other international media outlets.

Project 3. Biological responses, acclimations, adaptations, and resiliencies to environmental changes

Predicting ecosystem changes by a new model of ecosystem evolution

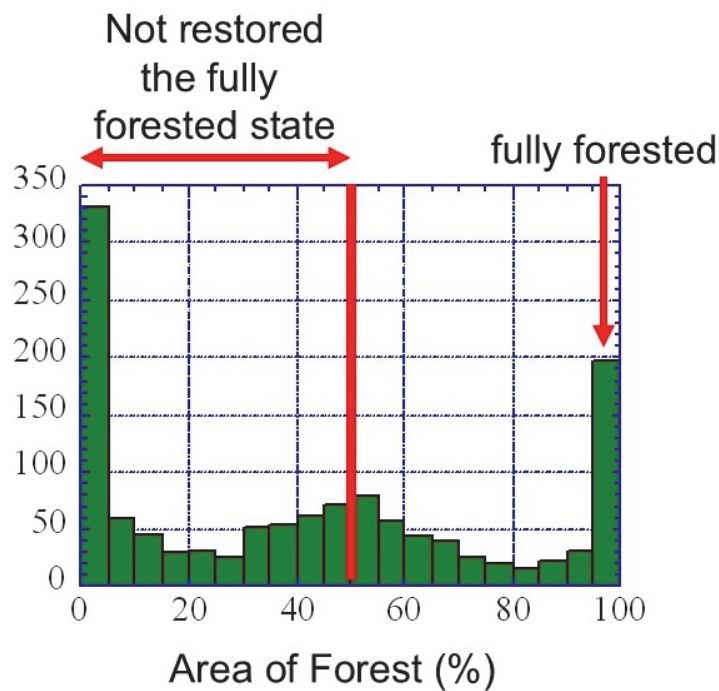
Computer simulation has been used widely to predict future events. Over the past decade, computer simulation has been increasingly used to predict changes in real ecosystems. In these studies, snapshots of ecosystems at certain points in time are instantly constructed, without consideration of their evolutionary histories. However, it may not be possible to correctly predict future events unless these evolutionary processes are considered, especially in ecosystems with unique evolutionary histories. In this study, we developed a new ecosystem model for reproducing the evolutionary process on an oceanic island, targeting Nakodojima in the Ogasawara Islands, located approximately 1000 km south of Tokyo. On this island, unique ecosystems evolved through isolation from the mainland. The ecosystems on an oceanic island are characterized by rare immigration and frequent on-island speciation. The model we developed incorporated these evolutionary processes of an oceanic island. The model successfully reproduced the primitive state of the ecosystem (the entire island covered with forest) before human settlement and the invasion of alien species. By adding multiple alien species to this

4. Harmonization with Nature Research Program

ecosystem, we were able to reproduce temporal changes in the ecosystem of Nakodojima after the invasion of alien species (shrinkage of forest, expansion of grassland and denuded areas). We then performed simulations in which feral goats were eradicated (as had actually been done on the island in 25 years ago.). The results suggested that, after the eradication of feral goats, the forests were unlikely to be restored (Fig. 6).

Fig. 6 Frequency of the area of forest in the final state of simulation.

The horizontal axis represents the area of forest (%). When the area of forest was lower the 50% of the area of island, it was regarded as that the forest was not restored. When the area of forest was larger than 95%, it was regarded that the forest was fully restored. In this study, in 768 cases of 1000 simulations, the forest was not restored. In 197 cases of 1000 simulations, the forest was fully restored.



In the island's simulated ecosystems in which the forests were not restored, arboreous plants with high growth rates had colonized the island during the early stage of evolution. Because arboreous plants with a high growth rate require large amounts of nutrient, in ecosystems dominated by such species, nutrient moved to the plants from soil, causing nutrient deficiency in the soil. This process is believed to be a cause of oligotrophic soil in tropical rainforests. As a result, after the disturbance of alien species, plants cannot grow, and the animal species that rely on such plants cannot maintain their biomass. Consequently, many animals and plants become extinct, as they cannot survive disturbance by alien species, and the ecosystem loses its resilience (In some cases, all arboreal species went extinct, and other cases, ecosystem consisted of a small number of species reached an equilibrium state⁵⁾ (May, 1972) in which the area of forest were lower than 50% of the simulated island.). Therefore, even if the feral goats are eradicated, the forests are not restored. Thus, the founder effect from the distant past influences future ecosystem changes. Our findings show that it is useful to consider the evolutionary process of an ecosystem in predicting its future events.⁶⁾

Reference:

- 5) May R.M. (1972) Will a large complex system be stable? *Nature* 238, 413-414
- 6) Yoshida K., Hata K., Kawakami K., Hiradate S., Osawa T., Kachi N. (2023) Predicting ecosystem changes by a new model of ecosystem evolution. *Scientific Reports* 13, 15353

Project 4. Research on problem solving using ecosystem functions

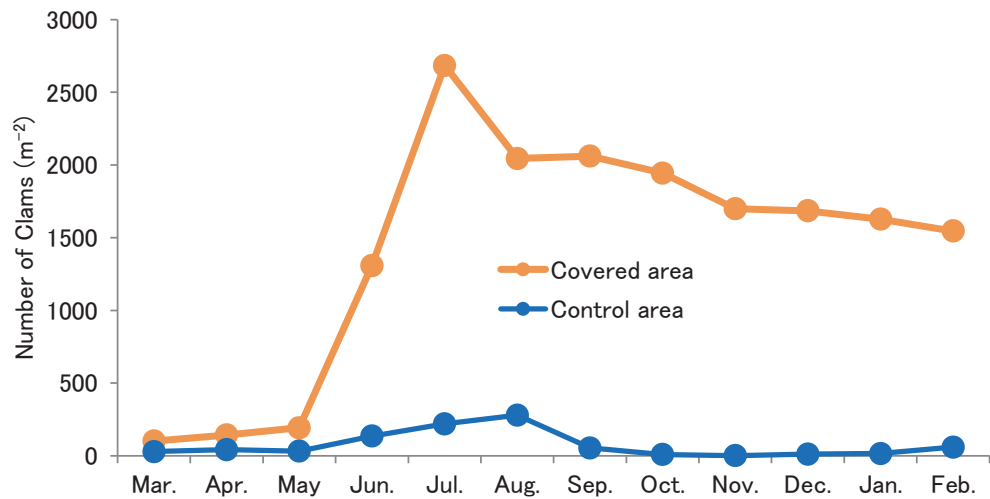
Nationwide, there have been low yields of the Japanese short-neck clam, *Ruditapes philippinarum*. We are engaged in restoration activities in the vast natural tidal flats of the Seto Inland Sea to enable the clams to be harvested again. In the citizen collaboration project “Satoumi Creation” we are focusing on social innovations such as reversal of the decline of fisheries and the revitalization of coastal areas. The results also include findings from Type II collaborative research between the NIES and local environmental research institutes, particularly the Yamaguchi Prefectural Institute of Environmental Health.

On the Fushino River estuary tidal flat in Yamaguchi Bay, although the natural environment regeneration activities are greatly appreciated, the clam harvest has decreased substantially and the number of fisheries workers has declined. Factors contributing to the decline in clam yield have included feeding damage due to predator invasion and increased predator activity associated with climate change, and inhibition of the settlement of floating larvae and growth of juvenile clams.

To mitigate these problems, we introduced a technique to cover the tidal flats with a mesh net and evaluated the effectiveness of this technique. Even during the summer months (July to September), when only 50 to 280 clams m^{-2} were observed without the nets, the test area with 9-mm-mesh-size nets demonstrated a significantly higher clam yield, with 2000 to 2700 clams m^{-2} observed (Fig. 7). Furthermore, the annual maximum numbers of individuals and species of benthic organisms, including clams, was 208 individuals of 10 species without the covered nets, compared with 760 individuals of 12 species with the covered nets. The clam conservation with the covered nets has also had a positive effect on other benthic biodiversity.

However, we estimated that maintenance of the nets would take considerable time and manpower. As an alternative technique, the study examined the net bag method practiced in Ono Seto, Hiroshima Prefecture. In this method, juvenile clams are placed in small mesh bags with the local sediment and incubated on site. Furthermore, to encourage the public to join in with natural environment restoration activities, and to promote public collaboration, the project aims to utilize the artificial tidal flats created in the adjacent nature observatory park.

Fig. 7 Effects of covering the tidal flats with 9mm mesh size nets on Japanese short-neck clam populations. Adapted from <https://www.pref.yamaguchi.lg.jp/uploaded/attachment/121426.pdf> (in Japanese).



Project 5. Integrated research for balancing conservation and utilization of biodiversity and behavioral change

The One Plan Approach: Innovating Conservation Practices

Conservation strategies for endangered species can be generally classified into two categories: *in situ* conservation and *ex situ* conservation. *In situ* conservation aims to ensure the sustainability of wild populations through measures such as the eradication of invasive species and the establishment of protected areas. An example of *ex situ* conservation is the long-term care of captive populations in captive facilities such as zoos and aquariums. Additionally, the long-term cryopreservation of genetic resources, such as cultured cells, gametes, blood, tissues, and nucleic acids such as RNA and DNA, can be classified as an *ex situ* conservation activity. The storage places for these resources are known as genome resource banks (GRBs) or genetic resource banks (GRBs). Generally, *ex situ* conservation is regarded as complementary to *in situ* conservation, and both are often performed independently, with insufficient collaboration between them.

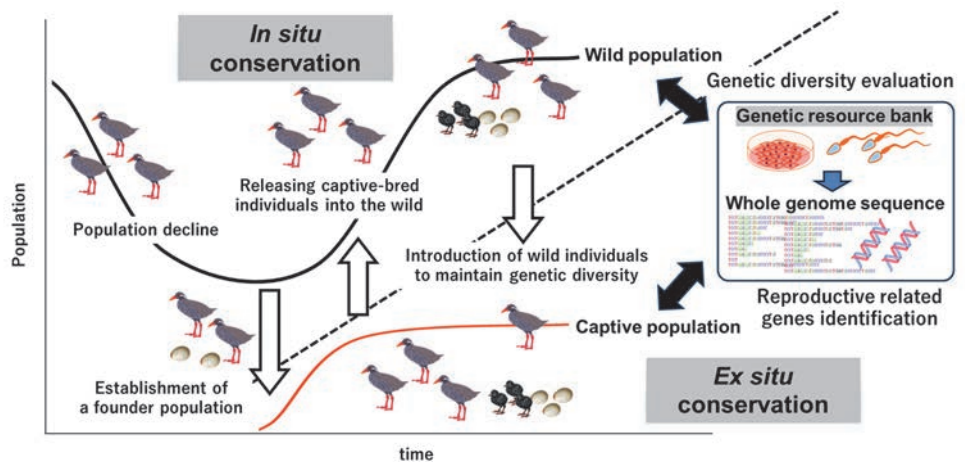
In response to this, the Conservation Planning Specialist Group (CPSG), one of the expert groups of the IUCN (International Union for Conservation of Nature), is promoting the integration of *in situ* and *ex situ* conservation efforts in conservation planning. This integrated approach is known as the One Plan Approach (OPA), and it aims to create species conservation plans by integrating the management of wild and captive populations. Among the endangered species in Japan, an example of a species for which a conservation plan has been developed through OPA, led by the CPSG, is the Okinawa rail (*Hypotaenidia okinawae*). By using OPA, NIES has helped to conserve the Okinawa rail through the cryopreservation of genetic resources and research utilizing these resources. A specific example of research utilizing the genetic resources is whole-genome analysis. The results of this whole-genome analysis are being applied to both *in situ* and *ex situ* conservation efforts.

Genome data utilization in practice for Okinawa rail conservation

An advantage of using cultured cells for whole-genome analysis is the potential to obtain high-purity, high-molecular-weight genomic DNA with minimal fragmentation. NIES utilized this advantage by conducting a whole-genome analysis by using cultured cells of the Okinawa rail, and we attempted to establish a genome database (Fig. 8). As a result, an approximately 3000-fold improvement in continuity was observed compared with the previously registered sequence of the Okinawa rail. Furthermore, we identified the sequences of 96.4% of the genes considered essential for the survival of various organisms.

With these highly precise genome data as a reference, the genetic diversity of wild Okinawa rail populations is currently being analyzed. Through this, the effects of the drastic population decrease in the early 2000s on genetic diversity can be evaluated. Additionally, the relationship between polymorphisms in various reproduction-related genes and reproductive success is under investigation. So far, 44 genes associated with fertilization have been identified from the genome sequence of the Okinawa rail. Among these, 17 have been found to have polymorphisms. We plan to utilize this polymorphism information to develop efficient captive breeding plans.

Fig. 8 Genomic-data-driven integration of *ex situ* and *in situ* conservation for the Okinawa rail.



Decarbonized and Sustainable Society Research Program

The goal of the Decarbonized and Sustainable Society Research Program is to present a vision and principle of a decarbonized and sustainable society at the global and national levels while ensuring intergenerational equity. To realize this goal, we will identify the long-term requirements for a decarbonized and sustainable society on a global scale. In addition to the global scale analyses, by taking into account the current national development stages, we will identify the actions and institutions needed at the national level to develop a decarbonized and sustainable society in Asian countries, including Japan. We intend to use our integrated assessment model to evaluate the necessary countermeasures at the global and national levels. On the basis of these quantitative and narrative results, we will develop medium- to long-term roadmaps for achieving a decarbonized and sustainable society both globally and nationally, thereby contributing to the various efforts to achieve this goal.

This research program consists of the following three research projects:

Project 1: Simultaneous Achievement of Global Decarbonization and Sustainability

Project 2: Quantification of National Decarbonization and Sustainable Society Scenarios

Project 3: Establishing a Regime Inclusive of Future Generations in a Sustainable Society.

Project 1. Simultaneous Achievement of Global Decarbonization and Sustainability

Project 1 consists of three subthemes with different target study periods: subtheme 1 (short/medium-term: present to 2050); subtheme 2 (long-term: present to 2100); and subtheme 3 (extra-long-term: present to 2100 and beyond). With the whole Earth as the target area, each subtheme attempts to grasp the relationships between decarbonization and sustainability; examine policies, systems, and measures for the simultaneous achievement of decarbonization and sustainability; and assess these efforts through the quantification of scenarios.

Subtheme 1 is developing a group of global models to evaluate mitigation measures centered on a bottom-up technology model. It is also assessing the emission pathways of greenhouse gases (GHGs) and short-lived climate forcers (SLCFs) in the short to medium term to meet the targets of the Paris Agreement. We are quantitatively evaluating the potential of drastic reduction measures for these gases and the impacts of the spillover effects of such measures on sustainable development. We are also conducting qualitative evaluations of, for example, the progress of nationally determined contributions (NDCs) for GHG mitigation, as well as the progress of international institutions and funding mechanisms under the Paris Agreement.

The results of our global bottom-up model suggest that achieving net-zero CO₂

emissions will require the substantial introduction of renewable energies, such as wind, solar, and biomass. Therefore, in FY 2023, we expanded our global renewable energy model to provide renewable energy that takes into account national land information, resource information, technical information, and the distance between urban areas that demand electricity and areas with potential supply of wind and solar power. The renewable supply potential is generally concentrated around cities, but there is an uneven regional distribution, and the characteristics of solar and wind power supply potential differ by country and region. There are regions where the country's electricity demand can be sufficiently covered by renewables under medium capacity-factor conditions (e.g., solar and wind power in China, wind power in the US and EU), and if we look at the total amount of renewable supply potential, including in areas with a high capacity factor, there are some regions (e.g., solar power in India and wind power in the US) that can cover the primary energy supply. The surplus in relation to regional electricity demand will likely be used for green hydrogen and ammonia production.

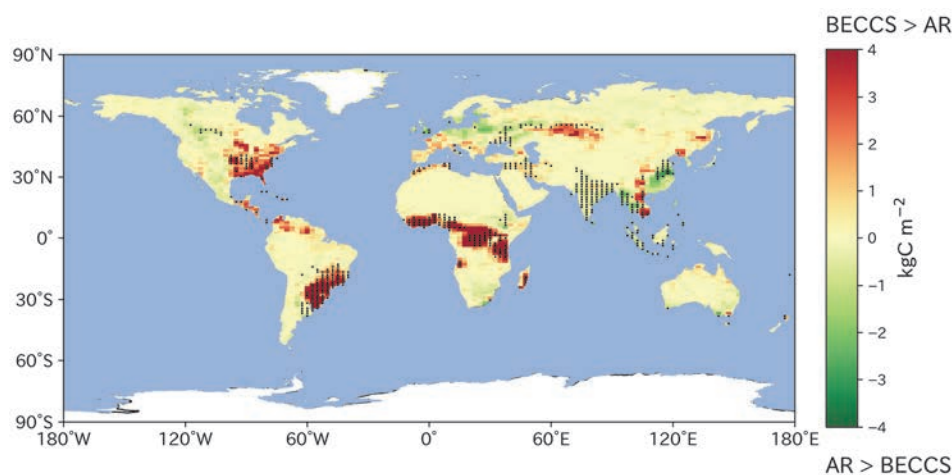
Subtheme 2 is developing a global sustainability assessment model that is based on the existing computable general equilibrium model and represents GHG emission pathways consistent with the Paris Agreement. We also intend to analyze the side effects of the mitigation measures employed for the emission pathways on sustainability, clarify the remaining climate risks under the emission pathways, and assess the equity of the expected consequences.

In FY 2023, as part of a scenario analysis of decarbonization and sustainability, we conducted an assessment of the impact of climate change and human activity (changes in the scale of population and economic activity) on wildfires, related carbon emissions, and human health. Future projections show that global carbon emissions from wildfires will decline owing to the impact of increased GDP per capita, which will lead to improved fire management. In contrast, in the case of large climate change, the number of fires in boreal forests is predicted to increase particularly markedly as the biomass becomes drier. We also investigated the impact of wildfires on human health through the release of air pollutants (particularly PM_{2.5}). Currently (2006–2015), forest fires contribute 8.4% of the total PM_{2.5} concentration across the global land area, and we estimated that the number of deaths worldwide due to forest-fire-derived PM_{2.5} is 135,180. We predicted that wildfire mortality rates in the mid-21st century would decrease in many scenarios and regions. We also predicted that wildfire mortality would increase in high-latitude regions in the second half of the 21st century.

Subtheme 3 is developing an Earth–human system model that incorporates a state-of-the-art Earth system model with human activity models that have critical impacts on climate states and policies on, for example, water use, crop growth, land use, and economic activities. By using an Earth–human system model (MIROC-INTEG-ES), we are investigating the long-term behavior of Earth–human systems under future socioeconomic scenarios, and we are trying to reveal the future social risks of climate change.

In FY 2023, by using an Earth system model, we analyzed the effectiveness of climate-mitigation measures such as BECCS (bioenergy use with CO₂ capture and storage) and afforestation and reforestation (Fig. 1). We found that, from a long-term carbon-removal perspective, BECCS generally has a greater ability than afforestation and reforestation to remove carbon, but depending on the location, the effects of afforestation and reforestation may exceed the effects of BECCS. Although BECCS is effective, we found that, over a short period of about 20 to 30 years, afforestation and reforestation may be as effective as, or even more effective than, BECCS.

Fig. 1 Difference in carbon content in 2100 between experiments using BECCS and experiments using afforestation/reforestation (AR). BECCS assumes that 50% of emitted CO₂ will be captured and stored. Sunspots in the figure are areas where the bioenergy crop area ratio is 20% or more in 2100.



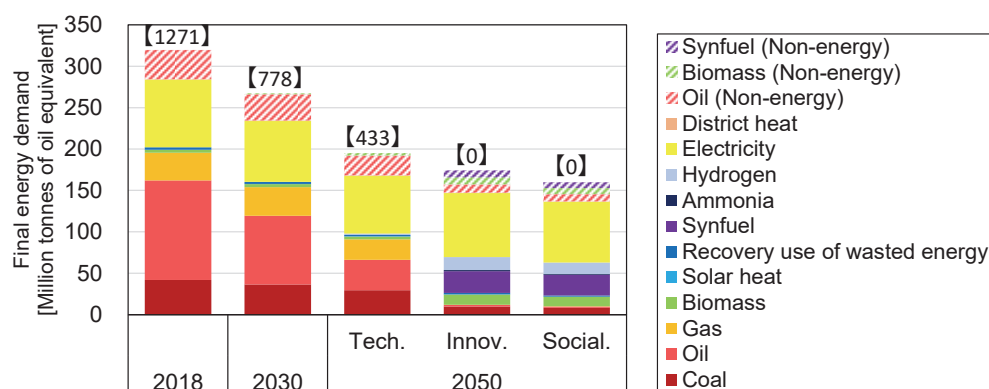
Project 2. Quantification of National Decarbonization and Sustainable Society Scenarios

Project 2 consists of two subthemes with different target areas, namely Japan (subtheme 1) and Asian countries excluding Japan (subtheme 2). Through this project, future scenarios in Japan and other Asian countries will be quantified. For Japan and some Asian countries, we are proposing measures, policies, and systems to achieve net-zero GHG emissions, as well as to quantitatively formulate short- and medium-term sustainable decarbonization roadmaps that are consistent with achieving the 1.5-°C target scenarios. We are considering the diversity of Japan and other Asian countries, together with ways of resolving the challenges facing each country, including NDC (Nationally Determined Contribution; a climate action plan required by each party under the Paris Agreement) ambitions and the economic, technological, and institutional constraints on long-term strategy formulation.

In **subtheme 1**, for Japan, we are updating the AIM (Asia-Pacific Integrated Model) to assess the effects of innovative energy-saving technologies, power grid systems introducing huge renewable energy supplies, and social transformation reducing energy service demand to achieve net-zero GHG emissions. To analyze drastic mitigation pathways, we are also considering socioeconomic issues, including demographic impacts such as the declining birth rate and the aging population, and

the impacts on energy demand of innovative technologies that promote behavior change. In FY 2023, we determined pathways for achieving net-zero GHG emissions in Japan. Simply extending GHG mitigation measures in accordance with the NDC after 2030 (the “Technology progress scenario”) will not achieve net-zero GHG emissions by 2050: Additional innovative technologies, or both innovative technologies and social transformation, will be needed to achieve the net-zero goal (Fig. 2). Social transformation will reduce GHG emissions by 25 million tCO₂eq in 2050 through the reduction of energy service demand, and it will reduce the total additional investment cost to reduce the GHG emissions by 50 trillion JPY from 2021 to 2050. To demonstrate more tangible pathways, we are now analyzing additional scenarios, taking into account the share of the renewable energy supply and the domestic production rate of new energies such as hydrogen and synfuel. These results were reported to the subcommittee of the Central Environment Council in 2023 and 2024.

Fig. 2 Estimation of final energy demand in Japan in 2030 and 2050 by using AIM. Values in square brackets are GHG emissions in MtCO₂eq. Tech: Technology progress scenario (extension of the NDC after 2030). Innov: Innovative technology scenario. Social: Social transformation scenario.



In **subtheme 2**, consistent with global GHG emission pathways for achieving the 2-°C and 1.5-°C targets analyzed in Project 1, we focused on scenario analyses for a sustainable and decarbonized society in major Asian countries. For example, in India, many cities still have severe outdoor air pollution due to heavy reliance on coal for power generation and industry. In addition, developing states and rural areas face indoor air pollution due to heavy reliance on biomass for household use. The Indian government has announced its goal of achieving net-zero GHG emissions by 2070, and it has set a target for the substantial adoption of renewable energy, which is expected to reduce both outdoor and indoor air pollution. Therefore, with a focus on the household sector in India, we developed the bottom-up type model named AIM/Enduse [India] and analyzed scenarios up to 2070. In the Business as Usual (BaU) scenario, economic development and urbanization will increase energy demand in the urban areas of each state through a shift from biomass and coal to gas and electricity. However, regional disparities are apparent, with some states still facing energy poverty; in these states, per capita energy consumption in 2070 would still be lower than the global average in 2010. Black carbon emissions from the household sector would decrease significantly by 2070 because of reduced biomass consumption, whereas CO₂ emissions and air pollution derived from electricity supply would increase substantially because of increased electrification. Under a deep decarbonization scenario, we found that promoting decarbonization

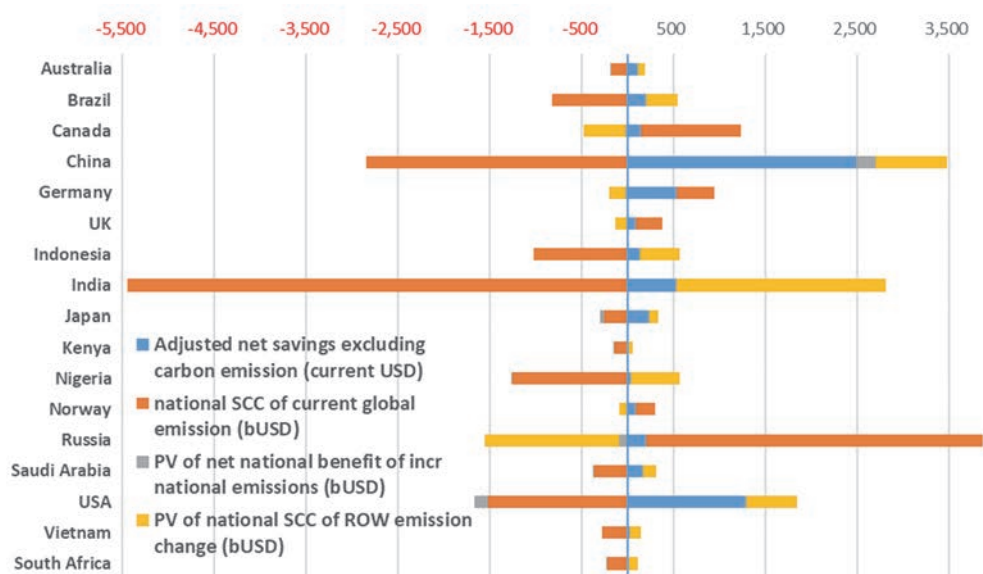
measures in the residential and power-generation sectors would reduce not only indoor air pollution in all states substantially by 2070 but also outdoor air pollution.

Project 3. Establishing a Regime Inclusive of Future Generations in a Sustainable Society

Project 3 aims to establish a regime that will help to improve intergenerational equity and enable future generations to inherit a better world. It consists of two subthemes with four elements of the regime: norms, indicators, institutions, and surveys. These elements are intertwined; subtheme 1 addresses mainly norms and indicators for intergenerational equity and justice, and subtheme 2 addresses institutions and surveys for the benefit of future generations.

In **subtheme 1**, we developed a capital-based indicator of sustainability that incorporates the consequences of GHG emissions, because the existing capital-based indicator of sustainability does not adequately capture climate change and the technological change influencing future generations. The new indicator is composed not only of 1) the current investment in capital (adjusted net savings) and 2) the national social cost of current global emissions, but also 3) the present value of the future net national benefit of increasing emissions (i.e., national social cost of carbon minus the mitigation cost) or the present value of the future net national cost of decreasing emissions and 4) the present value of the national social cost of the increasing emissions of other countries (Fig. 3). We applied the World Bank’s database, future emission projections, and the social cost of carbon data. Our results included the findings that 2) and 4) are significant in Brazil, Indonesia, India, and Nigeria, so that development turns out to be unsustainable in these developing countries.

Fig. 3 Components of capital-based sustainability, including CO₂ emissions (annual average from 2010–2019) (Units: billion USD, bUSD). Note: A negative value in total indicates that the country is not on a sustainable path. SCC, social cost of carbon; PV, present value; incr. increasing; ROW, rest of world.



In **subtheme 2**, we studied (a) how future-regarding institutions could contribute to the normative legitimacy of public governance and (b) the conditionality of political short-termism. For (a), we argued that future-regarding institutions could help to enhance the input legitimacy of public governance by representing future generations, they could enhance the throughput legitimacy by improving the quality of governance processes, and they could enhance the output legitimacy by reducing harmful short-termism. For (b), we identified the drivers and mitigators of political short-termism, drawing on a literature review of empirical and experimental studies.

We conducted an Internet questionnaire survey to determine the responses of members of the public to information on future climate impacts, highlighting the effects on future generations in Japan: Future generations who is born this year will experience in their lives (80 years) approximately 400 extremely hot days that the current generation has never experienced. The results showed that providing information increased people's intention to take action. However, the results also suggested that attitudes the respondents had already were more influential. This suggested that providing future climate change information might strengthen only the behavioral intentions of those people who are already trying to take action.

Co-design Approach for Local Sustainability Research Program

By working with local governments, local residents, and other local stakeholders as the implementing entities to create a sustainable society, we intend to construct measures to develop co-creative and sustainable local communities by using human, social, and scientific knowledge. We will also examine ways to support the implementation of these measures.

This Research Program will address the following four issues:

Project 1: Research on sustainable society implementation through regional collaboration

Project 2: Proposal and evaluation of eco-efficient technologies and systems in collaboration with local communities

Project 3: Development of a regional evaluation tool to simultaneously solve regional and lifestyle issues and achieve sustainability goals

Project 4: Construction of measures for creating sustainable local communities and support for introducing these measures into local communities.

Through these efforts, we will collaborate with local governments and other local stakeholders in local communities in Japan to co-create problem-solving measures that will create sustainable local communities by using scientific knowledge. We will clarify how support should be provided, with the aim of establishing these measures as feasible systems in local communities. Our aim is to promote the creation of a sustainable society in the region.

Project 1. Research on sustainable society implementation through regional collaboration

In collaboration with the town of Mishima in Fukushima Prefecture, we conducted research on supporting decarbonization measures through forest utilization centered on woody biomass. We continued to participate in the “Mishima Regional Recycling and Symbiosis Promotion Council” as an advisor, and we provided our research findings. Given that a decline in interest in forests among local residents has become a major issue, we developed a method of social impact assessment to evaluate the value of forests from the perspective of local residents. Specifically, a review of existing forest value assessments was conducted, and interviews were conducted with forest stakeholders in and outside the town to collect basic data on forest values from the residents’ perspectives. We plan to use the results to develop and test a prototype workshop program for local residents. We also plan to collaborate with Project 2 in developing a social impact assessment methodology.

Shiga Prefecture has developed 13 “Mother Lake Goals” (MLGs) for conserving Lake Biwa and creating a sustainable society around it by 2030. One of the 13 goals is “Goal 2: Restore bountiful seafood (‘lake food’) resources.” At the request of the prefecture, we evaluated the achievement of this goal in the second year of this

6. Co-design Approach for Local Sustainability Research Program

program. In addition, to help with goal achievement, we accumulated data on the spawning ecology and migration range of the native fishes used as food. By drawing from the 2030 MLGs and from discussions with stakeholders in Shiga Prefecture, we conducted a survey of the relationship between the distribution of fish species and water quality. This year, we added data on the species composition of phytoplankton to the datasets on fish species and water quality, and we have begun analyzing the relationships among them. We intend to use the results of the analysis to examine how to achieve a balanced water environment from the perspective of both the ecosystem and water quality. We also conducted a test study with the Shiga Prefecture Fisheries Experiment Station, introducing the wastewater treatment technology of Project 2 to address the issue of culturing freshwater pearls. The results obtained will contribute to multiple goals of the SDGs.

We also aim to provide balanced solutions for multiple environmental issues. In FY2023 we performed the following activities in the island city of Goto, in Nagasaki Prefecture. The CO₂ Reduction Diagnostic Tool developed in Project 3 was used to analyze the effectiveness of each of the measures and policies designed to achieve decarbonization by 2050. The tool was improved by using feedback from Goto. This improvement included the incorporation of the use of renewable energy sources such as offshore wind power and solar power generation, which Goto is particularly promoting. Moreover, a field survey for seaweed bed restoration has been initiated and model analysis is underway. The plan is to select priority areas for seaweed bed preservation and restoration. In addition, buoys were installed for coral protection and sustainable tourism use. Future projections were made for wastewater treatment, waste disposal, and local traffic. A questionnaire survey was conducted with the cooperation of local government in Goto to investigate the inhabitants' awareness of the natural and living environment and their vision for the future.

Project 2. Proposal and evaluation of eco-efficient technologies and systems in collaboration with local communities

We have been conducting research on carbon neutralization in the chemical and paper industries through the efficient use of waste, with the aim of achieving appropriate and economical levels of wastewater and waste treatment in a declining population environment. We conducted interviews with residents and tourists about transportation in depopulated areas such as Goto. Actions are being taken to implement solutions to some of the issues.

Two of these achievements are outlined here. In our research into the development of a model for estimating nitrogen excretion and treatment volumes on remote islands and its application to Goto, we improved a model for estimating these two parameters at the basic municipality level. The model had originally been developed to evaluate wastewater management in each region of Japan. We developed a remote island version of the model by fine-tuning the spatial resolution. This made it

possible to evaluate wastewater management in the secondary remote islands of Goto, and it enabled us to move forward in developing a foundation for collaboration with other project sub-themes.

In a study proposing sustainable transportation at community-scale, we investigated environmentally friendly transportation for local residents and visitors in remote areas and on islands, where depopulation and aging are rapidly progressing. Local public transport, which supports the lives of those with mobility issues (such as the elderly who have difficulty moving on their own), is rapidly declining, and the negative impact causes inconvenience not only to local residents but also to tourists. In response to these issues and the need to achieve a decarbonized society, we worked with local stakeholders in an area with declining population to develop a highly durable personal mobility device that can be adapted to the user's life stage. The mobility is similar to a bicycle. Currently, we are continuing our research with the aim of 1) changing the direction of transport policies that currently depend simply on cost reduction and government support; and 2) achieving road safety and extending the healthy life expectancy for users through the spread of our developing mobility.

Project 3. Development of a regional evaluation tool to simultaneously solve regional and lifestyle issues and achieve sustainability goals

By targeting two or three regions common to the Research Program, we intend to develop detailed socioeconomic, energy, environmental, and other data and analyze regional characteristics to determine the current and future state of the regions, taking into account national scenarios. In addition, this Project will study how to provide support from a scientific perspective to solve regional issues and create policies to achieve sustainability goals in collaboration with the public and other stakeholders in specific regions.

As part of an estimation of CO₂ emissions from the passenger transport sector in the context of regional characteristics, we estimated passenger car CO₂ emissions by city, town, and village throughout Japan by using vehicle inspection record data on distances traveled. These data were used to calculate passenger car CO₂ emissions per capita by using a tertiary mesh (approximately 1 km square) of population size. The results showed that a mesh size of 3000 to 10,000 persons/km², where approximately 40% of the population resides, gave a result close to the national average of 0.82 tCO₂/person. In the 1000 to 3000 persons/km² mesh, where about 20% of the population resides, the CO₂ emissions were 1.07 tCO₂/person (1.3 times the national average), and in the 100 to 1000 person/km² mesh, where about 15% of the population resides, the emissions were 1.7 times the national average. The mesh of 10,000 or more persons/km², where about 25% of residents live, gave a result 0.3 times the national average.

Our study of pathways for achieving decarbonization in local government expanded

on the analysis conducted last year targeting the year 2050. An analysis of the pathways for CO₂ reduction from the base year (2015) to 2050 and the changes in the effects of different measures and policies was conducted. In the analysis, we supposed that the measures and policies assumed as scenarios would be implemented from 2025 onward. We also assumed that the effects and adoption rates of the measures and policies set as countermeasure scenarios would be reached in 2050. The analysis was conducted in all 1741 municipalities of Japan. The results quantitatively revealed that the measures effective in reducing CO₂ emissions differ from municipality to municipality. For example, the city of Sendai in Miyagi Prefecture and the town of Oguni in Kumamoto Prefecture would have large CO₂ reduction effects from demand-side measures, whereas Sapporo in Hokkaido and Chiyoda Ward in Tokyo would have large effects from supply-side measures. Even in areas with rich renewable energy potential, the introduction of renewable energy will take time; in the medium term (around 2030–2035), we will need to rely on decarbonization of the power grid, so it is important to promote the introduction and local use of renewable energy as a whole. It is also important to work toward decarbonization of the electricity grid in parallel with national efforts to promote the introduction of renewable energy and its use in the local community.

Project 4. Construction of measures for creating sustainable local communities and support for introducing these measures into local communities

We have been discussing new issues that have become apparent in the course of our research into building a sustainable society. As an example, the new issues found in Project 1 are described below. An investigation of the utilization of forests in remote regions revealed that the increase in the number of woody biomass power-generation projects has resulted in a tight supply and demand situation for fuel. Moreover, forest management faces issues such as a lack of interest on the part of forest owners and a shortage of labor. Shiga Prefecture has set several environment goals for a sustainable society, two of which are to “revive native fish stocks” and “maintain a healthy water environment”. The issues are to determine the degree to which our “native fish stocks revival” research will help to make Shiga more attractive and to make environmental issues a personal matter for the people of Shiga. In addition, many factors are involved in “maintaining a healthy water environment”, including water quality, biodiversity, flood control, water utilization, odor, and blue-green algae control, so we need to continue examining what kind of water environment is best. Our activities on the remote islands of Nagasaki include studies of decarbonization, infrastructure maintenance, nature conservation and its utilization, future visions, and social transformation under a declining population. In terms of building a sustainable society, it is important to balance these multiple issues, but we do not yet fully understand the linkage and the overall balance among issues.

Environmental Emergency and Resilience Research Program

This relatively new program will engage in research and technological development to help address the environmental issues associated with disasters and accidents. Specifically, regional collaborative research will be promoted to help revitalize and manage the regional environment of Fukushima Prefecture and create an environment that utilizes regional resources in collaboration with regional stakeholders, taking into consideration the results of past efforts. Moreover, the program will build a resilient waste treatment system and an emergency response system for chemical risk management in the event of a large-scale disaster by accumulating, utilizing, and systematizing the experience and knowledge gained from past disasters, including the Great East Japan Earthquake. Through these efforts, the program will support the construction of a sustainable local environment that meets social needs in affected areas, including the zone of Fukushima Prefecture in which the evacuation order has been lifted. The program will also use our efforts in Fukushima to help improve the environmental disaster resilience of local communities in preparation for other large-scale disasters.

In this fourth year of the program, the following efforts were made in each project, mainly from the perspective of technological development. The goal is to implement the results of each project socially to help revitalize the environment of Fukushima and prepare for future disasters.

Project 1. Technical systems research for reconstruction and environmental recovery in areas of Fukushima where residents are returning

1) Development of technology and systems for volume reduction of removed soil and radioactively contaminated waste with the aim of final disposal

To achieve final disposal outside Fukushima Prefecture, we have developed several scenarios that combine characteristic volume-reduction methods and corresponding disposal systems. As the parameters of the disposal system, such as the disposal facility structure and the nature of the solidified product, vary depending on the chosen technology combination, we created a disposal model for each scenario. We then evaluated the leachate and leakage water concentrations at the lower edge of a modeled disposal facility to assess the overall safety of the system. The analysis revealed that the concentrations of leachate and leakage water were below the limit of 90 Bq/L in all disposal systems. This study successfully demonstrated a method for evaluating the safety of specific disposal systems to achieve final disposal outside the prefecture. It is important to ensure the system's safety while also making it flexible, efficient, and fail safe. This involves considering both the leaching characteristics of the stabilized material and the radioactive cesium (r-Cs) absorption by components such as filler materials and reinforced concrete. In addition, we started full-scale outdoor large-column tests (using three test cells) to confirm the environmental safety of molten slag, as part of joint research with JESCO (the Japan Energy Service Corporation).

2) Development of biomass utilization technology and systems as countermeasures

We investigated the behavior of r-Cs in woody power generation facilities. By using a mass-balance analysis of r-Cs, we clarified the ratio of r-Cs concentration to residue (e.g., biochar from feedstock in the power generation facilities). In addition, we determined the leachability of hazardous heavy metals, as well as of r-Cs, from the residues with a view to their recycling. We found that biochar from a downdraft gasifier can be utilized as a soil amendment to control the level of r-Cs to less than 400 Bq/kg. This utilization can be regarded as a type of carbon storage. These results will be useful in similar facilities under construction in Fukushima Prefecture.

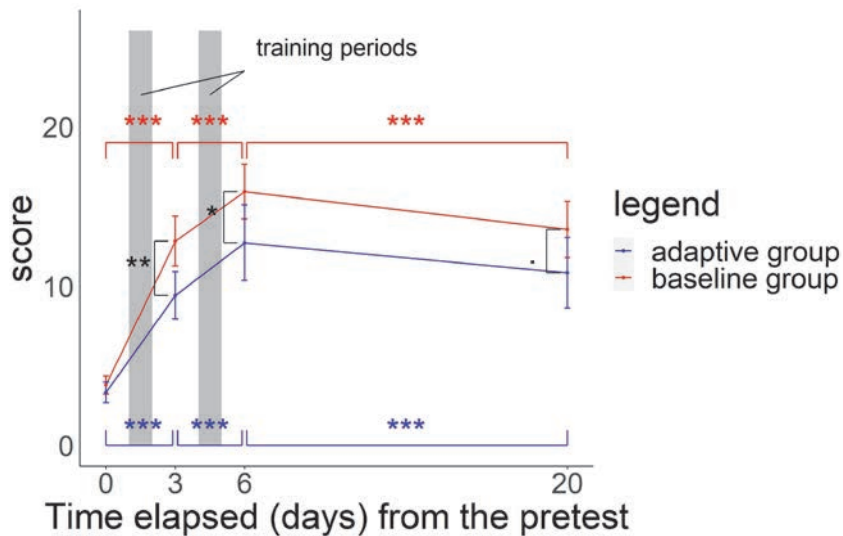
In collaboration with Project 4, we proposed the most feasible biogas method for generating power from local waste biomass, such as the grass cuttings from highway maintenance, which are currently disposed of. Furthermore, we designed a combined system employing the biogas method and a downdraft gasifier using woody biomass as an advanced biomass power generation system. The energy and mass balances, as well as the carbon storage capacity, of the system were estimated.

Project 2. Research into environmental impacts and management in the disaster areas of Fukushima

Entrance to the evacuation zone following the Fukushima Daiichi Nuclear Power Plant accident has been restricted, and even members of the public living in the surrounding area have no direct experience of the biodiversity status of the zone. NIES has been conducting acoustic monitoring of the evacuation zone, and experiences of the recorded songs of bird species are expected to support people's knowledge of the biodiversity status of the evacuation zone. However, considerable training is required to be able to identify species from these recorded sounds. To promote the involvement of the public in biodiversity monitoring, we have developed an online tool, named TORI-TORE¹⁾, for training people in birdsong identification. TORI-TORE is a quiz-style training tool that can be accessed through web browsers. TORI-TORE can generate quiz choices not only at random, but also in an adaptive manner for individual trainees; that is, by referring to the training history, it can more frequently generate questions including those bird species that the trainee has not correctly identified. To examine the effect of TORI-TORE on people's birdsong identification skills and interest in nature, we conducted an experiment in which the participants trained on the songs and calls of 26 common bird species in the Fukushima disaster area, including the evacuation zone. As a result, the species identification skills of the participants increased significantly (Fig. 1), as did their interest in nature. However, the adaptive algorithm for generating quiz choices did not improve the training effect against the baseline algorithm (random choice of bird species in a question), and it therefore needs to be improved. We have published TORI-TORE and its source code to make it

possible for more people to take an interest in biodiversity monitoring in the Fukushima evacuation zone.

Fig. 1 Effect of TORI-TORE on birdsong identification skills. Participants were assigned by stratified randomization to the “adaptive group” or the “baseline group” and underwent a training quiz consisting of 100 questions in TORI-TORE for 6 days. They took birdsong identification tests four times (before the training and after 3, 6, and 20 days) to measure their scores (number of correct answers in each test) as an indicator of their species identification skills. The asterisks indicate significant differences (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$). Distributed under Creative Commons CC-BY 4.0.¹⁾ For more details, please see the original paper.



Reference:

Ogawa Y., Fukasawa K., Yoshioka A., Kumada N., Takenaka A., Ito T. (2023) Quiz-style online training tool helps to learn birdsong identification and support citizen science. *PeerJ* 11, e15387

Project 3. Evaluation and analysis of regional revitalization and sustainable town reconstruction and development

We continued to compile a reconstruction status database by collecting, estimating, and organizing data on various factors, including population dynamics, farming resumption, solar sharing potential (agrivoltaics), commuting to office/school patterns, and non-resident populations in areas where evacuation orders have been lifted. The residency rates in these areas (the percentages of registered residents living in each area) were analyzed, and the factors influencing the monthly increase in the residency rates were examined. The results showed that, as the period between the occurrence of the disaster and the lifting of the evacuation orders lengthened, the decrease in the residency rate became greater; that is, the rate decreased as more time passed after the lifting of the evacuation orders. Moreover, the residency rate increased as the distance between the residence and the nuclear power plant increased. In contrast, no significant impact was observed on the proportion of the older population or on the areas where evacuation orders had not yet been lifted within the same municipalities. Additionally, resident intention survey responses showed that the residency rate tended to remain near the combined percentage of “want to return” and “undecided”. In developing the Reboot-type Regional Integrated Assessment Model (R2-AIM), we incorporated the abovementioned information on the recovery of the residency rate as reference values for future population projections. Projections were made for population,

7. Environmental Emergency and Resilience Research Program

industry, energy supply and demand, and land-use trends in 13 municipalities in the Hamadori region of Fukushima.

Development of the regional analysis system continued this year with a focus on refining the demand–response control model in leading model areas, including the town of Shinchi, in Fukushima Prefecture, building on the efforts of the previous year. In the development of a model targeting sewage treatment plants, which has been underway since last year, a power demand estimation model with a 30-min resolution was constructed by using power monitoring data from the purification center in Shinchi. This led to the design of an operational plan that merges energy conservation with power load adjustments, in collaboration with photovoltaics, thus confirming the efficiency of power demand management at sewage treatment plants. In conjunction with this, as part of a macro-level evaluation of demand–response control, we evaluated the potential for optimizing supply and demand across the entire region by adjusting the timing of electricity usage through the use of electric vehicles, heat-pump water heaters, and storage batteries. This research centered on real urban areas and used empirical data, such as data on renewable energy generation and output curtailment. The supply–demand balance was calculated by correlating these data with the energy consumption of households and businesses, which was estimated by using the unit consumption method. By using this information, scenarios were created for the efficient operation of energy-use equipment and work-hours shifts in residential and commercial buildings, thus demonstrating strategies for optimizing the use of electricity from photovoltaics, a variable renewable energy source. Furthermore, as part of our research into the development of a preliminary evaluation method for wind condition surveys to introduce wind-power generation in reconstructive town development, we constructed a system to evaluate the potential use of wind power on the basis of the local supply–demand balance.

Project 4. Studies of the emergence of regional resources and systems in Hamadori, Fukushima, after lifting of the evacuation orders

The main themes of Project 4 are the recovery and reconstruction of natural and social systems after the Fukushima nuclear disaster. Subtopic 1 relates to studies from a natural science perspective of regional resources and environmental technologies, including the resource-management processes required to make use of these resources. Subtopic 2 relates to investigating the characteristics of the region and developing methods for applying the scientific findings of Subtopic 1 in society. Notable research results for this fiscal year are described below.

Subtopic 1: In the reconstruction of the region, a safe local resource utilization and sustainable energy system has been studied and a concept for an RE100 Industrial Park has been designed; a gasification–methane fermentation combined heat and power plant, the technology for which is being developed in Project 1 and Project 2, is a promising option. In cooperation with Subtopic 2, we have started to discuss

the project with stakeholders in order to implement the concept. We also conducted a questionnaire survey on the amounts of woody biomass fuel used in large-scale woody biomass power-generation projects in Fukushima Prefecture. We used the results of these surveys to conduct a study of the potential use of woody biomass as a renewable energy option in the Hamadori region.

Subtopic 2: We worked on developing a platform to disseminate the knowledge from regions in Japan that are practicing sustainable community development (hereafter referred to as 'advanced regions') to other regions. This year, we focused on the town of Tomioka in Fukushima Prefecture, which is progressing with post-recovery town development after the Great East Japan Earthquake. A workshop was held with local stakeholders to discuss how to apply insights from advanced case studies. As a result, we were able to identify the strengths and challenges of the current community by comparing it with the advanced cases. Furthermore, a future direction was shared among participants, emphasizing the need to explore collaboration with the government through private-sector-led initiatives. Following the workshop, concrete actions were taken, such as planning a visit by Tomioka stakeholders to the advanced regions (the towns of Shiwa and Onagawa).

Project 5. Making a resilient material cycle and waste management system at the local level to tackle mega-disasters

We formally conceptualized “Disaster waste governance” by combining existing research on disaster waste management with network governance theory. The conceptual model shows that a network of waste-management-related local actors interacts to influence waste management during normal times and during disasters. As an empirical study to verify this concept, we conducted a social network analysis of 34 entities involved in disaster waste management in Municipality A, which was affected by the East Japan Typhoon in 2019. The results showed that, although the relationships among actors is more sparse during disasters than during normal times (the network density decreases by about 30%), local environmental offices and industry associations have increased their connections, suggesting that they are actors whose importance increases particularly during disasters. We have also initiated a survey of the river waste governance structure in Jakarta as an example of overseas disaster waste governance.

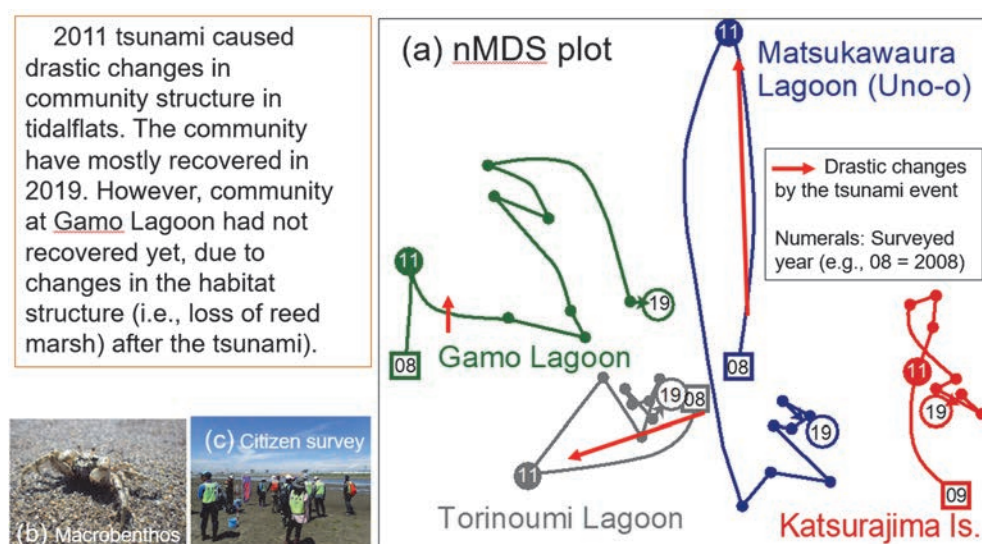
As an exit strategy for the large amounts of concrete debris anticipated from the future Shuto-chokka Mega Earthquake, a new marine-use scenario involving the building of mound reefs was proposed and evaluated in comparison with the conventional roadbed-material-use scenario on land. Mound reefs are aimed at increasing plankton proliferation and fisheries resources through the generation of upwelling currents. This year, the life-cycle CO₂ generated by different treatment scenarios was evaluated by considering the functions of mound-reef construction and the use of roadbed materials. Although there are issues with precise quantitative assessment, we estimated that the new scenario could offset the CO₂ generated by

mound-reef construction within 0.4 to 102 years; that is, carbon neutrality could be achieved in the new scenario, considering the range of values in the literature. The environmental safety of marine use of the concrete debris was examined through leaching tests; we found that although chromium leaching is enhanced in seawater, the leaching concentration decreases significantly as the grain size of the concrete shells increases.

Project 6. Strategic chemical risk-management research in emergencies

This project will examine appropriate management and monitoring systems for chemical substances in the case of emergencies. In addition, the project will use the results to build an information infrastructure and systematize a risk-management system to cope with emergencies and disasters. It also aims to develop a practical comprehensive survey method to quickly and accurately assess the impact of chemical substances in the event of disasters. The overall goal of this project is to integrate scientific methods of addressing risks and the direction of future chemical management systems into environmental policies. One of the notable achievements in FY 2023 was a study of the prediction of changes in coastal ecosystems. The results of an analysis of tidal flat survey data from local people for 9 years after the earthquake showed that the diversity and frequency of benthic fauna will generally recover in about 10 years (Fig. 2). In March 2023, a symposium was planned and organized in the city of Sendai, and research lectures on coastal ecosystem restoration and conservation were delivered. Also, in June, at a meeting of the Council on the Natural Regeneration of Gamo Tidal Flat, the results of interannual changes in beach vegetation and recovery predictions were presented (Fig. 2).

Fig. 2 A nonmetric multidimensional scaling (nMDS) plot (a) showing the changes and recovery of the macrobenthic invertebrate community (b) on four tidal flats in Sendai Bay after the 2011 tsunami. Distance in the plot indicates “similarity of community structure among the samples. Data were obtained in a citizen-based scientific survey project (c). The plot was modified from Yuhara et al.²⁾



Reference:

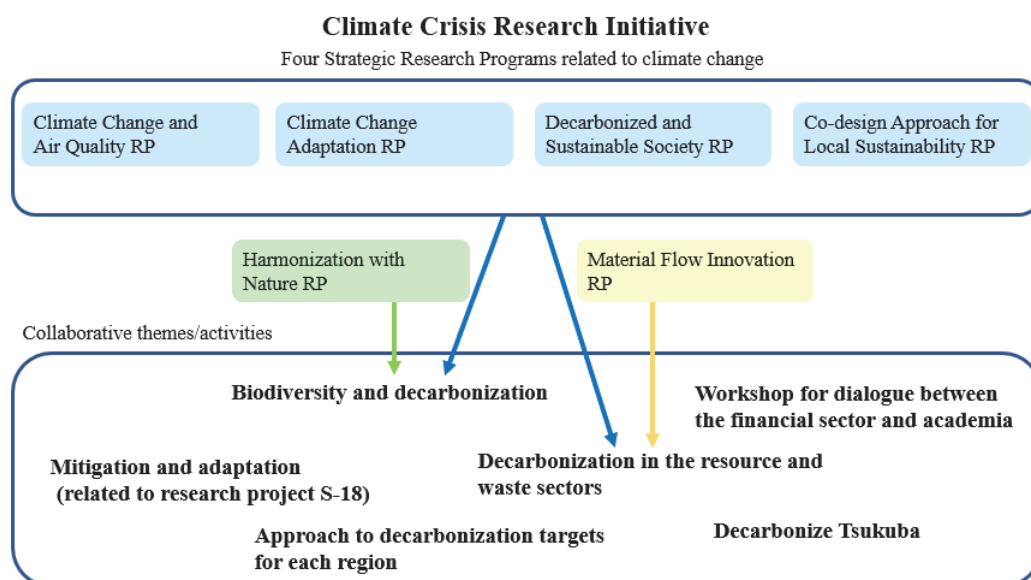
Yuhara T., Suzuki T., Nishita T., Murakami J., Makino W., Kanaya G., Kinoshita K., Yasuno N., Uchino T., Urabe J. (2023) Recovery of macrobenthic communities in tidal flats following the Great East Japan Earthquake. *Limnology and Oceanography Letters* 8(3), 473–480

Climate Crisis Research Initiative

1. About

The Climate Crisis Research Initiative (hereinafter referred to as the Initiative) is responsible for coordinating four climate-change-related Strategic Research Programs (Climate Change and Air Quality Research Program, Climate Change Adaptation Research Program, Decarbonized and Sustainable Society Research Program, and Co-design Approach for Local Sustainability Research Program). It also collaborates with Harmonization with Nature Research Program, Material Flow Innovation Research Program, and other divisions, and it consolidates and disseminates findings that are relevant to public concerns (Fig. 1).

Fig. 1 Structure of the Climate Crisis Research Initiative and the four Strategic Research Programs related to climate change (Climate Change and Air Quality Research Program, Climate Change Adaptation Research Program, Decarbonized and Sustainable Society Research Program, and Co-design Approach for Local Sustainability Research Program).



2. Activities in FY 2023

2.1 Monthly meetings

The research directors of the four climate-change-related Strategic Research Programs, along with the project leaders, the research directors of the Harmonization with Nature Research Program and Material Flow Innovation Research Program, the directors of Earth System Division, and other members, including the president of NIES, the vice president for research, and the leader of the Initiative, held monthly briefings on the progress of each Research Program and discussed shared issues for collaboration, as described in section 2.2. In addition, efforts were made to discuss timely and socially relevant topics, as described in section 2.3. Moreover, we created two maps that provide a bird's-eye view of NIES's research activities. They consisted of a network diagram that compares NIES's research with reports compiled by IPCC (Intergovernmental Panel on Climate Change), IPBES (Intergovernmental Science-Policy Platform on

Biodiversity and Ecosystem Services), and IRP (International Resource Panel), and a linkage chart showing external research funding projects.

2.2 Collaborative themes

The Initiative has identified six cross-disciplinary issues as collaborative themes that are discussed at our monthly meetings: (1) Biodiversity and decarbonization, (2) Workshop for dialogue between the financial sector and academia, (3) Mitigation and adaptation, (4) Decarbonization in the resource and waste sectors, (5) Approach to decarbonization targets for each region, and (6) Decarbonize Tsukuba. This section gives details of the progress in three of the themes, (3), (5), and (6), during this fiscal year.

2.2.1 Mitigation and adaptation

It is often said that mitigation and adaptation are two wheels of a cart. We have been discussing the possibility of integrating the two in climate change measures. In GHG emission reduction analysis at the global scale, integrated assessments have been conducted for land use, taking climate change impacts and adaptation measures into account. On the other hand, so far, analyses at the national level have not considered climate impacts and adaptation explicitly enough. This is despite the fact that the impact of climate change on mitigation will be very important, and integrated analyses of mitigation and adaptation will become an important topic, e.g., the demand for air-conditioning will increase when it is unusually hot, materials will be needed to raise levees to cope with heavy rainfall, and the output of solar panels will vary depending on the weather. It has also been pointed out that, even in the development of global-scale scenarios, mitigation and adaptation capacity may be damaged when climate impacts spill over to socioeconomic development; such feedback effects have not yet been well quantified.

2.2.2 Approach to decarbonization targets for each region

As a background, only 945 of 1741 cities, wards, towns, and villages in Japan have declared that they will have virtually zero CO₂ emissions by 2050 (as of December 2023). Moreover, many of those municipalities that have declared this have simply adopted the reduction targets set by the national and prefectural governments, but have not yet incorporated them into their plans. We have developed a tool for use by local governments to estimate CO₂ emission reductions so that they can propose a rational approach to target setting. Each municipality can select a level of implementation of various decarbonization measures and can graph the future energy supply and demand and CO₂ emissions. Although the tool has a strong focus on mitigation, it also has some degree of functions relevant to integrated assessment. We are considering the future possibility of including nature conservation, blue carbon, and other nature-conserving activities in the tool.

2.2.3 Decarbonize Tsukuba

We have been conducting research and outreach activities in Tsukuba Science City, where NIES is based. Discussions are held about once a month at a meeting of about 15 volunteers, in addition to the regular meetings of the Initiative. We have identified the following three pillars and conducted the following activities within each pillar:

(1) Decarbonization of NIES

- held discussions on the ZEB (net zero energy building) concept and the electricity billing system for saving electricity in the construction of a new building to replace the current aging Institute building
- registered some of the green space within the Institute as Nationally Certified Sustainably Managed Natural Sites, and consideration of the compatibility of the green space with solar panels in conjunction with construction of the new building
- discussed appropriate management of the dense bamboo-leaf oak forest at the Institute by logging, and consideration of the effective use of the wood for carbon fixation after logging

(2) Decarbonization through research institution collaboration

- conducted lectures about the registration of OECS (other effective area-based conservation measures) at several other research institutes on the basis of our experience regarding our Nationally Certified Sustainably Managed Natural Sites
- discussed about the compatibility of solar panels and green spaces at other institutes

(3) Decarbonization of Tsukuba City

- conducted a carbon-negative study session with the mayor of Tsukuba City, and proposed a climate citizens' conference. We planned, designed, and ran the conference in collaboration with Tsukuba City, The National Institute of Advanced Industrial Science and Technology, and the University of Tsukuba. At the conference, eight members of NIES each provided a topic about decarbonization.

2.3 Other hot topics

2.3.1 Seminar by international experts about the IPCC's institutional research

A Critical Assessment of the Intergovernmental Panel on Climate Change, the first book on the IPCC written from a social science perspective, was published in December 2022. Its editors, Mike Hulme and Kari De Pryck, were invited to give a public and in-house seminar, "Seeing the IPCC from Social Science: History, Institution and Future Reform." As climate change becomes more serious and emission reductions efforts make little progress, the IPCC's mission itself is being called for review, and the seminar provided an opportunity to discuss the future

direction of the IPCC and the potential for reform, if any. On the basis of the discussions at the seminar, Dr. S. Asayama, a senior researcher in the Social Systems Division, along with the invited researchers, published an international co-authored paper, “Three institutional pathways to envision the future of the IPCC”, in *Nature Climate Change*.

Fig. 2 Seminar on “Seeing the IPCC from Social Science: History, Institution and Future Reform”.



2.3.2 Dealing with the problems of the COVID-19 pandemic and the Russian military invasion of Ukraine in future scenarios

At last year’s external evaluation meeting, it was noted that it was necessary to discuss the impact of the pandemic and the Russian military invasion of Ukraine on climate change. At the Initiative’s monthly meeting in February 2023, we summarized those international issues that could be considered by scenario analyses at both the national and global levels.

From the viewpoint of scenario analyses at the national level, it was shared that population decline, information technology, and decarbonization remain basic important trends despite the two abovementioned recent global incidents, although a longer perspective is needed to consider potential impacts better.

From the viewpoint of scenario analyses at the global scale, it was shared that, as an impact of the pandemic, the climate response from a temporary reduction in GHG emissions through regulation of the movement of society as a whole would not exceed the range of natural variability. Moreover, the pandemic was viewed as a factor that raised society’s vulnerability to climate impacts. An analysis of the impact of the military invasion of Ukraine revealed that the increase in coal demand due to the interruption of natural gas supplies by Russia would be temporary according to the outlook by International Energy Agency. Both problems are not yet over and will require continued study. In addition, because global incidents comparable to them may occur in the future, the way in which unforeseeable large-scale incidents should be treated in the analysis of long-term climate scenarios remains an issue for further study.

2.4 External activities

As this year was the final year of the IPCC AR6 (Sixth Assessment Report) cycle, we held a study session for members of the press in advance of the release of the Synthesis Report. We also held a public webinar on climate change scenarios for experts in the field.

Research Domain

Earth System Domain

The surface of the Earth is covered with the atmosphere, oceans, and land, and preserving this surface environment is indispensable for creating a sustainable human society. However, human activity has caused changes in the climate, including not only rising average temperatures but also an increase in extreme weather events, rising sea levels, and damage to ecosystems and food production. Countries and regions are required to take further measures to reduce greenhouse gas (GHG) emissions under the Paris Agreement, an international framework for climate change countermeasures. There is growing concern about the climate crisis in the world, and Japan has pledged to achieve net-zero GHG emissions by 2050.

Researchers in NIES's Earth System Domain will, in collaboration with scientists in Japan and overseas, work on a variety of research issues, such as the prediction of future changes in the global environment, assessment of risks, and development of the advanced measurement technologies and models needed for their research. The intellectual research infrastructure (e.g., long-term monitoring and databases) will continue to be maintained by the CGER (Center for Global Environmental Research), established in 1990. We will also work closely with the Satellite Observation Center, which is responsible for the "IBUKI" (GOSAT) series of GHG observation satellites. We will disseminate our research results more quickly and widely than has been possible before. Scientific knowledge and data will be actively transmitted to international frameworks such as the UNFCCC (United Nations Framework Convention on Climate Change) and the IPCC (Intergovernmental Panel on Climate Change). We hope that, through the above activities, we can help to achieve a sustainable global environment and society.

1. Foresight and Advanced Basic Research

Dissolved N₂O concentrations in oil-palm-plantation drainage in a Malaysian peat swamp

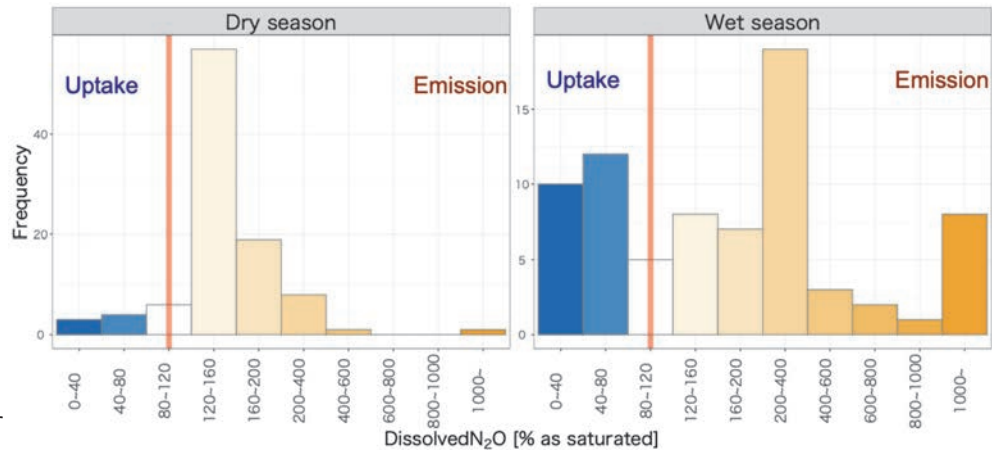
Oil palm plantations in Southeast Asia are the world's largest supplier of palm oil products and have been rapidly expanding in the last three decades, even in peat-swamp areas. Oil palm plantations on peat ecosystems have unique water management regimes that lower the water table with drainage and thus can be potential sources of indirect N₂O emissions from the peat drainage system. We conducted dry- and wet-season spatial monitoring of dissolved N₂O concentrations in the drainage and adjacent rivers of palm oil plantations on peat swamps in Sarawak, Malaysia, to evaluate the magnitude of indirect N₂O emissions from this ecosystem.¹⁾

The results revealed that the spatial distribution of dissolved N₂O concentrations in the drainage water differed considerably between the wet and dry seasons (Fig. 1).

1. Earth System Domain

During the wet season, many observation points were found to be strong sources of GHGs, whereas others were strong sinks. Investigation of the intramolecular isotope ratios of dissolved N₂O (¹⁵N-site preference in the NNO molecule) revealed that most of the N₂O produced was reduced to N₂, and a substantial portion was removed by the time it reached the river. This may have been due to the high organic matter supplied by the peat soils.

Fig. 1 Spatial distribution of dissolved N₂O concentrations. Left: dry season ($N = 99$). Right: wet season ($N = 75$). At low N₂O concentrations, water absorbs N₂O from the atmosphere because the dissolved N₂O concentration is lower than the equilibrium atmospheric concentration. At high concentrations, N₂O is released from the water surface to the atmosphere.



Reference:

- 1) Nishina K., Melling L., Toyoda S., Itoh M., Terajima K., Waili J.W.B., Wong G.X., Kiew F., Aeries E.B., Hirata R., Takahashi Y., Onodera T. (2023) Dissolved N₂O concentrations in oil palm plantation drainage in a peat swamp of Malaysia. *Science of the Total Environment* 872, 162062, doi: 10.1016/j.scitotenv.2023.162062

2. Policy-oriented Research

The Arctic region is the area most affected by global warming, and early detection of the progress of global warming and its impacts on Arctic nature and society is important in the effort to support Japan's science and technology diplomacy. As part of research collaboration under a Memorandum of Cooperation between NIES and the Finnish Environment Institute (SYKE), we invited two SYKE researchers to speak at a symposium on Essential Biodiversity Valuables during the 71st Annual Meeting of the Ecological Society of Japan, held in Yokohama in March 2024. They also visited the Fujihokuroku Flux site and the Biodiversity Center of Japan in the city of Fujiyoshida to exchange insights. Additionally, we held a seminar at the NIES campus in Tsukuba to share the latest information.

3. Intellectual Research Infrastructure Development

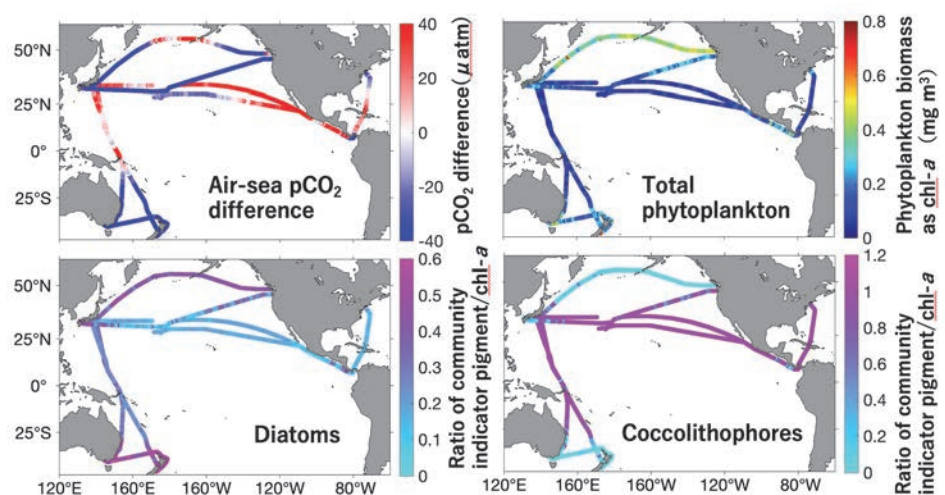
Establishment of a simultaneous monitoring system for ocean-surface pCO₂ and phytoplankton communities

NIES has continued its long-term monitoring of CO₂ exchange between the atmosphere and oceans since 1995, with the aim of clarifying the global GHG cycle. With the cooperation of a private shipping company (Toyofuji Shipping Co.), we conducted offshore atmospheric and ocean surface observations based on two regular cargo vessels traveling between Japan and North America and Japan and Oceania, as well as atmospheric observations based on one cargo vessel traveling between Japan and Southeast Asia.

The North Pacific is the highest contributor in the global ocean to atmospheric CO₂ absorption by biological processes. In this region, climate change is expected to alter phytoplankton community composition, which in turn affects biological drawdown of the CO₂ partial pressure (pCO₂). Therefore, we need to quantitatively elucidate the relationship between seasonal or inter-annual variations in the ocean's CO₂ absorption and the phytoplankton community. On the Japan–North America shipping route, we have started monitoring pCO₂ and phytoplankton communities in the ocean surface layer at the same spatiotemporal resolution (which has been difficult to achieve so far) (Fig. 2). To measure the phytoplankton community composition, we are using an automatic sensor installed in the previous fiscal year. As seen in Figure 2, the ratio of diatoms to total plankton increases in many areas of the ocean where the pCO₂ difference between the atmosphere and the ocean is negative.

We expect that the long-term continuous data to be collected in the future will help elucidate the CO₂ absorption mechanism of the ocean—a complex interplay of physical, chemical, and biological factors. A proposal by the person in charge of this monitoring was selected for a JST PRESTO New Research Project for FY2023.

Fig. 2 Differences in air–sea CO₂ partial pressure (pCO₂) and continuous observations of ocean surface phytoplankton communities. Top left: pCO₂; top right: biomass of total phytoplankton (as chlorophyll *a* concentration: chl-*a*); bottom left: diatoms; bottom right: coccolithophores (ratio of indicator pigment in each community to chl-*a*).



Material Cycles Domain

As part of our **Foresight and Advanced Basic Research**, we are conducting two main research activities. One is sustainability assessment and design of a future vision of resource utilization. The other is advanced science and engineering for material cycles.

As part of our **Policy-Oriented Research**, we have been conducting three main research activities. The first is research on social systems in material cycles and waste management. The second is impact assessment of hazardous substances in material cycles measurement, testing, and evaluation of hazardous substances in the resource-recycling process. The third is advancement and implementation of waste management technologies for social adaptation and improvement of waste treatment and disposal technologies.

In addition to the main research activities mentioned above, we launched an international project with overseas academic institutions to strengthen international joint research. As participants in several technical committees of the International Organization for Standardization (ISO), we also helped issue standard documents and scientific findings.

As part of the ongoing development of intellectual research infrastructure, we have begun not only to visualize international resource flows and Japanese municipal waste data but also to improve the user interface for data visualization.

Details of the abovementioned research activities are given below.

1. Foresight and Advanced Basic Research

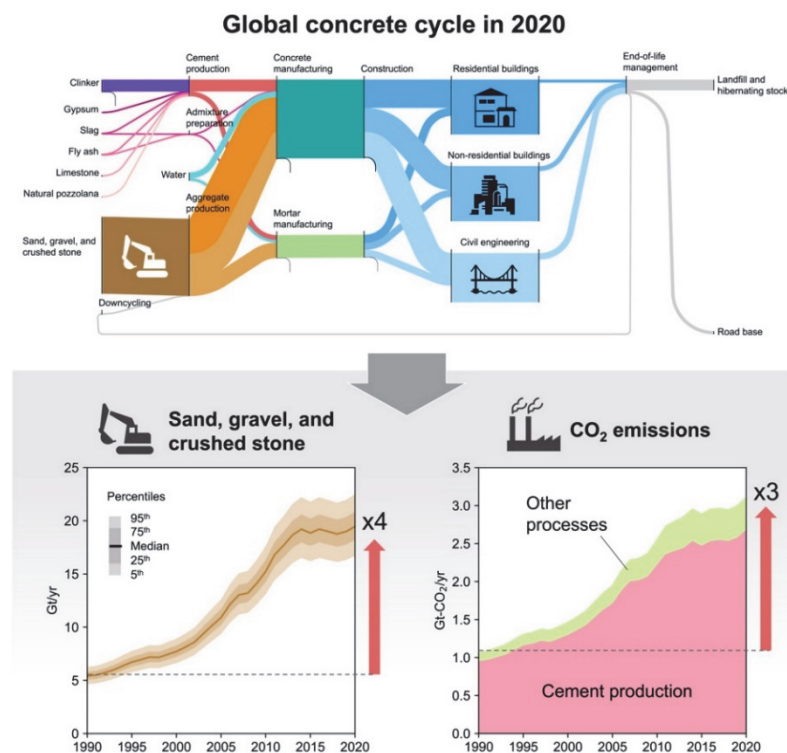
1.1 Sustainability assessment and design of a future vision for resource utilization

It has been pointed out that the mass production of concrete—the basic material of modern society—is a major factor inducing massive resource extraction and CO₂ emissions. However, the basic question of how much the global production of concrete has contributed to resource extraction and CO₂ emissions remains unanswered. Therefore, in this research, we estimated a series of material flows and CO₂ emissions related to concrete and based on standards and various statistics, industrial shipment data.

The results of the analysis showed that global concrete production (including mortar) quadrupled between 1990 and 2020, reaching approximately 26 Gt in 2020 (Fig. 1). The amount of used concrete generated in 2020 was only about 14% of annual concrete production, and almost all of it was landfilled or downcycled as

road bed material. As a result, recycled aggregate accounts for less than 1% of aggregate production, and there was a sharp increase in demand for virgin aggregate (i.e., sand, gravel, and crushed stone). Whereas the demand for virgin aggregate for concrete was about 60% of the total demand for fossil fuels in 1990, the demand for virgin aggregate (about 20 Gt/year) exceeded the total demand for fossil fuels (about 15 Gt/year) in 2020. We also estimated changes in CO₂ emissions associated with concrete production and found that the contribution of concrete production to total CO₂ emissions increased from about 5% to about 9% from 1990 to 2020. During this period, the cement and concrete industries achieved a nearly 20% reduction in CO₂ emissions per unit of production through clinker substitution, alternative fuel use, and efficiency improvements of thermal and electrical energy, but the increase in emissions due to expanded production outweighed the reductions achieved by increased efficiency.

Fig. 1 Time-series changes in global concrete flows (top) and associated resource extraction (bottom left) and CO₂ emissions (bottom right).



1.2 Advanced science and engineering for material cycles

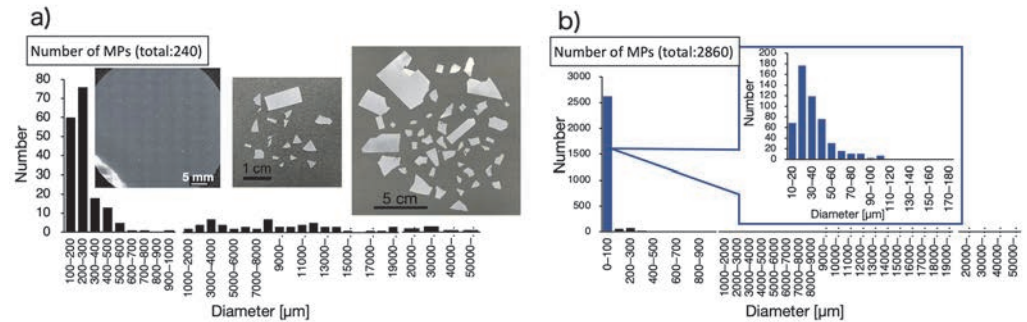
Although the dynamics and environmental risks of nanoplastics (NPs) are of substantial concern, labeled NP standard particles (such as those labeled with isotopes) necessary for quantitative analysis and toxicity testing of NPs are not available. Additionally, understanding the mechanisms of degradation and fragmentation of plastics exposed to the environment is essential for assessing the generation of microplastics (MPs). Therefore, we conducted two studies focusing on different sizes of plastics: NPs and MPs.

In our research on the dynamics and environmental risks of NPs, we used an NP particle-preparation method that we developed to prepare particles labeled with stable isotope elements or fluorescent dyes. We synthesized stable isotope-labeled particles through the synthesis of raw materials and the development of an impurity removal method. Fluorescence-labeled particles were prepared by immersing the particles in a fluorescent dye solution. The stable isotope-labeled particles are useful as surrogates (standard materials for recovery correction in quantitative analysis). The fluorescence-labeled particles enable nondestructive observation of the internal dynamics of the particles during toxicity testing. In fact, we introduced stable isotope-labeled particles into NP analysis using pyrolysis gas chromatography – mass spectrometry and confirmed their effectiveness as surrogates. This was the first-ever attempt to introduce surrogates into NP analysis. By proposing this method as a reliable analytical approach, we expect to contribute to an accurate understanding of the amounts and risks of NPs in the environment.

In our research on plastics fragmentation, we continued efforts from last fiscal year to complete the preparation of fragmentation test equipment that reproduces physical actions in the marine environment (e.g., impacts from waves and sand). We also established a method to evaluate the fragmentation speed of plastics. MPs smaller than 100 μm are difficult to detect accurately by using conventional methods, but in this research we succeeded in detecting MPs as small as approximately 2 μm by utilizing a scanning electron microscope. The results showed that there was a negative correlation between the size and number of MP particles generated by the fragmentation of degraded plastics, and that the number of MPs increased exponentially as the size decreased (Fig. 2). Improvement of the lower limit of detectable size in MP analysis is particularly important for evaluating the fragmentation speed.

We also continued the plastics outdoor exposure test that was started last fiscal year and were able to obtain plastics samples that had been exposed to the outdoors for about 1 year at 10 locations across the country. By applying the above methods of fragmentation testing and analysis to these samples, by the end of this fiscal year we expect to determine regional differences in the speed of plastics degradation and fragmentation, as well as the relationship of this speed with various plastic shapes and the results of a characteristics analysis. These results will be useful for understanding the mechanism of plastic fragmentation and forecasting the amount of MPs formed by degradation of plastic products in the marine environment—especially the beach. We also plan to provide information on the environmental aspects of plastics to the committee of ISO standards.

Fig.2 Results of the fragmentation test for degraded polypropylene. Distribution by MP particle size: (a) > 100 μm , (b) < 100 μm .



2. Policy-Oriented Research

2.1 Research on social systems in material cycles and waste management

We assessed the reliability of pollutant release and transfer register (PRTR)-reported data on the amount of release and transfer, which is fundamental information for chemical substance management. We surveyed the release estimation techniques (RETs) used for the calculation of PRTR-reported data through a questionnaire survey of reporting business operators. By using this information and by referring to the national calculation manual and OECD technical documents, we examined whether the reported data were calculated by using appropriate RETs. We found that 20%–25% of the total reported data on releases to the atmosphere and transfers to waste disposal may have been calculated with RETs that were not necessarily appropriate. To improve the reliability of the data, appropriate RETs need to be clearly recommended in the calculation manual and emission factors must be checked and reviewed.

We also reviewed and improved the structure of the municipal waste model to assess a scenario for the large-scale implementation of the 3R (reduce, reuse, recycle) initiative. In the previous fiscal year, we focused on an analysis of the impact of the increase in telework on the amount of municipal waste generated. Following up on that research, we discussed the direction and content of specific studies, reviewed existing research, and extracted and organized factors other than telework that may affect the generation and separation of municipal waste.

Last fiscal year, a questionnaire survey was conducted on the disaster waste cleanup in Tateyama City, in Chiba Prefecture, following the Boso Peninsula Typhoon in 2019. This year, we further analyzed the results, which revealed that households with elderly members (aged 75 or older) in particular experienced problems such as not having suitable vehicles to carry disaster waste or not being able to transport waste to the designated disposal areas.

We developed a logic model for plastic material cycles and visualized various plastics material-cycle initiatives and their effects. We assembled a list of major activities of stakeholders through online and literature research, and we discussed their effects and achievements from the perspective of theory assessment.

To advance a system transition toward a global circular economy, we proposed an indicator framework with five characteristics: a focus on important shifts, goal setting, and progress evaluation for outcome indicators; use of a phased approach; active adoption of indicators to be developed; use of indicators in communication with stakeholders; and exploration of entry points for transition. In addition, we developed tools (e.g., an impact matrix and nexus mapping) with the aim of integrating circular economy policies and carbon-neutral and nature-positive policies. The identification of control points and monitoring points was deemed to be important to meet this goal.

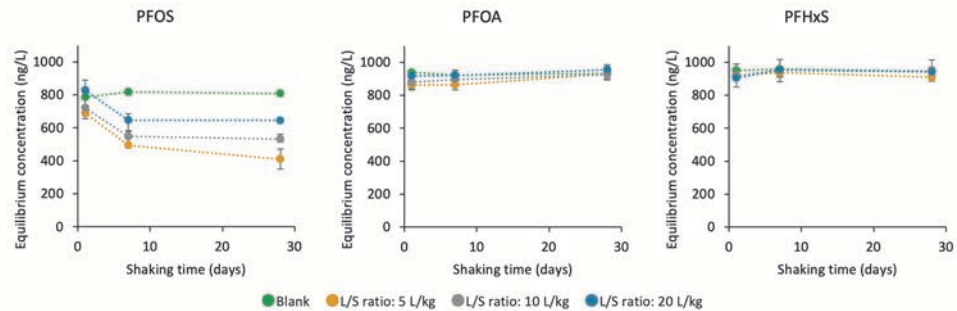
As part of a safety assessment of the material-cycle process, and to determine the current status of ignition and other incidents caused by LIBs in waste treatment, we conducted surveys of lithium-ion batteries (LIBs) mixed in non-combustible waste at municipal treatment facilities. The results showed that there were several treatment facilities that had more than 0.1 ignition accidents per tonne of non-combustible and bulky waste collected in FY 2020. Although small home appliances containing LIBs made up only 0.3% of the total non-combustible waste by weight, they were the cause of most of the incidents involving ignition. We pointed out that to avoid these LIB-caused ignition incidents it is essential not to crush small home appliances containing LIBs.

2.2 Impact assessment of hazardous substances in material cycles

Sorption tests of PFOS, PFOA, and PFHxS with a decomposed granite soil sample were conducted. The distribution equilibrium of PFOS between the decomposed granite soil and water was reached 7 to 28 days after the start of the test (Fig. 3). The sorption of PFOA and PFHxS onto the decomposed granite soil sample was extremely low, and the equilibrium concentrations of PFOA and PFHxS did not change significantly after the start of the sorption test. A comparison of the physicochemical properties indicated that the sorption of PFOS, PFOA, and PFHxS onto the decomposed granite soil sample was related to their water solubilities and hydrophilicities. A good correlation ($R^2 = 0.98$) was observed between the equilibrium concentration of the material and the amount of sorption after 28 days of shaking, and the PFOS water–soil partition coefficient in the decomposed granite soil was calculated to be 9.5 L/kg, which is lower than the range (9–444 L/kg) reported in previous studies. In addition to the sorption tests, we performed desorption tests with the same decomposed granite soils after the sorption tests, and we then analyzed the mass balance of PFOS in the sorption–desorption tests. Specifically, the decomposed granite soil samples after the 7-day sorption test were subjected to desorption tests with liquid to solid ratios of 5, 10, and 20 L/kg. The

amount of PFOS eluted after the test was only 10%–30% of the PFOS content before the desorption tests. There was no significant change in the amount of PFOS eluted, even when the sorption period before the test or the shaking period during the test were changed. The results of this testing are expected to contribute to soil contamination countermeasures. They should also help to elucidate the behavior of PFAS in contaminated soil and to develop purification technologies.

Fig. 3 Relationship between shaking time and equilibrium concentrations of PFOS, PFOA, and PFHxS in sorption tests using decomposed granite soil.



To evaluate the application of steel slag to green infrastructure, technology that actively utilizes the functions of the natural environment, we prepared hydrated solidified material, which is composed of blast furnace slag and steelmaking slag, and dredged-soil solidified material, which is composed of dredged soil and steelmaking slag. We then conducted sequential batch tests in pots to examine the applicability of each solidified material as a planting base for reeds. In all test systems, reed sprouts formed after 2 weeks, but in the hydrated solidified material and in the mortar used as a control, the sprouts stopped growing and died after 6 weeks. In the dredged-soil solidified material, the reeds showed good growth throughout the test period (12 weeks), indicating that it can be used as a planting base for reeds, even when used alone. In addition, the planted system showed a decrease in pH in the range of 0.4 to 1.0 compared with an unplanted test system. The concentrations of Cd, Pb, Cr, As, Se, and B were below the environmental standard values in all batches in the tests of the hydrated solidified material and the dredged-soil solidified material. In the mortar, the concentration of Cr was above 0.02 mg/L, indicating that further detailed study, such as an investigation of the valence of Cr, is required. In the test system of the dredged-soil solidified material, removal of ammonia (initial concentration: 32 mg/L) and nitric acid (initial concentration: 330 mg/L) was confirmed, with the removal rates reaching 99% and 55%, respectively, by the end of the test. Whereas the nitrogen removal rate at the end of the test was 6% in the unplanted test system, it was 52% in the planted test system, confirming its water-purification function. These outcomes are expected to be utilized as fundamental knowledge for future applications of steel slag to green infrastructure.

2.3 Advancement and implementation of waste-management technologies for society

We have been conducting a multifaceted evaluation of final waste disposal sites in Japan; developing appropriate waste treatment and resource-recovery technologies based on an assessment of waste characteristics in Asian cities; and studying the establishment of a Johkasou management technology system to adapt decentralized wastewater treatment technology to Southeast Asia.

By using an approach that combines physics and statistics, we developed a landfill emissions model for determining the post-closure care period. A time-dependent concentration profile was estimated in the physics-based transport model in dual porous media, and the model parameter (the Sherwood number) was determined for the profile to be closest to the observed concentrations. This approach can provide reliable predictions that can be revised as more observed concentrations are accumulated in the future. We provided this prediction method in a web application, and we encouraged practitioners to make effective use of their data.

We have continued disseminating standard operating procedures (SOPs) developed in previous years for the field-investigation methods required when important environmental safety and pollution issues arise at final waste disposal sites and illegal dumping sites. We held several workshops and seminars for users doing administrative work at final disposal sites for local governments.

We have continued to advise officials about feasible policies for promoting the recycling of construction and demolition waste (CDW) in Quang Ninh Province, Vietnam, by working with the provincial Department of Construction's taskforce. We have engaged in discussions about practical CDW recycling schemes, focusing on promoting the utilization of recycled materials in public construction projects and applying a standard pricing system in construction works.

We are compiling a risk-assessment table for 20 possible situations (locations and actions) where infection with COVID-19 could occur in municipal solid waste collection operations from the start to the end of the work day. A questionnaire survey of government-designated cities and other large cities in Japan allowed us to determine the frequencies of 14 of the 20 situations in which infection would occur.

We performed the test method, which had been developed in previous research, on a trial basis for some local on-site domestic wastewater treatment products in Indonesia. Through this campaign, we confirmed that the testing method works well in Indonesia. We also held seminars and training programs to disseminate information on how to secure the performance of domestic wastewater treatment facilities by using these testing methods. The characteristics of the accumulated sludge in wastewater treatment facilities was also analyzed to evaluate the effects

of biochar production on greenhouse gas sequestration.

2.4 International Waste Management Research Administration Office

We intend to support the proposal and implementation of international joint research by integrating research interests in multiple fields, with the resource-recycling field as the core. We will promote the efficient social implementation of research results and policy recommendations by promoting cooperation with academic institutions and local governments overseas and by quickly identifying needs. In addition, we support the reflection of research results through international organizations and international activities.

We hosted two guest researchers from Thailand under a program (“Enabling Waste Management Scheme in Response to Disaster and Climate Change”) that was jointly run with King Mongkut’s University of Technology, Thonburi, and funded by the Office of National Higher Education Science Research and Innovation Policy Council, Thailand. As part of the program, we developed the “Guideline for Disaster Waste Management for Local Cities” and held a joint workshop to disseminate the information. In addition, we coordinated visits by delegates from Indonesia, China, and Korea to our division, including facility tours, as well as exchanges about recent issues related to waste management, and other related matters. One such visit led to the signing of a Memorandum of Understanding of collaboration with the National Institute of Environmental Research in Korea.

We supported the application and management of international research funding in the field of the material cycles and waste management. The researchers who were supported by this office have been successfully funded by international schemes in the UNEP, the UK, and Thailand.

We also organized a research seminar (“Building a Global Research Reputation: Mastering Networking Skills”) to develop communication and networking skills related to international academic opportunities. The seminar included a guest speaker from the Japan Science and Technology Agency.

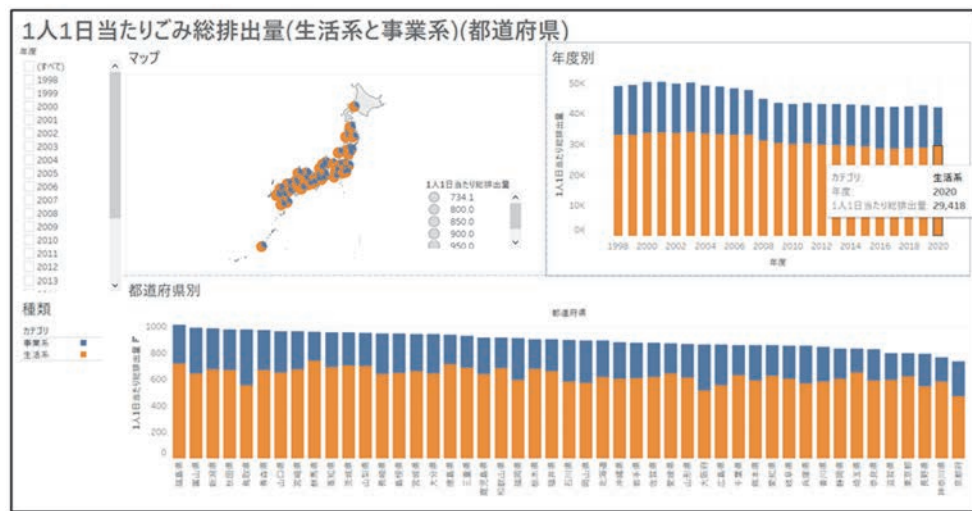
3. Intellectual Research Infrastructure Development

An internal review for the release of the “NIES Global Trade of Materials” is in progress. In response to feedback from this review, we are working on modifying the algorithms related to drawing methods and color combinations, as well as expanding the information provided. To expand the use of Japan’s long-term database on municipal solid waste management, developed by NIES, we extracted essential items from the database. We then prepared an interactive display by using the visual data analytics platform “Tableau”. We converted datasets into mutually comparable indicators (e.g., per capita, per amount disposed, %) for each prefecture and municipality in Japan and displayed them in Tableau (Fig. 4).

2. Material Cycles Domain

With the increase in waste generation due to economic development and population growth, there are many landfills in developing countries where waste is poorly managed and improperly treated. With the aim of detecting and creating a database of inappropriate landfills in developing countries by using Earth observation satellite data, we first conducted a wavelength measurement survey at landfill sites in Nha Trang and Hue in Vietnam. Certain regularities were observed in the reflection characteristics of the waste. This was an important achievement in the development of the database.

Fig. 4 Example of indicators displayed on the visual data analytics platform Tableau. The figures on the top right and bottom show municipal solid waste generation per capita over time and by prefecture, respectively. The blue and orange areas represent commercial waste and household waste, respectively.



Health and Environmental Risk Domain

In the field of health and environmental risk, we aim to promote foresight and advanced basic research and policy-oriented research to help protect human health and preserve ecosystems from environmental stressors such as chemical substances.

Our foresight and advanced basic research includes: (1) evaluation of the toxic effects of a variety of chemicals on aquatic/benthic organisms from the molecular level to the individual and population levels; (2) studies of exposure to chemicals via the environment, and advancement of methods for understanding and predicting actual states of exposure; (3) development of new methods to assess the impacts of ecosystem disturbance factors by using surveys, experiments, and model analysis; (4) systematization of chemical risk management and assessment of chemical kinetics and exposure; (5) development of methods for evaluating the health effects of micro/nano plastics and environmental pollutants such as PM_{2.5}, and elucidation of the effect mechanisms; (6) new health impact assessment and mechanism elucidation considering multiple environmental factors, multiple diseases, and next-generation effects; (7) evaluation of biological effects on the cranial nervous system and elucidation of mechanisms; (8) development of a biomarker-based method for measuring lifetime exposure; and (9) elucidation of the health effects of environmental pollutants and environmental factors by using epidemiological methods and statistical analysis methods for epidemiological studies as a basis for the Japan Environment and Children's Study (JECS).

In our policy-oriented research, we intend to promote regulatory science research to help protect human health and preserve ecosystems from hazardous chemicals by using the latest scientific findings, including the results of our foresight and advanced basic research and our comprehensive environmental risk research program. We intend to contribute to environmental policy through these results and will promote our efforts as a reference laboratory.

Below are brief accounts of some of the important results of our research in FY 2023.

1. Foresight and Advanced Basic Research

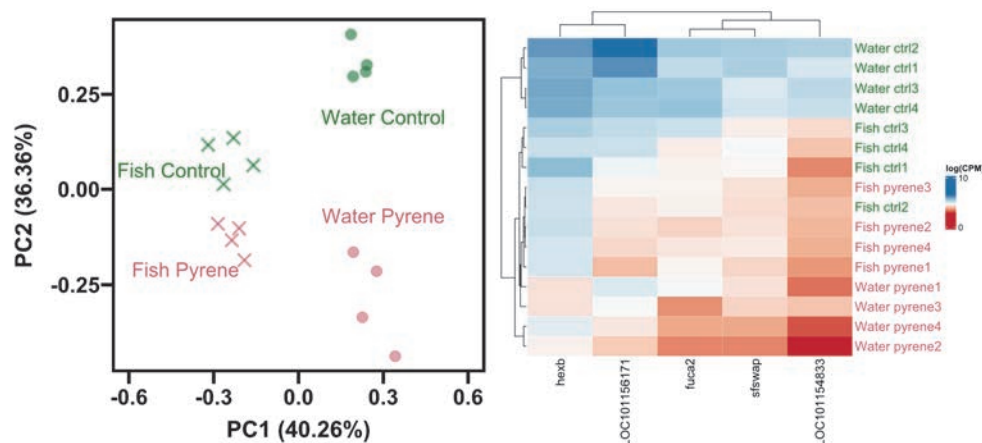
1.1 Exploring the potential of environmental RNA as a non-invasive tool to assess toxic effects in aquatic organisms

Environmental RNA (eRNA) is emerging as a non-invasive tool for assessing the health status of aquatic macroorganisms; however, the potential of eRNA has not been tested. In this study, we investigated the ability of eRNA to detect changes in gene expression in Japanese medaka fish (*Oryzias latipes*) in response to sub-lethal exposure to pyrene, a model toxic chemical. We performed standardized acute toxicity tests and collected eRNA from tank water and RNA from fish tissue after

3. Health and Environmental Risk Domain

96 h of exposure. Our results revealed that 1100 genes were detected in eRNA, and the sequenced read counts of these genes were correlated with those in the fish tissue ($r = 0.50$). Moreover, there were 86 differentially expressed genes (DEGs) in the eRNA in response to pyrene, some of which were shared by fish body RNA, including the suppression of collagen fiber genes. Multivariate analyses showed that control and exposure treatments could be separated on the basis of the expression profiles of the 86 DEGs (Fig. 1 and Hiki et al.¹).

Fig. 1 Genes differentially expressed in fish tissue and eRNA (water) in response to pyrene. (Left) Principal component analysis (PCA) based on the counts per million (CPM) of 86 DEGs in eRNA. Different colors and symbols represent different exposure treatments and RNA sources, respectively. (Right) Heatmap of five genes that had the largest loading scores for PC2. Color represents logarithmic CPM of each gene. Adapted with permission from Hiki et al.¹ Copyright 2023 American Chemical Society.

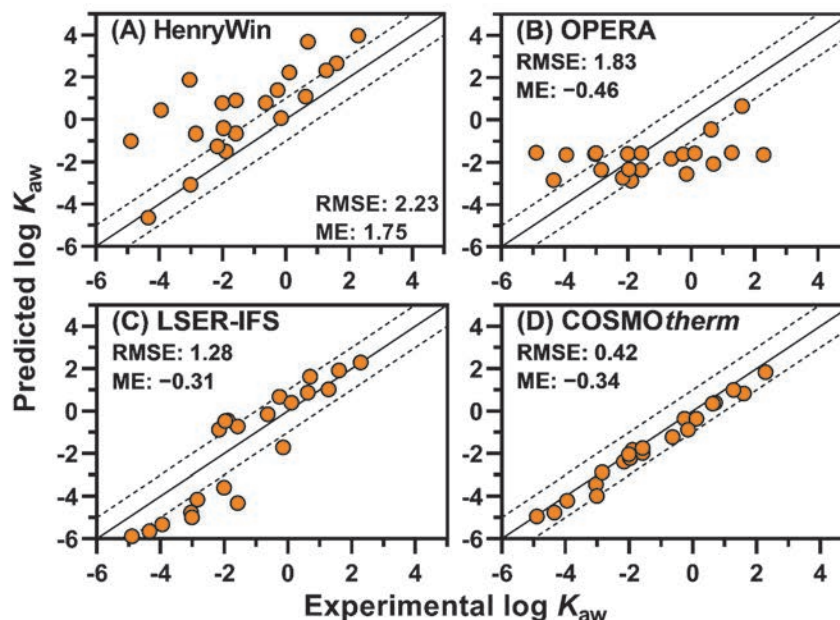


1.2 Environmental properties of per- and polyfluoroalkyl substances (PFAS): New experimental data and model predictions for air–water partition coefficients

The environmental fate and distribution of organic contaminants are largely determined by the physicochemical properties of the contaminants. Among several key properties, the air–water partition coefficient (K_{aw} [L/L]) (or Henry's law constant) is of particular importance. However, surprisingly few K_{aw} data have been reported for PFAS, despite the growing concern about their environmental distribution and potential health impacts. Here, K_{aw} values at 25 °C were newly measured for 21 neutral PFAS by using the hexadecane/air/water thermodynamic cycle approach. The measured K_{aw} values spanned over seven orders of magnitude ($10^{-4.9}$ – $10^{2.3}$ L/L), demonstrating the high level of diversity of the PFAS considered. The measured K_{aw} data were compared with the values predicted by four existing models: HenryWin, OPERA, LSER-IFS, and COSMOtherm. The first three models produced large prediction errors in K_{aw} for some of the studied PFAS (Fig. 2 and Endo et al. 2023²). The root mean squared errors (RMSEs) were 1.28–2.23 log units, and an error of 5 log units was observed in the worst case. The results indicate that these empirical models cannot provide even order-of-magnitude estimates of K_{aw} for PFAS. In contrast, the quantum-chemical-based COSMOtherm provided accurate predictions for all PFAS considered, with an RMSE of 0.42 log units. We conclude that models based on empirical training with experimental data cannot provide accurate predictions for a data-poor class of chemicals such as PFAS, whereas theoretical-based models such as COSMOtherm can be robust for a

previously unexplored group of chemicals.

Fig. 2 Model-predicted vs. experimentally determined air-water partition coefficients (K_{aw}) for 21 PFAS. Solid and dashed lines indicate 1:1 agreement and 1 log unit difference, respectively. RMSE, root mean squared error; ME, mean error. Figure from Endo et al.²⁾ Published under the CC-BY 4.0 license.



1.3 Exposure to dogs and cats and risk of asthma in Japan

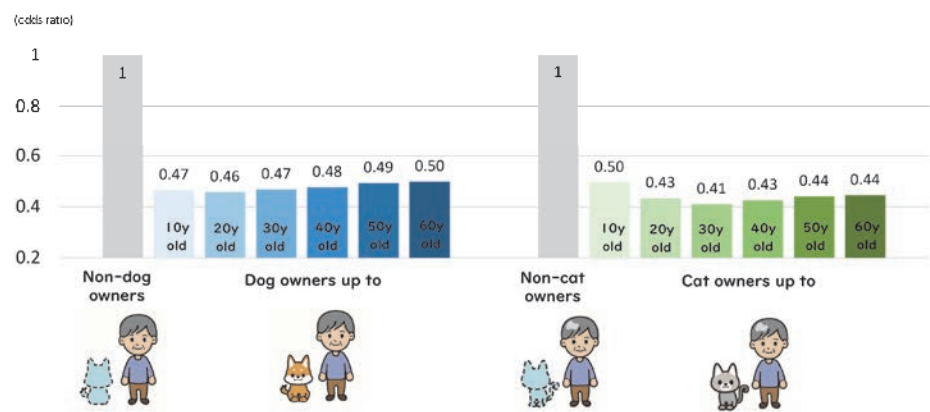
Exposure to furry pets is known as a potential risk factor for allergic diseases such as asthma, because these pets harbor animal-derived allergens. In fact, clinicians may discourage pet ownership by families with children who develop asthma in infancy to improve the children's asthma symptoms. Although a systematic review of 32 studies suggested that pet exposure was associated with a slight increase in the risk of asthma and wheezing in older children,³⁾ another meta-analysis of 32 studies reported that cat exposure had a slight preventive effect on asthma, whereas exposure to dogs slightly increased the risk of asthma.⁴⁾ A recent study of more than 1000 children 7 to 8 years old reported that the prevalence of allergic diseases decreases in a dose-dependent manner with the number of pets living with the child during their first year of life, suggesting that owning dogs or cats, or both, could protect against allergy development.⁵⁾ Whether owning a dog or cat has a protective effect against asthma in Japanese populations remains unknown.

This retrospective study examined the association of dog or cat ownership with the onset of asthma in Japanese people across a wide range of ages from birth to old age. We analyzed data collected in an internet survey conducted by the Japan Pet Food Association in 2021. Valid data were obtained from 4290 participants for analysis of dog ownership and 4308 participants for analysis of cat ownership. In these respective groups, 41.2% had owned a dog and 26.5% had owned a cat. During the follow-up period, 5.7% of dog owners and 14.8% of non-dog owners developed asthma, as did 5.6% of cat owners and 13.5% of non-cat owners. A

3. Health and Environmental Risk Domain

binomial logistic regression analysis showed that participants who had owned a dog had an odds ratio (OR) of 0.50 (95% confidence interval (CI): 0.36–0.69) of developing asthma compared with those who had not owned a dog after adjustment for sociodemographic characteristics. The corresponding OR of asthma onset among participants who had owned a cat was 0.45 (95% CI: 0.31–0.64). Stratified analysis showed that whereas younger participants who had not owned a dog had higher ORs of developing asthma, those who had not owned a cat had similar ORs of asthma onset across all age categories (Fig. 3). These results suggest that, although there may be a critical window in early life during which exposure to dogs can prevent asthma onset, the protective effect of cat exposure is constant across all ages in Japan.

Fig. 3 Independent associations of dog or cat with the onset of asthma were examined by using binomial logistic regression analysis after adjustment for sex, type of residence, household income, number of family members, medical history of allergy, and follow-up period. Stratified analysis was conducted according to the earliest age at which participants were exposed to a dog or cat through ownership.



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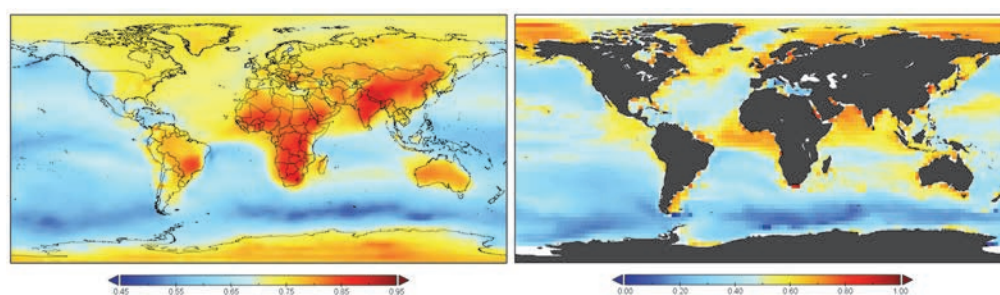
2. Policy-Oriented Research

2.1 Assessing the impact of mercury emission reductions by using future projections from global modeling

Seven years have passed since the Minamata Convention on Mercury came into effect, and now, both domestically and internationally, discussions are underway in preparation for the first effectiveness evaluation. In these discussions, model-based future projections are essential components of the research. Up until last fiscal year, we had been developing and refining the global mercury model, FATE-Hg, which we have used to advance the development of an integrated model that addresses the dynamics, exposure, and impacts of mercury. By incorporating input data such as climate data, carbon cycles, and reactant concentrations from Earth system model predictions, we have made it possible to conduct future projections under various climate scenarios.

This fiscal year, we conducted simulations by using scenarios that considered the presence or absence of reduction measures for future mercury emissions, and we quantitatively evaluated the effectiveness of these reductions. The results showed that, without emission-reduction measures, mercury concentrations in the lower troposphere and upper ocean would increase significantly. On the other hand, implementing emission-reduction measures would greatly mitigate this increase. In more realistic, stepwise reduction scenarios, it is predicted that mercury levels could be maintained close to current levels in the mid-term. Additionally, by analyzing the geographical distribution of the mercury reduction rates due to emission control measures, we identified regions and ocean areas where the effects of these measures would be more pronounced. For gaseous elemental mercury in the atmospheric boundary layer, significant reductions were observed in regions such as Africa, South Asia, China, and South America (left panel of Fig. 4). For methylmercury in marine particulate organic matter, larger reduction rates were observed in the central Atlantic, the Arctic Ocean, the North Atlantic, and the Indian Ocean (right panel of Fig. 4). Given that the effects of these measures are more detectable in these regions and ocean areas, they are considered crucial for the development of future strategic monitoring plans for the atmosphere and marine fishes as part of the effectiveness evaluation of the Minamata Convention on Mercury.

Fig. 4 Projected reduction rates of gaseous elemental mercury in the atmospheric boundary layer (left) and of methylmercury in marine particulate organic matter in the upper ocean (right) under a stepwise reduction scenario for 2050.



Regional Environment Conservation Domain

Human activities have a substantial impact on both human life and ecosystems through environmental media such as the atmosphere, water, and soil. To minimize the environmental impacts of human activities, the Regional Environment Conservation Division has been studying the dynamics and effects of substances in each medium; developing new measurement and analysis methods; and investigating environmental restoration, regeneration, and conservation technologies at various spatial scales, from cities to Asia-wide. Furthermore, in cooperation with local environmental research institutes, we are promoting research on environmental management technologies suitable for each region. Our aim is to achieve comprehensive regional environment conservation.

This Division consists of six sections (Regional Atmospheric Modeling, Regional Atmosphere Research, Lake and River, Marine Environment, Soil Environment, and Environmental Management and Technology) and has one Principal Researcher.

In FY 2023, we implemented many research projects covering a wide range of regional environmental issues. Most of the projects are collaborations with other NIES divisions. Our main research projects in **Foresight and Advanced Basic Research** were as follows:

- Evaluating the fate of pathogenic bacteria and developing and supporting the implementation of domestic wastewater treatment technology aimed at reducing hygiene risks
- Influence of volcanic ash in soils on Ca cycling in forest ecosystems.

We have also developed an air-pollution-simulation support system and measured oxygen consumption in the bottom layer of Lake Biwa as part of **Policy-Oriented Research**. Additionally, there are two long-term monitoring programs as part of **Intellectual Research Infrastructure Development**, namely the Regional Atmospheric Monitoring Program, which monitors the air quality in East Asia at Okinawa and Nagasaki, and the Global Environment Monitoring System (GEMS)/Water Program in Lake Kasumigaura, which is a collaboration with the Biodiversity Division. In the following section, we briefly describe some of our important results in FY 2023.

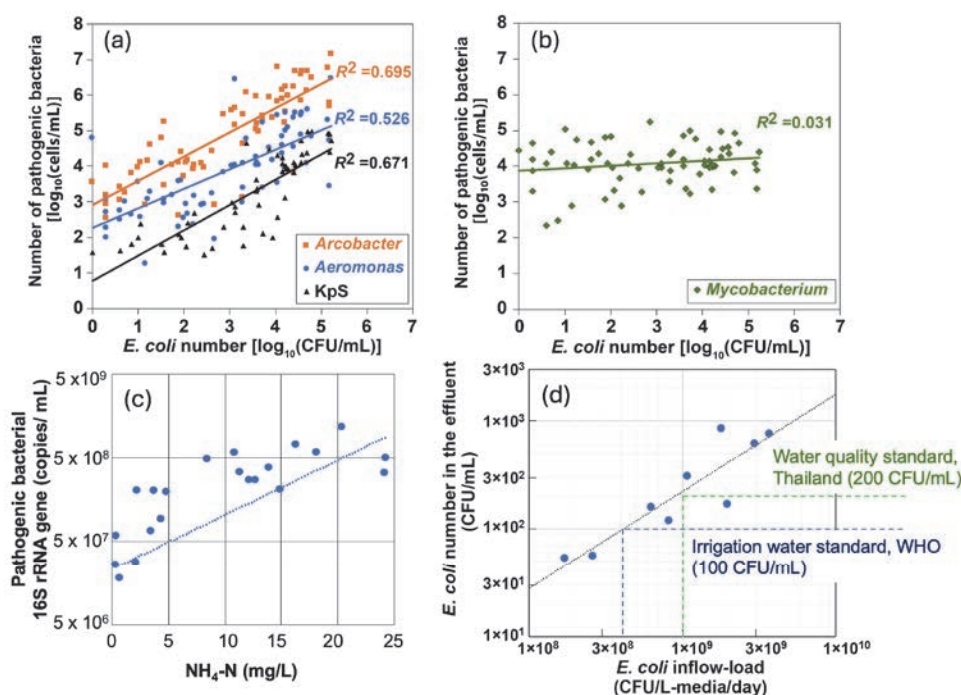
1. Foresight and Advanced Basic Research

1.1 Evaluating the fate of pathogenic bacteria and developing and supporting the implementation of domestic wastewater treatment technology aimed at reducing hygiene risks

To gain an understanding of the fate of pathogenic bacteria in the water environment and wastewater treatment systems, we developed comprehensive and specific

detection techniques for pathogenic bacteria originating from domestic wastewater. As a result of comprehensive 16S rRNA gene analysis of domestic wastewater from wastewater treatment facilities, 18 major groups of pathogenic bacteria were found that are universally and predominantly detected. Specific primer sets for real-time PCR (polymerase chain reaction) for a number of these bacteria, namely *Aeromonas*, *Arcobacter*, *Mycobacterium*, *Klebsiella pneumoniae* species complex (KpS), and *Escherichia coli*, were prepared, and the trends of the bacteria were evaluated in various wastewater treatment facilities and in the water environment. In wastewater treatment facilities operating properly, many of the major pathogenic bacterial groups were efficiently removed, and the removal characteristics were found to be correlated with the number of *E. coli*, which was used as a hygiene indicator in the water quality standard (Fig. 1a). On the other hand, *Mycobacterium* numbers were not significantly reduced by aerobic wastewater treatment (such as the activated sludge process), and the correlation with *E. coli* numbers was low, suggesting the need for future monitoring (Fig. 1b). In addition, there was a positive correlation between the amounts of pathogenic bacteria in polluted drainage canals in Bangkok, in Thailand, and the concentration of ammonium nitrogen ($\text{NH}_4\text{-N}$) (Fig. 1c), indicating the possibility of regulating nitrogen concentration and reducing hygiene risks by introducing appropriate treatment technology.

Fig. 1 (a), (b) Relationship between number of pathogenic bacteria and *E. coli* in domestic wastewater treatment facilities. (c) Correlation between the number of pathogenic bacterial 16S rRNA genes and ammonium nitrogen concentration in a drainage canal. (d) Relation between effluent *E. coli* number and *E. coli* inflow-load in a pilot-scale performance evaluation of an aerobic trickling filter.



In developing countries, the effluent quality of domestic wastewater treatment facilities is often low, and this leads to the deterioration of hygiene conditions in the water environment and problems in ensuring safety when treated water is reused. Therefore, with the aim of developing a post-treatment technology that is easy to maintain and can be operated at low cost for effluent from domestic wastewater treatment facilities with insufficient water quality purification, we conducted a

4. Regional Environment Conservation Domain

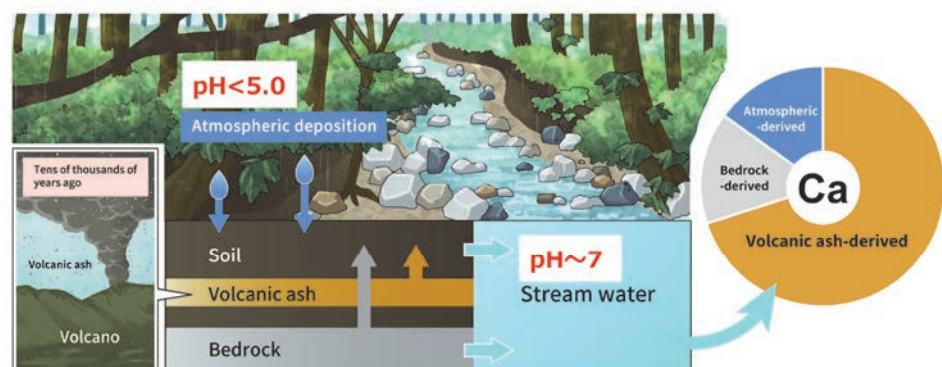
pilot-scale on-site performance evaluation to attempt to reduce hygiene risk. A pilot-scale aerobic trickling filter (down-flow hanging sponge: DHS) packed with polyurethane foam was operated in an actual wastewater treatment facility in collaboration with the Bangkok Metropolitan Administration. The results indicated that the remaining organic matter and $\text{NH}_4\text{-N}$ in the effluent of the treatment facility could be treated efficiently and quickly (<0.5 h) in year-round operations. In addition, the *E. coli* removal rate reached $2 \log_{10}$ and the water quality met the water quality standard of Thailand. Moreover, the World Health Organization (WHO) irrigation water standard can be met when the *E. coli* load is below 4×10^8 CFU/L-media/day (Fig. 1d). Furthermore, the DHS had high removal performance ($> 2 \log_{10}$), equivalent to that of the activated sludge process, against the pathogenic bacterium *Arcobacter*, which is found in large quantities ($10^5\text{--}10^6$ cells/mL) in domestic wastewater. In sum, the introduction of the treatment system that we developed improved the treated-water quality and enabled the safe reuse of the water.

In order to support the social implementation of DHS technology, we collaborated with private companies and applied for and obtained overseas technology certification from the Japan Sewage Works Agency as an energy-saving and easy-to-maintain wastewater treatment technology for Thailand. As a result, DHS is currently installed as a post-treatment system of septic tank for the treatment of domestic wastewater at a company housing facility in Thailand. The system has demonstrated stable removal efficiency of residual nitrogen and *E. coli*.

1.2 Influence of volcanic ash in soils on Ca cycling in forest ecosystems

The sources of Ca in forest ecosystems in Japan are considered to be sea salt, bedrock, and Asian dust. However, volcanic ash may also be an important source of Ca in areas with volcanic ash soil, especially in areas where the Ca supply from bedrock is low (Fig. 2). We determined the concentrations of Sr and Ca and the isotope ratio of Sr (a good proxy for Ca) in stream waters, as well as in precipitation, bedrock, and volcanic ash, and we estimated the contribution of volcanic ash to Sr and Ca in the stream waters. A significant contribution of volcanic ash in soil to Ca in stream waters was found in a granite watershed in Ibaraki Prefecture and in chert watersheds and sandstone watersheds in Tochigi Prefecture.

Fig. 2 Schematic description of the influence of volcanic ash in soils on Ca cycling in forest ecosystems in volcanic regions of Japan.

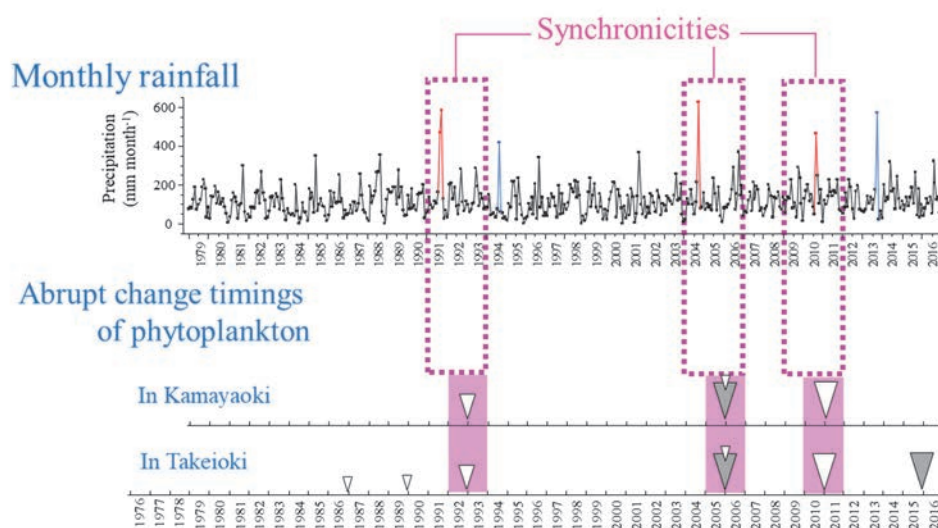


2. Intellectual Research Infrastructure Development

2.1 Identifying the true drivers of abrupt changes in ecosystem states, with a focus on time lags: extreme precipitation can determine water quality in shallow lakes

A better understanding of abrupt ecosystem changes is needed to improve our prediction of future ecosystem states under climate change. Chronological analysis based on long-term monitoring data is an effective way to estimate the frequency and magnitude of abrupt ecosystem changes. In this study, we used abrupt-change detection to differentiate the changes of algal community composition in two Japanese lakes and to identify the causes of long-term ecological transitions. Additionally, we focused on finding statistically significant relationships between abrupt changes to aid with factor analysis. To estimate the strength of the driver–response relationships underlying abrupt algal transitions, the timing of the algal transitions was compared with that of abrupt changes in climate and basin characteristics to identify any synchronicities between them. The timings of abrupt algal changes in the two study lakes corresponded most closely to that of heavy runoff events during the past 30–40 years (Kohzu et al. 2023; Fig. 3 in Lake Kitaura). This strongly suggests that changes in the frequency of extreme events (e.g., heavy rain, prolonged drought) have a greater effect on lake chemistry and community composition than do shifts in the means of climate and basin factors. Our analysis of synchronicity (with a focus on time lags) could provide an easy method to identify better adaptive strategies for future climate change.

Fig. 3 Synchronicities between extreme precipitation events and the abrupt change in the timings of phytoplankton in Lake Kitaura (two sites: Kamayaoki and Takeioki). Significance in synchronicity was evaluated by comparing with simulated results in random models. Significant synchronicity was found only in extreme precipitation events among four kinds of outside/inside lake conditions and three kinds of climate events. From Kohzu et al.¹⁾



Reference:

Kohzu A. et al. (2023) Identifying the true drivers of abrupt changes in ecosystem state with a focus on time lags: Extreme precipitation can determine water quality in shallow lakes. *Science of the Total Environment*, 881, 163097

Biodiversity Domain

We intend to conduct surveys and research on the structure, functions, and relationships of ecosystems, which consist of diverse organisms on the Earth and their surrounding environment, and on the benefits that humans receive from ecosystems. We will also clarify and evaluate the impacts and risks that human activities impose on biodiversity and ecosystems at various spatial and temporal scales.

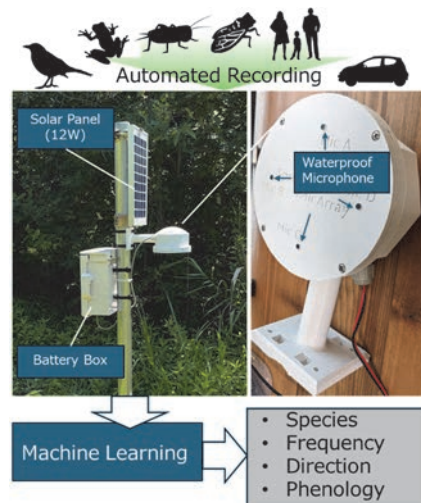
In our **Foresight and Advanced Basic Research**, we will promote research aimed at developing new technologies with future development potential and proactive responses to possible future problems. In our **Policy-Oriented Research**, we will contribute to the Convention on Biological Diversity and the policies of national and local governments through biodiversity assessment and indexing, and by proposing conservation methods. In our **Intellectual Research Infrastructure Development**, the Division will contribute to the conservation and sustainable use of biodiversity both within and outside NIES by building and maintaining internal and external research infrastructure, including by preserving biological samples, monitoring, providing analysis support, and developing databases.

1. Foresight and Advanced Basic Research

Development of an eco-acoustic monitoring method

With recent advances in recording devices and audio recognition techniques, passive acoustic monitoring has become an essential tool for ecosystem surveillance. We have developed a recording system that uses a microphone array and automated audio recognition techniques for the long-term monitoring of eco-acoustic environments in outdoor ecosystems (Fig. 1). This system features a four-channel microphone array capable of estimating sound source directions, thus helping to identify individual animals and providing detailed behavioral analysis. It enables spatially explicit eco-acoustic monitoring across multiple locations over extended periods, including landscape-scale assessment of bird activity and investigation of how soundscapes respond to disturbances, human activities, and land-use changes.

Fig. 1 Eco-acoustic monitoring system.



2. Policy-Oriented Research

To achieve the goals and targets of the Kunming–Montreal Global Biodiversity Framework (KM-GBF), urgent and comprehensive conservation actions are essential to address biodiversity loss and avoid substantial social and economic costs from ecosystem degradation. Monitoring of actions, tracking of policy effectiveness, and reducing the factors driving biodiversity loss are necessary to implement KM-GBF. These processes rely on specific indicators that are calculated by using standardized variables such as Essential Biodiversity Variables (EBVs) and Essential Ecosystem Services Variables (EESVs). Indicators must be assessed at the national level and aggregated regionally and globally to effectively monitor progress. Comprehensive biodiversity data collection and equitable access across countries are needed for fair and consistent global monitoring systems.

To bridge these gaps and support the KM-GBF, the Global Biodiversity Observation System (GBiOS) (Fig. 2) has been proposed in collaboration with the Collaborative Research Core on Biodiversity at NIES. This initiative, led by the Group on Earth Observations Biodiversity Observation Network (GEO BON) and by regional networks such as the Asia-Pacific Biodiversity Observation Network (APBON), aims to establish a global framework for biodiversity observation. GBiOS will enable rapid, multiscale assessments of biodiversity trends and progress toward KM-GBF goals by integrating national and regional BONs and sharing key biodiversity and ecosystem service data (EBVs and EESVs) across international platforms.

To meet these goals, a strong science–policy interface is required. This interface includes four critical elements: 1) biodiversity monitoring aligned with policy needs, 2) rapid detection and identification of biodiversity changes and their causes, 3) predictive models to forecast biodiversity loss and resilience, and 4) systems that translate monitoring outcomes into actionable policy options. Currently, these elements are underdeveloped, thus delaying the delivery of policy-relevant biodiversity information. GBiOS will play a key role in addressing these challenges and is the essential component of the science–policy interface needed to ensure the successful implementation of KM-GBF.

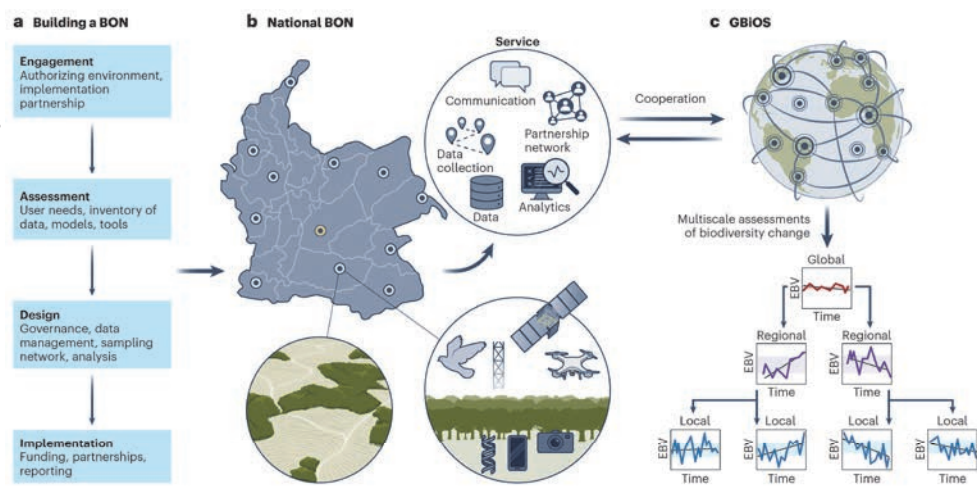
In summary, GBiOS will play a vital role in providing comprehensive and accessible biodiversity data, supporting KM-GBF targets, and fostering global collaboration to halt and reverse biodiversity loss by 2030.

Reference:

Gonzalez, A., Vihervaara, P., Balvanera, P., ..., Muraoka, H., ..., Takeuchi, Y. et al. A global biodiversity observing system to unite monitoring and guide action. *Nat Ecol Evol* 7, 1947–1952 (2023). <https://doi.org/10.1038/s41559-023-02171-0>

5. Biodiversity Domain

Fig. 2 GBiOS is a global network connecting national and regional Biodiversity Observation Networks (BONs) to assess biodiversity trends. (a) Countries without a national BON can establish and implement one by following the multistep process identified by GEO BON. (b) Each BON uses standardized methods for biodiversity observation, data sharing, and policy support. (c) GBiOS connects BONs (circles) in an international network to share biodiversity data and technologies, thus allowing rapid assessments of global biodiversity progress. ENV, Essential Biodiversity Variable

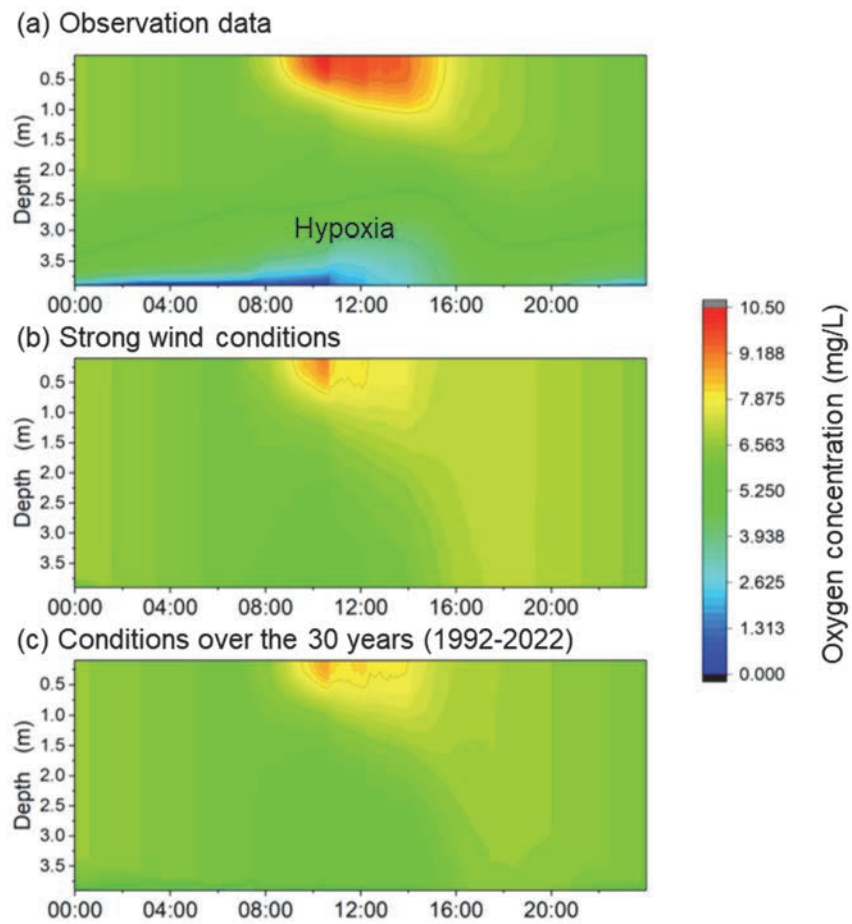


3. Intellectual Research Infrastructure Development

We have continued monthly monitoring in Lake Kasumigaura since 1976. In 2020, we began high-frequency (every 10 mins) monitoring by using a buoy. We deployed high-frequency automated sensors to measure water temperature, water level, chlorophyll-*a* and phycocyanin relative fluorescence, turbidity, dissolved oxygen (DO) concentration, and pH. In 2022, Japan experienced a heat wave from June to July, and our high-frequency monitoring data showed that hypoxia occurred in Lake Kasumigaura during that time. We also observed higher solar radiation and air temperatures, and weaker winds, in 2022 than the average for the previous 30 years. We developed a one-dimensional numerical simulation model to assess whether and how the heat wave affected the bottom DO concentrations (Fig. 3a). The model demonstrated that insufficient convection led to hypoxia because of the combined effects of weak winds, high solar radiation, and high air temperatures. If the wind speed had equaled its average speed during the previous 30 years, the simulations show no hypoxia (Fig. 3b). Furthermore, if solar radiation and air temperatures had equaled their respective averages during the previous 30 years, hypoxia would not have occurred (Fig. 3c). Our study suggests that summer heat waves will lead to more frequent occurrences of hypoxia, even in shallow lakes.

We joined the international lake comparison project of plastic debris through the Global Lake Ecological Observatory Network (GLEON). We sampled plastic debris (>250 μm) by following a common standardized procedure. Plastic debris occurred in all 38 lakes studied, but plastics concentrations varied widely among the lakes. The plastics concentration of Lake Kasumigaura was 1.52 ± 0.37 SE particles m^{-3} , which was close to the mean concentration of the 38 lakes (1.82 ± 0.37 SE particles m^{-3}). The plastic debris of Lake Kasumigaura was dominated by fragments (52%) and some fibers (26%), with a polymer composition of polyethylene (56%) and polypropylene (27%).

Fig. 3 Results of a numerical simulation model of vertical dissolved oxygen concentrations during the heatwave on 6 June 2022, based on (a) observation data, (b) simulated data with strong wind conditions, and (c) simulated data using historical data (1992–2022).



Social Systems Domain

The Social Systems Domain addresses the challenges of social systems to achieve the future vision that human socioeconomic activities—the root cause of our environmental problems—will be sustainable for both the environment and human society. We are conducting research to support the transition to sustainable social systems, including developing theories and methodologies such as those related to mathematical models, as well as social surveys that take an integrated approach to examining the relationship between socioeconomic human activities and various environmental issues. We are also developing scenarios and roadmaps to achieve a vision for a sustainable society that harmonizes the environment and the economy, and we are proposing specific measures and policies in collaboration with stakeholders.

The Social Systems Domain consists of the following five research sections:

Global Sustainability Integrated Assessment Section: Develops integrated models to assess various comprehensive issues on a global scale to achieve global sustainability for society and the environment.

Decarbonization Measures Assessment Section: Develops models and databases for assessing decarbonization initiatives to tackle climate change problems.

System Innovation Section: Studies the sustainable use of energy and resources, including the development of measures for substantially improving their utilization efficiencies.

Regional Planning Section: Studies lifestyle and regional planning to balance the environment and quality of life in urban and rural communities.

Economics and Policy Studies Section: Performs environmental policy assessments and theoretical research on environmental evaluation and methodological developments in the field of economics.

Researchers in the Social Systems Domain are engaged mainly in the Decarbonized and Sustainable Society Research Program and the Co-design Approach for Local Sustainability Research Program.

1. Foresight and Advanced Basic Research

In FY 2023, the Social Systems Domain conducted the following research activities as **Foresight and Advanced Basic Research** to improve the relationship between socioeconomic activities and the environment.

1.1 Study of energy price volatility in major countries and analysis of future scenarios

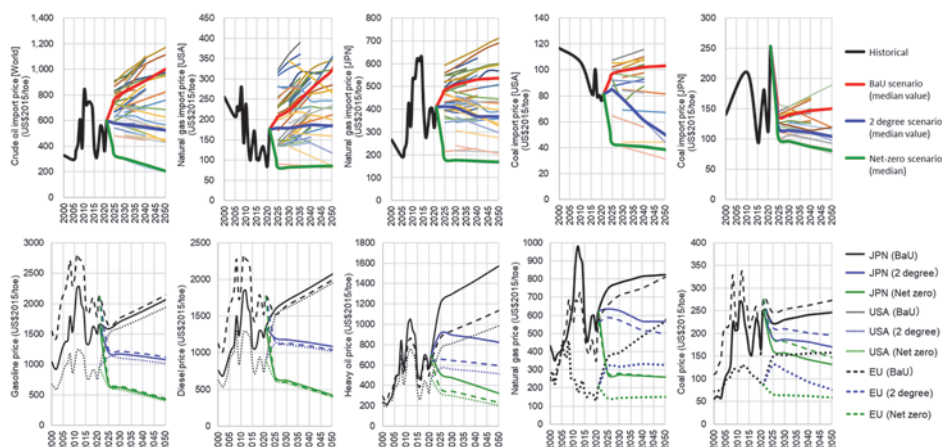
Because of the impacts of the COVID-19 pandemic and the war in Ukraine, in recent years the world has been faced with high global energy prices and their impact on economic activity. Energy prices affect import–export prices and

consumer prices in many countries and are related to various factors, such as fluctuations in resource prices and global conditions. Therefore, it is not easy to forecast long-term energy prices both globally and nationally. In particular, we need to keep a close eye on the outlook for energy prices not only under a business-as-usual (BaU) scenario, but also when decarbonization measures are implemented to achieve net-zero emissions by 2050.

To determine the trend of fossil fuel energy prices up to the present, we first analyzed the historical trends of market prices of coal, natural gas, and gasoline in both OECD countries and some major developing countries on the basis of the energy price database compiled by the International Energy Agency (IEA). Next, we analyzed the “Future Prospects for Import Prices of Fossil Fuels” reported in the IEA World Energy Outlook published annually and in the IEA Energy Technology Outlook published every few years, by making a database and evaluating all reports published from 2010 to 2023. The reported units differed depending on the type of energy, so we used the unit of “tonne of oil equivalent” (toe) for all energy types. In addition, as nominal prices or real prices with different base years are used, depending on the year of publication of the report, we standardized the energy price units to real prices in 2015 US dollar equivalent.

Our analysis of the transition of the real prices of fossil fuel imports and market prices up to the present revealed that the volatility of these prices has been large and that some countries and energy types have had periods of higher prices relative to current energy prices in what is called the energy crisis. Therefore, although the current energy price spike is one factor that may contribute to future scenarios, it is not the dominant factor in the long-term perspective. On the contrary, the prospects of future energy price trends in the IEA report show that, with the exception of natural gas import price, import prices are projected to decline with decarbonization in the 2-degree and net-zero CO₂ scenarios (Fig. 1, upper panels), because the impact of reductions in fossil fuel demand would be taken into account. If we assume that import prices will decrease in line with this trend and that market prices of coal, natural gas, gasoline, and diesel in each country will also decrease in tandem, then the future gasoline and diesel prices in 2050 in the transport sector, for example, will decrease to less than half of the current values under the net-zero CO₂ scenario.

Fig. 1 Historical fossil fuel prices and future outlook in major industrialized countries (upper panels: import prices; lower panels: market prices).



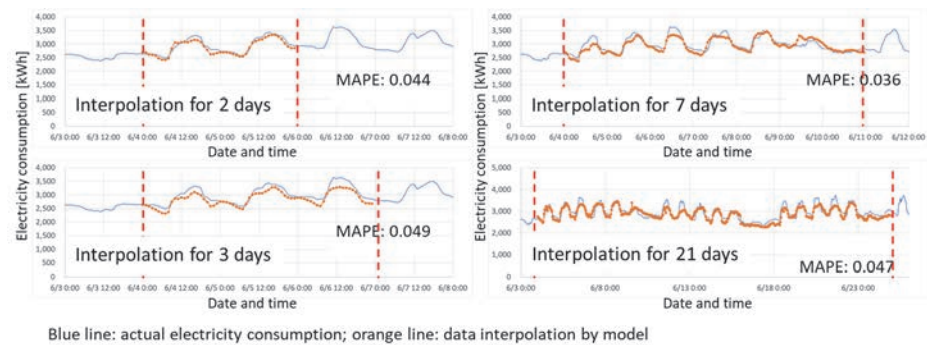
1.2 Research on improvement of evaluation methods and data for measures and policies to realize a decarbonized society

In FY 2023, we have developed models and methodologies to assess scenarios and measures for reaching net-zero emission of greenhouse gases (GHGs) (i.e., a decarbonized society). The potentials of photovoltaic and wind power as sources of renewable energy were assessed by using improved methodology and updated datasets. We also applied machine learning to an analysis of characteristics of electricity consumption.

The energy potential of renewable energy was assessed at a global scale by using the most updated data for land cover, as well as other georeferenced data, along with hourly data for solar radiation and wind speed. From these, the hourly energy potentials of solar photovoltaic and onshore wind power were assessed at a spatial resolution of 0.25 arc-degrees, showing the national and regional characteristics of the distribution of the energy potential. For example, the potential in Thailand is close to 10 times the electricity demand, thanks to the existence of wide areas of agricultural land, which are compatible with solar and wind power facilities. In contrast, in Malaysia, the energy potential is only around double the electricity demand, given that a large proportion of the country’s area is covered by forests. These outcomes were delivered to the strategic research program to be used as basic information in the analysis of scenarios for the decarbonization of society.

We also have developed a model to estimate hourly electricity consumption by applying Long Short-Term Memory (LSTM), a machine-learning method. We then conducted numerical experiments on data interpolation and prediction of electricity consumption. Figure 2 is an example of the results of an analysis using electricity consumption data from our Tsukuba Headquarters for the period FY 2009 to FY 2023. The results of data interpolation experiments showed that, in the short term, the model reproduced hourly electricity consumption trends reasonably well, but consumption patterns tended to be smoothed and did not capture random and high electricity consumption, such as from the irregular operation of large-scale experimental facilities.

Fig. 2 Examples of numerical experiments of data interpolation using simulated and actual electricity consumption data from NIES's Tsukuba Headquarters. MAPE, mean absolute percentage error.



In addition to these activities, we have modified the AIM/ExSS (Asia-Pacific Integrated Model Extended SnapShot) tool, which can be used to design future visions of society under carbon-neutral conditions with quantified information. We used the results to engage in dialog with policymakers to consider innovative climate-change-mitigation measures, including carbon-recycling technologies, hydrogen use, and ammonia supply. The modified model has been applied to research work on building carbon neutral societies in Japan and Asian countries.

1.3 Comparison of design of municipal-level citizens' climate assemblies

Researchers interested in climate assemblies collaborated to compare and organize the design elements of local case studies in Japan and England. The comparison table was published in the Repository of NIES in April 2023. A public seminar was held, and participants, including over 30 local government officials, exchanged views, contributing to providing basic foundational information for the management of Climate Assembly Tsukuba 2023 and subsequent assemblies. Specifically, we systematically organized the main elements to be considered in planning domestic local-level climate assemblies, referring to KNOCA (Knowledge Network on Climate Assemblies) case studies, and we summarized them into 19 items as basic design elements. Then, we presented an overview of representative examples of climate citizen meetings held at four domestic locations and at two international ones from 2019 to 2022 in accordance with these 19 items. In addition, we included a sample basic design, assuming a case of holding a conference in a municipality with a population of 200,000 in Japan. This is available as: Basic Design Summary Table for the Climate Citizens' Assembly – Trial Version 2304, <https://doi.org/10.34462/0002000004>.

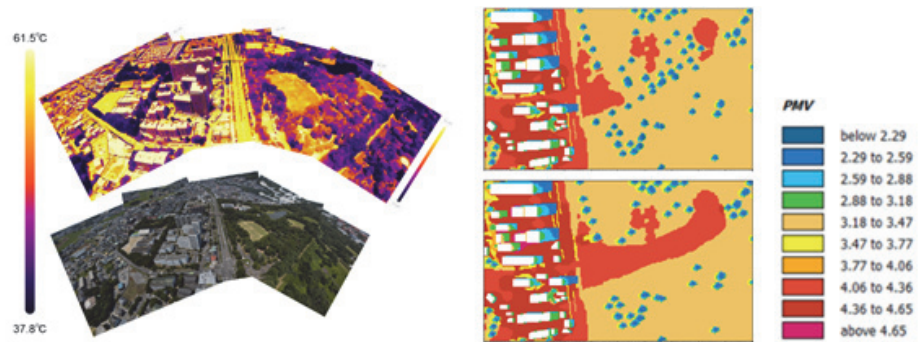
1.4 Assessment of the outdoor thermal environment impact of a large-scale green park redevelopment project

On the basis of an actual redevelopment plan for a large green park in the city, we used a numerical simulation of the outdoor thermal environment to estimate the increased risk of heat during the day in summer due to changes in building shape and land cover. In this redevelopment of a large urban green park, not a small

amount of green forest will be cut and that part is transferred to the glamping facilities including visitors parking covered with asphalt.

We used ENVI-met, a tool developed in Germany, to evaluate outdoor thermal environments at the neighborhood scale (several hundred square meters). Assuming the worst case in a year, we set the calculation target at 3 pm on a very hot day at the end of July on a mid- to high-rise residential block on the west side of the park across the road (Fig. 3). We input weather data for a sunny day when the sea breeze (easterly wind) from the Kashima Nada Sea was dominant. On the other hand, when we narrowed down the weather conditions of concern (Tsukuba AMeDAS) to daily maximum temperatures of 30 °C or higher, easterly winds dominant, and sufficient solar radiation, we found that these conditions occurred about 5% of the time during the day in July and August (only 30 min, even if they occurred every day). The increase in the physical thermal index (PMV) between the buildings in the residential block was estimated to be about 0.3. This change represents a level where about 10% of the residents would feel that the degree of heat had changed compared with before. In other words, we found that the effects of ground-surface temperature, wind speed, air temperature, and humidity resulted in thermal environment changes between buildings in adjacent residential areas that may be noticed by a small but noticeable percentage of residents depending on the season, time of day, and weather conditions. This result was at odds with the perceptions of residents who were closely watching the plan and opposed the development.

Fig. 3 (left) Unmanned aerial vehicle observation results of the ground-surface temperature around Doho Park at 12:37 on 26 July 2023. (right) Comparison of the impact of development on the outdoor thermal environment (PMV, physical thermal index). Before (top) and after (bottom) development comparison is shown for an area 500 m east–west by 300 m north–south.



2. Policy-Oriented Research

2.1 Capacity development for realization of a sustainable society in Asia

Online training workshops on the AIM/Enduse model and AIM/ExSS tool were conducted in January–February 2023. They helped to increase the capacity to develop the AIM/Enduse model AIM/ExSS tool, respectively, and to develop decarbonization scenarios based on the models. From August to November 2023, a training workshop on AIM/CGE (Asia-Pacific Integrated Model – Computable General Equilibrium) was held for Japanese researchers to enable them to use the model in research funded by the Environment Research and Technology Development Fund. In addition, training

sessions on ExSS for policymakers in developing countries were conducted in February, July, and October 2023 at the request of JICA (the Japan International Cooperation Agency).

The 29th AIM International Workshop (Fig. 4) was held at NIES on 14 and 15 September 2023 as a hybrid face-to-face/online meeting, with more than 140 participants discussing the status of AIM development and policy contributions in Asian countries. On 13 September 2023, a meeting was held with representatives from Thailand and Indonesia, which have already begun to incorporate the results of analyses using AIM into their long-term strategies, to share their experiences with representatives from other countries (e.g., Bangladesh and the Philippines), which have requested support for model development and scenario analysis. The participants discussed how to respond to issues that will arise in the future.

Fig. 4 Group photo at the 29th AIM International Workshop at NIES.



3. Intellectual Research Infrastructure Development

3.1 Mass media coverage of environmental issues and formation of public opinion

To implement effective environmental policies, agencies must understand the public's understanding and support of the policies in a democratic society. However, the public's understanding and support are not always stable, and this subject has been investigated in several academic fields, such as media communications, public opinion, international relations, and governance. One theory under study is the agenda-setting theory in public opinion research. We adopted this theory to analyze the media coverage of climate change and its impact on public opinion.

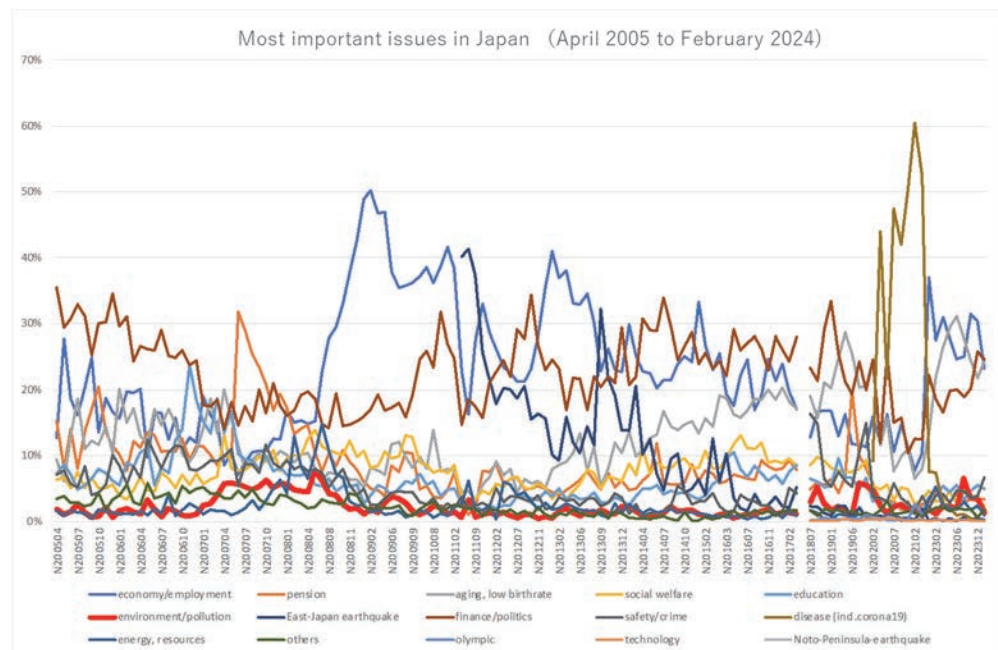
We have collected two types of data in this research. One concerns the mass media coverage of climate change. For this effort, we joined the international project Mecco (Media and Climate Change Observatory; Principal Investigator: Maxwell Boykoff, University of Colorado Boulder, USA). In this project, we monitor 131

6. Social Systems Domain

sources (across newspapers, radio, and TV) in 59 countries in seven regions around the world. We assemble the data by accessing archives through the Factiva, Infomedia, ProQuest, Nifty, and NexisUni databases. The second type of data is from public opinion surveys of “the most important issues in Japan” and “the most important issues in the world” that are implemented monthly by Central Research Co. We have been collecting results from these two questionnaires since April 2005 (Fig. 5).

In FY 2023, we implemented six survey rounds, in February, April, June, August, October, and December (Fig. 5). The results show that the number of responses for “communicable disease risk (Corona)” has decreased dramatically, and “falling birthrate and aging population,” “economy, opportunities and employment,” and “finance, politics and administration” are now recognized as important issues. Reflecting the hot summer of July and August, concern about “environment/pollution” (bold red line in Fig. 5) increased to become the fourth most important issue. The response rate for “climate change” increased in the August 2023 survey. When combined with the separate response for “extreme weather events,” the rates relating to climate change increased by about 10%.

Fig. 5 The most important issues in Japan, April 2005 to February 2024.



Environmental Emergency and Resilience Research Domain

Much empirical knowledge has been obtained from large-scale disasters such as the Great East Japan Earthquake, including the accident at TEPCO's Fukushima Daiichi Nuclear Power Plant (FDNPP). By studying environmental emergency and resilience studies, we intend to use this knowledge to promote research and surveys to understand and evaluate the actual medium- and long-term environmental impacts in the disaster area. We will also conduct practical research for post-disaster environmental reconstruction in collaboration with the local community, as well as other research that will build strong and sustainable communities in preparation for future large-scale disasters. Specifically, as an issue continuing on from NIES's Fourth Five-Year Plan, we aim to solve technical issues such as disaster waste disposal and establish a technical support framework to further improve disaster environmental management capabilities. Similarly, we will further investigate and gain an understanding of the process of environmental recovery from nuclear disasters, and we will conduct strategic monitoring research that will resolve the issues that have become obstacles to revitalization. As a new initiative of the Fifth Five-Year Plan, we intend to establish a comprehensive environmental management approach to prepare for future nuclear disasters from certain environmental perspectives. Similarly, we aim to support local governments in Fukushima Prefecture in formulating environmental policies. Furthermore, we will build a system to promote regional cooperation that contributes to environmental revitalization and sustainable regional development in Fukushima.

1. Foresight and Advanced Basic Research

1.1 Development of environmental management methods in a river catchment in the early stages of a nuclear disaster

To start the world's first simulation of ^{137}Cs runoff immediately after the FDNPP accident in a forested river basin upstream of the Ota River—one of the major rivers in the Hamadori region of Fukushima Prefecture (with a catchment area of 21 km²)—we first improved an atmospheric dynamics model to calculate the time series data of ^{137}Cs initial deposition as input data. After updating the meteorological model WRF (Weather Research and Forecasting, v. 4.1.5) and the chemical transport model CMAQ (Community Multiscale Air Quality, v. 5.3.2) and increasing the spatial resolution of the grid size (from 3 km to 1 km), we used the deposition distribution data from atmospheric observations immediately after the FDNPP accident and from aircraft monitoring in the early post-accident period to improve the reproducibility of ^{137}Cs behavior in the meteorological and deposition fields. Next, a ^{137}Cs runoff simulation starting from immediately after the FDNPP accident was conducted on a trial basis, using the ^{137}Cs initial deposition time series data calculated by the improved atmospheric dynamic model as input data. A model that can reproduce the leaching of radiocesium (r-Cs) from forest litter and its

inflow into rivers was used to model ^{137}Cs runoff by incorporating a forest ecosystem compartment model into GETFLOWS, a three-dimensional water and material dynamics model. Although still at the trial calculation stage, the results indicated that dissolved ^{137}Cs in river water showed a significant temporary concentration peak in response to the largest release event from FDNPP from midnight of 14 to 16 March 2011. We will continue to examine the simulation work in detail, including the impact on downstream water bodies.

2. Policy-Oriented Research

2.1. A survey of municipal environmental plans and environmental policies in Fukushima Prefecture

This study aims to help with environmental recovery and creation in the affected areas following the FDNPP accident. In addition, it aims to provide knowledge that will contribute to the environmental policies implemented by municipalities in Fukushima Prefecture. Data on policy infrastructure, administrative plans formulated by municipalities, and local community stakeholders involved in environmental and reconstruction policies will be collected and analyzed to contribute to environmental recovery in areas affected by the FDNPP accident. On the basis of the above, recommendations for the formulation of environmental plans and environmental policies of municipalities will be made.

In one of the most notable achievements this fiscal year, we conducted a case study of Okuma and Futaba towns, where FDNPP is located. Both towns were evacuated entirely after the FDNPP accident. We conducted a comparative analysis of how the form and content of public participation in the administrative planning process (planning organizations and methods of public participation) changed over time as the reconstruction plan was revised several times after the FDNPP accident in the two towns. Data were obtained from the contents of the administrative master plans and reconstruction plans, interviews with officials of the policy planning departments in charge of formulating the administrative master plans and reconstruction plans in the two towns, and interviews with experts who served on the planning committees. On the basis of this analysis, issues of community governance encountered in the Fukushima–Hamadori region before the nuclear accident, and issues of the legal system and recovery policy for nuclear disaster recovery set by the central government, were discussed.

The results of the comparative analysis were discussed at the Research Group for Creative Reconstruction, organized by the Fukushima–Hamadori Future Creation Research Centre at Waseda University held on 23 December 2022. The discussions included representatives from private companies and public organizations, as well as local government administrators and others who participated in the research group.

2.2 Study of major technical aspects of the development of local disaster-waste-management policies

To estimate the volume of disaster waste generated, a prototype of an online tool using R shiny was developed to support the estimation based on the revised method presented in the Disaster Waste Countermeasures Guidelines by the Ministry of Environment. To examine candidate sites for temporary storage sites, we have conducted interpretive structural modelling to systematically analyze the relationship between the requirements for suitable sites (e.g., area, access roads, land managers) and issues related to the operation of temporary storage sites (e.g., mixed waste generation, land-use constraints). The size of candidate sites and public ownership of the sites were suggested as the most important requirements. In addition, a basic survey was conducted on the time trends of the activities of the disaster volunteers who are helping to clean up damaged houses, because this is an important element in the overall estimation of time trends for waste cleanup. The results suggest that the activities of these disaster volunteers are more prolonged than the activities of those collecting disaster waste from households.

To clarify the relationship between load and fatigue in the manual sorting of disaster waste, workers engaged in manual sorting of PET bottles, glass bottles, and cans at an industrial waste treatment plant were fitted with biosensors to monitor their physical activity, workload, and lumbar muscle load. This allowed us to quantitatively evaluate the increase in different kinds of loads associated with an increase in workload. Furthermore, we proposed an evaluation of the relationship between subjective and unconscious fatigue levels and load. We believe that these findings can be used to design an efficient work environment for sorting using conveyor belts during disasters.

As part of ongoing efforts to develop a technology that can be applied in disaster contexts for the rapid measurement of airborne asbestos, we continued to develop an artificial intelligence model by using simulated atmospheric samples prepared from standard samples of amosite and chrysotile. Satisfactory results were obtained with the multilevel aggregation network (MA-Net) model.

2.3 Environmental Emergency Management Office

In FY 2023, we supported the national and local governments in their efforts to develop human resources and disaster-waste-management plans. Two staff members serve as members of a national committee on disaster waste management and asbestos management during disasters (Ministry of the Environment, Kanto block), whereas two visiting researchers give lectures and serve as training lecturers at the Block Council on Disaster Waste Management (Chu-shikoku block), thereby providing expert knowledge. In addition, support was provided to municipalities in conducting disaster waste management drills (Niigata, Aichi, Tokyo, Aomori, and Toyohashi prefectures) and in providing technical knowledge on the formulation

and revision of treatment plans (Tokyo Metropolitan Government).

We added contents and information (e.g., administrative plans and articles) to our Disaster Waste Information Platform. In particular, the newly publicized *Kari-hai* tool for the automatic creation of temporary-storage-site layout maps was used in training programs for government officials. We also collaborated with the Japan Society of Material Cycles and Waste Management to review the current state of research in Japan regarding disaster waste management. We identified 10 academic papers that could be of interest to disaster waste managers.

In terms of disaster response activities, we shared knowledge and information on appropriate disaster waste management with public bodies after the 2024 Noto Peninsula Earthquake. In particular, technical advice on asbestos management is being provided to national and prefectural governments to ensure safe and environmentally sound demolition of stricken houses.

3. Intellectual Research Infrastructure Development

3.1 Estimated amount of r-Cs that has migrated with industrial waste in Fukushima Prefecture

To avoid unnecessary or harmful public misinformation and promote proper recycling of industrial wastes since the nuclear power plant accident, it is important to show the public and waste professionals how to appropriately recycle wastes according to the degree of radioactive contamination. The contaminated wastes were located mainly outdoors at the time of the nuclear accident, and most of those were construction wastes derived from the demolition of buildings and civil engineering structures. We estimated the amount of industrial waste and r-Cs migration associated with the treatment and disposal of construction waste in Fukushima Prefecture. At the same time, we took into account the effect of reduction of the surface contamination density of buildings and other structures due to decontamination activities that have been performed sequentially since the accident.

Industrial waste manifest information for Fukushima Prefecture from FY 2011 to FY 2015 was used to estimate the amounts of waste transferred. The amount of waste transferred after disposal of external building components was estimated for each type of construction waste, such as wood and concrete, by analyzing the names of business sites, the percentage of wood waste generated, and representative building structure blueprints in the manifest data. The amount of r-Cs transferred with these wastes was estimated from the air dose rate at the place of waste generation.

We conducted a survey to measure the surface contamination density of buildings, roads, and other structures in Fukushima Prefecture, and we determined the

relationship between air dose rate and contamination density for each type of component and each horizontal and vertical installation direction. The surface contamination density of the exterior surfaces of buildings that had not been decontaminated in the difficult-to-return zone was measured for 2 years and 3 months, and the decrease in surface contamination density over time due to washing away by precipitation or to environmental attenuation was determined in relation to the amount of precipitation measured at the site. The surface contamination density at the time of measurement was corrected to the value at the end of each year when the waste was generated by environmental and physical decay. Furthermore, we assumed that the surface contamination density was reduced by decontamination in the case of waste generated from areas with air doses of $0.23 \mu\text{Sv/h}$ or higher, which is the standard for designation of priority contamination investigation areas. By using information on the progress of decontamination in Fukushima Prefecture, we calculated the decontamination progress rate as the percentage of houses, public facilities, and roads that had been decontaminated, by fiscal year. The reduction in surface contamination density due to decontamination was assumed to follow the reduction in air dose rates at residences or schools and parks due to decontamination by municipalities and directly by the national government.

We attempted to determine the amount of r-Cs transferred by multiplying the concentration of r-Cs by waste type (concrete waste and asphalt concrete waste) by the amount of waste (concrete waste and asphalt concrete waste) transferred to the concentration of r-Cs by waste type and by the place of generation obtained above.

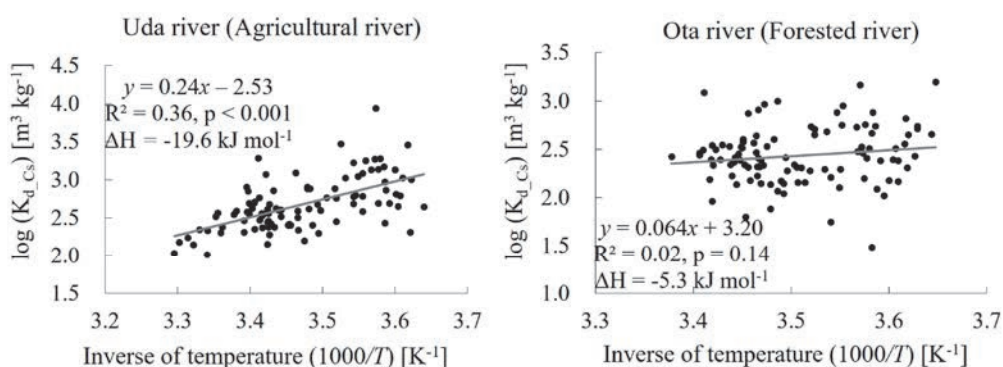
We then estimated the amount of r-Cs that migrated from the treatment and disposal of concrete waste, asphalt concrete waste, plastic waste, and wood waste generated from construction and demolition work. The analysis showed that, in 2015, approximately 5.8 GBq of r-Cs was transferred from the treatment and disposal of concrete waste. For asphalt concrete waste, the amount was 498 GBq; for waste plastics, 45 GBq; and for wood waste, 41 GBq. The study showed that, in Fukushima Prefecture, most of the waste (with the exception of wood waste in 2011) has been intermediately processed and subsequently recycled.

3.2 Monitoring of r-Cs behavior in a multimedia environment

This study evaluated the effects of temperature, water quality, and an intense typhoon event on changes in the ^{137}Cs concentration in the water of agricultural and forested rivers near the FDNPP, by using monthly stationary observations obtained under baseflow conditions 2.8–10.6 years after the nuclear accident in 2011. The dissolved ^{137}Cs concentration fluctuated seasonally with the water temperature, and the increase in dissolved ^{137}Cs concentration per unit increase in temperature was higher in forested rivers than in agricultural rivers. The relationship between water temperature and the apparent distribution coefficient of ^{137}Cs , calculated by dividing the ^{137}Cs concentration in the suspended solids by that in dissolved form, followed the van't Hoff equation well in the two agricultural rivers, where the

enthalpy of reaction was estimated as -15.6 and -19.6 kJ mol^{-1} (Fig. 1). Concentrations of dissolved ^{137}Cs in the forested river, where the suspended solids comprised mainly organic matter, did not follow the van't Hoff equation. The results suggest that the dominant process determining dissolved ^{137}Cs concentrations in forested rivers is not simple ion exchange; instead, it is the input of ^{137}Cs and K^+ (competing with ^{137}Cs for exchange sites on mineral particles) into the water phase via litter leaching. At some sites, and ^{137}Cs concentrations in dissolved form and in suspended solids were reduced sharply in association with the passage of Typhoon Hagibis in October 2019, suggesting that Typhoon Hagibis caused large-scale surface erosion that removed the source of ^{137}Cs .

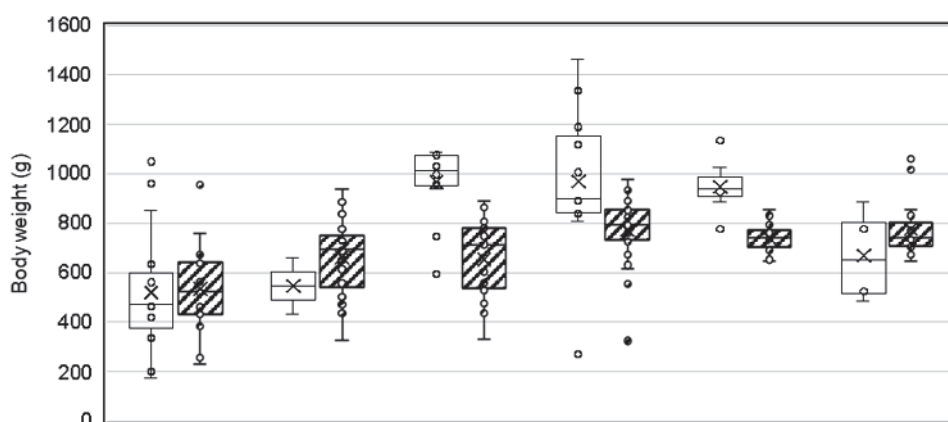
Fig. 1 Relationship between the inverse of water temperature and the distribution coefficient of ^{137}Cs (van't Hoff plot). ΔH indicates the reaction enthalpy calculated from the slope of the regression equation.



3.3 Biodiversity and ecosystem monitoring for regional collaboration

We investigated the accumulation of ^{90}Sr derived from the FDNPP in the vertebrae of various marine benthic fishes off the coast of Fukushima Prefecture. Among the species collected in 2014, a high ^{90}Sr radioactivity concentration was observed in rays (*Okamejei kenojei* and *Hemitrygon akajei*). In particular, the highest radioactivity concentration and detection frequency were observed in *O. kenojei* collected from off the coasts near the FDNPP (central) and Iwaki (south). We examined temporal changes of ^{90}Sr , focusing on *O. kenojei* in central and south

Fig. 2 Box and whisker plots show temporal changes in the body weight of ^{90}Sr -detected *Okamejei kenojei* collected at central and south sites from January 2013 to July 2015. The cross and the solid line inside the box indicate the mean and median value, respectively. The upper and lower limits of the box indicate the first and third quartiles. Whiskers represent the maximum and the minimum data values, excluding outliers.



regions from 2013 to 2015. Samples were collected in January and July in each year. During the sampling period, although both the mean value and standard deviation of ^{90}Sr concentrations (omitting values below the detection limit) showed decreasing trends (the mean values were 54.0 ± 33.1 ($n = 29$), 44.7 ± 12.3 ($n = 29$), 37.3 ± 13.9 ($n = 36$), 36.3 ± 21.0 ($n = 36$), 31.8 ± 13.1 ($n = 28$), and 26.9 ± 9.8 mBq/(g Ca) ($n = 19$) from January 2013 to July 2015, respectively), ^{90}Sr was still detected from the vertebral samples in July 2015. Markedly high ^{90}Sr concentrations (416, 674, 800, and 1112 mBq/(g Ca) in January 2013 and 307 mBq/(g Ca) in July 2013) were detected, although these data were excluded from calculation of the mean value. Figure 2 shows the temporal change in body weight of *O. kenojei* in which ^{90}Sr was detected. The mean body weight showed an increasing trend, indicating that individuals exposed to the radioactivity-contaminated water during their early life stages grew with ^{90}Sr retained in their vertebrae. These results suggest that ^{90}Sr could remain in the vertebrae over time, probably until the individual's death.

In addition, monitoring of terrestrial biodiversity (mammals, birds, frogs, and insects) in and around the evacuation area was conducted in FY 2023, continuing on from the previous year. Notably, camera traps for mammal monitoring were relocated for more accurate population density estimation while fully considering comparability with past data.

3.4 Promotion of regional collaboration

To further promote collaboration with the local community, we conducted public relations activities, dialogues with the local community, and research in collaboration with the community in an integrated manner. In terms of content planning and production, a cartoon (a manga on decarbonization) was produced at the Fukushima Regional Collaborative Research Center (FRCRC) to raise social awareness of efforts to build a decarbonized society. On the basis of the manual for developing a “Zero Carbon Vision” prepared and published by the FRCRC in March 2021, a cartoon was published on the FRECC+ website, a web magazine designed to stimulate thinking about the future of the Fukushima region and its environment. The cartoon was on the theme of establishing a vision development council, which is the main process for developing and realizing a Zero Carbon Vision in regional government areas. For the purpose of learning and educating, and fostering the next generation of local human resources, we continued activities from the previous year at the Fukushima Environmental Cafe. The cafe was held with 11 volunteers, mainly from the chemistry club of Fukushima Prefectural Asaka Reimei High School, as a place to foster a sense of approach to environmental issues. This year, a dialogue program was also held throughout the year under the theme “Decarbonized Society,” and a presentation of the results was held at the end of the fiscal year with the participation of FRCRC staff. In addition, as part of efforts to build relationships with local stakeholders, in June we entered into a cooperation agreement with Okuma city government in the Hamadori region on “Reconstruction

7. Environmental Emergency and Resilience Research Domain

Urban Planning through the Promotion of a Zero Carbon Footprint.” In the city of Mishima in the Okuaizu region, we provided operational support for the Executive Committee of the Council for the Promotion of Regional Recycling and Symbiosis, which focuses on the use of forest biomass, and in the Koriyama region we provided planning and operational support for the Study Group for the Promotion of Climate Change Countermeasures.

Environmental Measurement Research and Affairs

Environmental measurement research and affairs are managed by the Center for Environmental Standards and Measurement. In this center, two laboratories, namely the Environmental Standards Section and the Environmental Measurement and Analysis Section, are responsible for fundamental measurement work in a cross-disciplinary manner, as well as for advanced measurement research in cooperation with other research domains. In addition to performing analyses on request by using chemical measuring instruments, the center prepares and provides environmental reference materials that meet international standards in response to social needs. We also add certified values and reference values to existing environmental reference materials in order to increase their usefulness. In addition, to improve our understanding of the status of chemicals in the environment, we are promoting a long-term preservation project for environmental samples, including the collection, long-term preservation, and analysis of bivalve mollusks from the coast of Japan.

Below are brief accounts of some of the important results of our research in FY 2023.

1. Foresight and Advanced Basic Research

1.1 Effect of livestock manure and compost on the quality and quantity of humic substances in soil

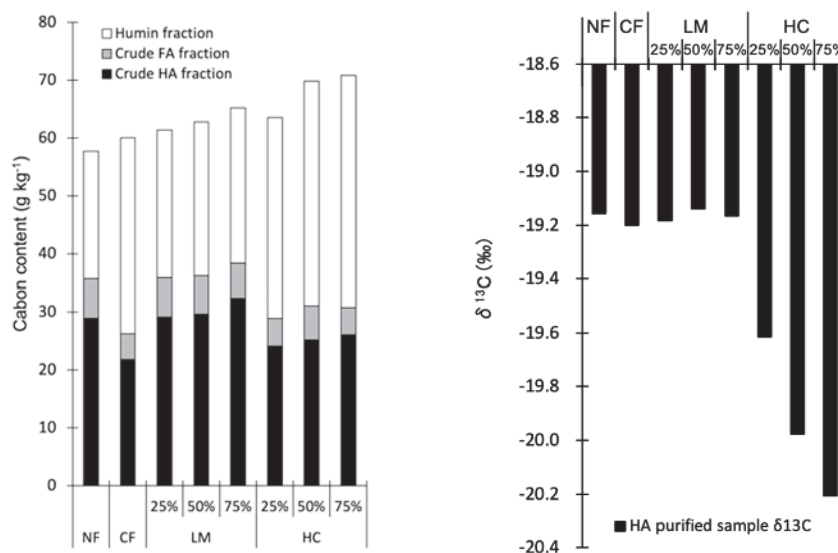
Humic substances extracted from soil or compost can have direct effects on plant growth, including hormone-like effects. Therefore, knowledge of the effects of soil humic substances is extremely important for agricultural production. Continuous application of compost is expected to affect the chemical structural properties of humic substances, but the extent of the effect has not been clarified. In this study, the effects of organic fertilizer from livestock waste (OFLW) on soil humic substances—humic acids (HAs) and fulvic acids (FAs)—were evaluated.

First, two types of OFLW—cattle manure – sawdust compost with a high C/N ratio (HC) and dried swine manure with a low C/N ratio (LM)—were applied to soils for 9 years. We varied the ratio of chemical to organic fertilizer while keeping the amount of nitrogen applied to the soil constant. HAs and FAs were extracted from soil samples and fractionated according to the International Humic Substances Society (IHSS) method. We determined the proportion of crude HAs and crude FAs in soil organic carbon for each fertilizer treatment. We found a decrease in humic substances when chemical fertilizer (CF) was applied alone, but not when it was applied with OFLW (Fig. 1, left panel). Within the OFLW applications, adding LM to the soil increased the HA content (to 29.1–32.3 g kg⁻¹) more than did adding HC (24.1–26.0 g kg⁻¹).

To evaluate the impact of OFLW application on soil humic substances, the $\delta^{13}\text{C}$ of the purified HA, purified FA, and OFLW samples was measured by using EA-IRMS. In addition, to investigate the effect of OFLW on HA-C species, the average composition of C species in the purified HA samples was analyzed by using ^{13}C -nuclear magnetic resonance (NMR) spectroscopy²⁾. When HC was added to the soil, the $\delta^{13}\text{C}$ value of purified HA tended to decrease as the amount of C applied increased (Fig. 1, right panel). This suggests that HC-derived C was incorporated into the HA fraction. In both the LM and HC applications, the proportion of carboxyl-C was higher than in the CF application.

These results indicate that the application of OFLW has a substantial effect on the chemical structure of HA. Application of CF and OFLW had different effects, both quantitatively and qualitatively, on the soil humic substances. Our findings suggest that LM, which is easily degraded by microorganisms in the soil, may enhance the activity of soil microorganisms and promote the biosynthesis of humic substances. These results provide important scientific insights for soil management.

Fig. 1 (Left) Carbon fractions in soil under different fertilizer treatments. Crude humic acid (HA) fraction, crude fulvic acid (FA) fraction, and humin fraction. NF = no fertilizer; CF = chemical fertilizer, LM = low C/N ratio manure; and HC = high C/N ratio compost¹⁾. Humin fractions were calculated by subtracting the amount of crude HA-C and crude FA-C from the total soil organic C. (Figures are cited from the original.)



(Right) $\delta^{13}\text{C}$ value of purified humic acid (HA) extracted from soil from different fertilizer treatments. NF = no fertilizer; CF = chemical fertilizer; LM = low C/N ratio manure; and HC = high C/N ratio soil compost. The $\delta^{13}\text{C}$ values of HC and LM before addition to soil were -26.0‰ and -20.1‰ , respectively¹⁾. (Figures are cited from the original.)

References:

- 1) Kato T., Kondo M., Iimura Y., Oshima H., Maeda Y., Fujitake N. (2023) Effect of livestock manure and compost on the quality and quantity of humic substances in soil. *Humic Substances Research*, 19, 9–15
- 2) Fujitake N., Asakawa D., Yanagi Y. (2012) Characterization of soil humic acids by ^{13}C NMR spectroscopy and high performance size exclusion chromatography. *Bunseki Kagaku*, 61, 287–298

2. Policy-Oriented Research

2.1 Results of super-site monitoring in Hedo, Japan, from 2021

Cape Hedo is located on the northern edge of Okinawa Island, and the monitoring station is about 1500 km south of Tokyo. Okinawa is an optimal location for monitoring the atmospheric conditions in East Asia, because air masses from Japan, Korea, China, and Southeast Asia can all be captured there, depending on the season. These data were observed from April 2020 to March 2022, and including the field operation and travel blanks, surrogate recovery, and duplicate analysis, they have already been reviewed and accepted by a committee of Japanese QA/QC experts. Here, we report an overview of the observation.

The station is equipped mainly with instruments for observing chemical, optical, and physical properties. The area surrounding the facility is rural and is considered to be relatively lightly affected by industrial activities. High-frequency monitoring of persistent organic pollutants (POPs) at Cape Hedo started in 2009 and is still ongoing. Air masses were collected with a high-volume (HV) air sampler at 700 L/min. A sample is taken over 24 h, during which approximately 1000 m³ of air masses are vacuumed. Data for 1 month consist of 3 continuous days, and 3 days were individually analyzed and quantified. The Shimadzu Techno-Research analytical method was used in a multicomponent analysis. Hexachlorobutadiene (HCB) was sampled by using a portable pump at the same time as the HV sampling, but the sampling volume was 0.144 m³ in 24 h at 0.1 L/min.

Back-trajectory analysis is a tool that shows where an air mass collected at a sampling site originated and what path it took to reach the sampling site. The backward trajectory results indicated that the air mass of the collected samples originated from northern regions such as Japan and Korea between October 2020 and March 2021. The continuous result of backward trajectories from April 2021 to March 2022 showed a similar tendency; that is, the air masses flowed from north to south between October and March.

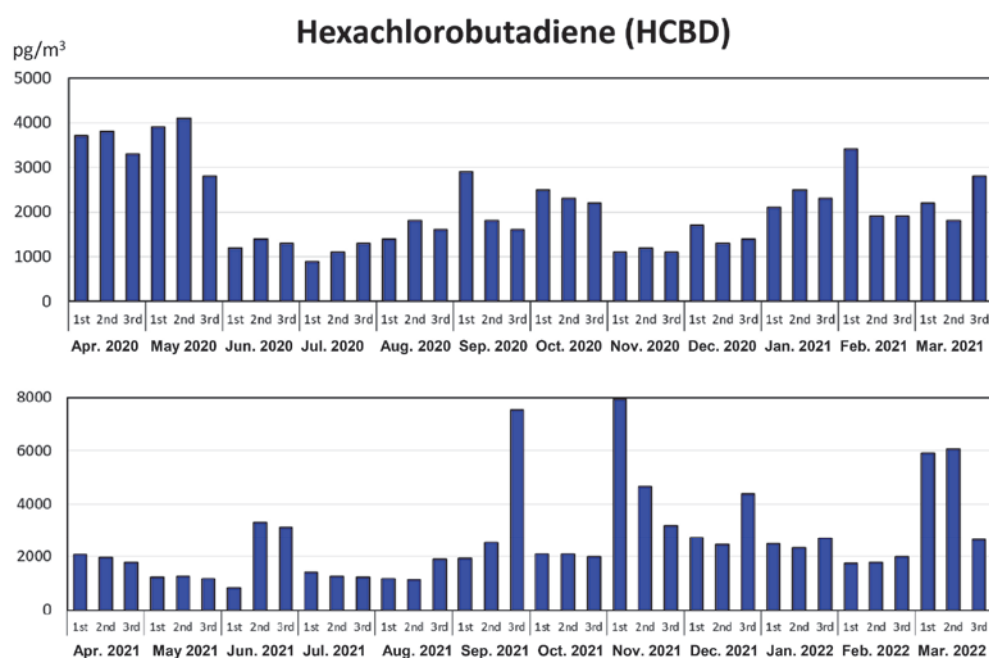
The polychlorinated biphenyls (PCB) concentration ranged from 50 to 100 pg/m³, with a higher trend in the summer and a lower one in the winter. In the homolog composition of PCBs, di-chlorinated PCBs and tri-chlorinated PCBs were dominant.

Concentrations of DDT-related compounds ranged from 0.5 to 4 pg/m³ and were minor POPs at Cape Hedo. We have previously reported that the geometric mean concentration of DDT-related compounds from April 2009 to March 2014 was 2.5 pg/m³. This result suggests that the latest DDT-related compounds observed at Cape Hedo are at a constant, low concentration. In the composition of DDT isomers, *o,p'*-DDT, *p,p'*-DDT, and *p,p'*-DDE were dominant. In addition, the ratio of DDTs (*o,p'*-DDT and *p,p'*-DDT) to overall DDT-related compounds (*o,p'*-DDD, *p,p'*-DDD, *o,p'*-DDE, *p,p'*-DDE, *o,p'*-DDT, and *p,p'*-DDT) appears to have a decreasing

trend. The ratio was obviously over 40% from April 2020 to August 2020, but observations from 2021 to 2022 showed the ratio to be under 40%, suggesting a decrease in the unintentional release of newly produced DDTs.

Chlorobenzene (CB) was one of the most dominant POPs observed at Cape Hedo. The sum of hexa-CB and penta-CB was usually constant at 100 pg/m^3 but sometimes exceeded 200 pg/m^3 . Almost constant concentrations throughout the year may reflect the high vapor pressure of hexa-CB and penta-CB. Currently, HCBd is considered to be the predominant POP in the atmosphere at Cape Hedo. The mean concentration of HCBd was about 2000 pg/m^3 , although the maximum concentration reached 8000 pg/m^3 (Fig. 2).

Fig. 2
Airborne concentration of HCBd observed from April 2020 to March 2022 at Cape Hedo.



3. Intellectual Research Infrastructure Development

3.1 Development of NIES CRM No. 13-a (human hair)

Human hair has been used extensively to monitor exposure to heavy metals such as mercury (Hg) owing to both its ability to accumulate these substances and the ease of non-invasive sampling. The development of Certified Reference Materials (CRMs) for human hair is critical to ensure accurate and precise chemical analysis, especially for hazardous substances such as Hg.

Among heavy metals, Hg is recognized by the World Health Organization (WHO) as one of the top 10 chemicals of public health concern. Seafood consumption of heavy metals—particularly of methylmercury (MeHg)—represents the primary route of Hg exposure for both humans and wildlife. The Minamata Convention on Mercury, which came into force in 2017, mandates that parties manage and control

the use of Hg, including making provisions for monitoring and assessing exposure-related health risks. Hg concentrations in hair are particularly suitable for MeHg biomonitoring, because hair is a noninvasive and highly conservative matrix.

To support these efforts, we developed a CRM using scalp hair from East Asian women (Fig. 3). The hair was washed with non-ionic detergent, crushed by using a roll press and a cold-grinding pin mill, classified (74 μm or less) by using the air jet sieve method, and homogenized. The powder samples (3 g each) were packed in 806 glass bottles and sterilized by ^{60}Co irradiation (20 kGy), with all procedures complying with ISO Guide 34.

Table 1 Certified values of NIES CRM No. 13-a (human hair).

Element	Mass Fraction			Analytical Method
	Unit	Certified Value	Uncertainty	
Methyl Mercury (as Hg)	mg/kg	0.858	0.075	GC-CV-AFS, GC-ECD, ID-GC-ICP-MS, LC-ICP-MS
Total Mercury (THg)	mg/kg	1.06	0.07	CV-AAS, ICP-MS, ID-GC-ICP-MS, TD-CV-AAS
Arsenic (As)	mg/kg	0.255	0.016	HG-AAS, ICP-MS
Cadmium (Cd)	mg/kg	0.165	0.012	ICP-MS
Lead (Pb)	mg/kg	7.42	0.62	ICP-MS
Selenium (Se)	mg/kg	0.463	0.052	HG-AAS, ICP-MS
Zinc (Zn)	mg/kg	337	22	ICP-MS, ICP-OES

Fig. 3 Pictures of raw material, scalp hair (left), the bottling operation (middle), and the developed CRM (right).



Homogeneity testing was performed on 10 sample bottles selected by stratified random sampling. The between-bottle variation, evaluated by one-way analysis of variance, showed that the homogeneity standard deviations between bottles were less than 2.6% for MeHg and 2% for other trace elements. The material is sufficiently homogeneous for its intended use as a reference material. Stability tests demonstrated that any long-term variations in the values of MeHg and selected trace elements in the material were insignificant. The property values of the material were statistically determined on the basis of chemical analyses by 13 organizations (19 laboratories) using various methods (Table 1). The uncertainty associated with the certified values is the expanded uncertainty using a coverage factor $k = 2$, corresponding to the half-width of a confidence interval of approximately 95%. As a result, the samples we developed have been approved by NIES as NIES CRM No. 13-a.

Research Projects

Satellite Observation Project

The Satellite Observation Project contributes to improving scientific understanding of the global carbon cycle, more accurate prediction of the future climate, and climate-change-related policymaking by the Ministry of the Environment (MOE) through activities that use data from satellites of the GOSAT Series, namely the Greenhouse gases Observing SATellite (GOSAT), launched in 2009; GOSAT-2, launched in 2018; and the Global Observing SATellite for Greenhouse gases and Water cycle (GOSAT-GW) to be launched in FY 2024. Activities include developing and operating data-processing systems for the GOSAT Series. These systems are being used to calculate the concentrations and fluxes of greenhouse gases (GHGs) and to verify, archive, or distribute GOSAT Series products. The GOSAT Series projects are jointly promoted by MOE, the Japan Aerospace Exploration Agency (JAXA), and NIES.

NIES's Satellite Observation Center (SOC) is responsible for implementing the Satellite Observation Project. Major achievements of the Satellite Observation Project in FY 2023, including a newly started study of GOSAT-GW follow-on, were as follows:

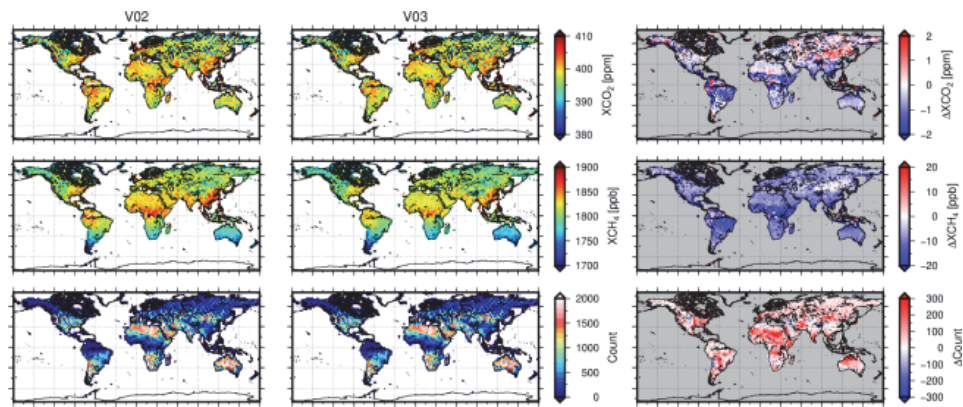
1. GOSAT

Operational data processing for GOSAT, which has been in space for more than 14 years, continued, as did the generation, validation, and distribution of GOSAT products, such as the concentrations and fluxes of carbon dioxide (CO₂) and methane (CH₄). Concentration products up to February 2024 (V03.00), CO₂ flux products up to October 2021 (V02.09), and CH₄ flux products up to September 2020 (V01.07) are freely available from GOSAT Data Archive Service (GDAS; <https://data2.gosat.nies.go.jp>). Maintenance and operation of the GOSAT Data Handling Facility, a computer system necessary for these activities, were also conducted. Moreover, we have continued to provide GOSAT FTS (Fourier Transform Spectrometer) Level 2 CO₂ data to the World Data Centre for Greenhouse Gases, which is operated by the Japan Meteorological Agency under an agreement with the World Meteorological Organization.

A paper updating the method used to estimate greenhouse gas (GHG) concentrations from GOSAT was published in March 2023¹⁾. The updated method can process those scenes that cannot be processed by using the previous method owing to the existence of optically thin clouds. Additionally, several supplemental datasets, such as a dataset on the strength of light absorption by GHGs, which was needed for the GHG analysis, were updated. These updates allow us to increase the available GHG concentration data without diminishing the accuracy of the analysis over land (Fig. 1). Products of the updated method are now available from GDAS as GOSAT FTS SWIR Level 2 Products (V03.00).

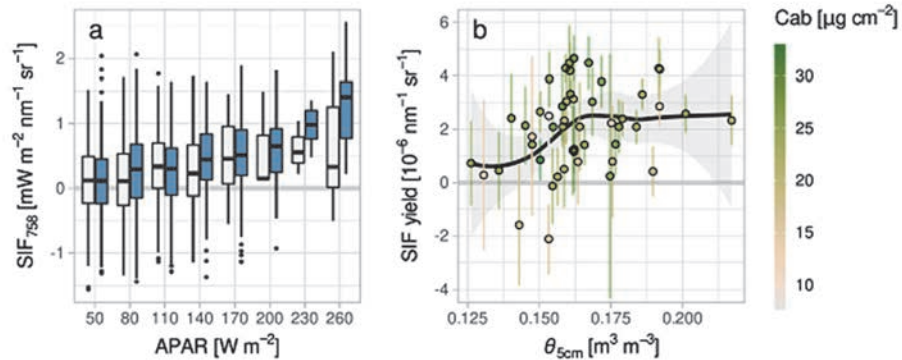
1. Satellite Observation Project

Fig. 1 Changes in CO₂ concentrations, CH₄ concentrations, and the number of data between results from the updated and non-updated methods. Upper panels: CO₂ concentrations; middle panels: CH₄ concentrations; lower panels: number of data. Left panels shown results from the method before the update (V02). Middle panels show results from the updated method (V03). Right panels show the differences between the two. Data are shown over land for the period analyzed (2009-2021).



Ten-year solar-induced chlorophyll fluorescence (SIF) data were derived from GOSAT observations over a grassland on the Mongolian Plateau, and the relationship between GOSAT SIF and the impact of drought on grassland vegetation was examined²⁾. On the Mongolian Plateau, SIF values decrease in response to soil drought, which adversely affects plant photosynthetic activity, even when the leaves do not wilt (Fig. 2). Our results showed that SIF is an excellent indicator of the impacts of soil drought on herbaceous vegetation before plants wilt.

Fig. 2 Relationships among SIF (solar-induced chlorophyll fluorescence), light absorption, and soil moisture content (SMC): (a) box and whisker plot of SIF against APAR (absorbed photosynthetically active radiation). Gray boxes, dry conditions (SMC < 15.4%); blue boxes, wet conditions (SMC ≥ 15.4%). (b) graph of SIF yield against SMC at 0 to 5 cm depth. The color of each symbol indicates the amount of chlorophyll (“Cab”): a higher green content indicates that the leaves remain green. Θ , water fraction by volume.



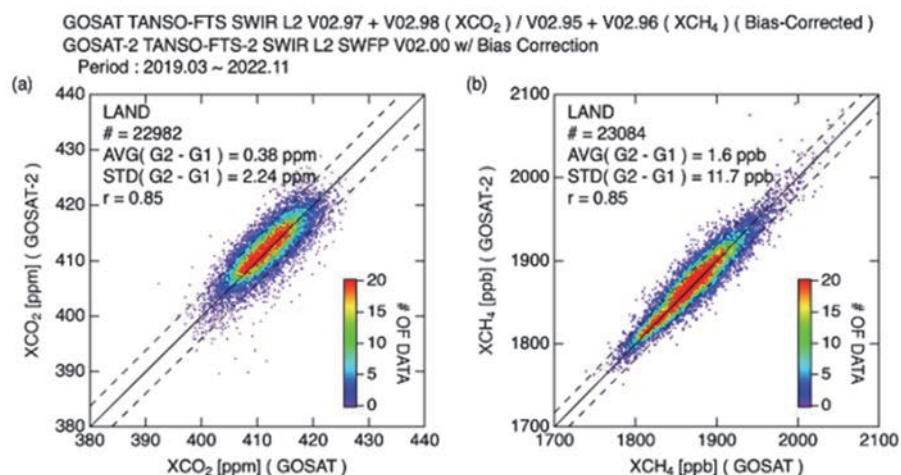
2. GOSAT-2

GOSAT-2 data have been distributed by the GOSAT-2 Product Archive (<https://prdct.gosat-2.nies.go.jp>) since 2019. Concentration products up to December 2023 (CO₂, CH₄, CO, and SIF, V02.00) and CO₂ flux products from October 2019 to October 2020 (V01.02) are freely available from the GOSAT-2 Product Archive. Three GOSAT-2 Science Team Meetings were held in FY 2023 to discuss issues such as data quality, validation analysis, and releases of standard products. In addition, JAXA’s review to end the 5-year nominal operation of GOSAT-2 and start its extended operation was convened in October 2023, and SOC contributed several materials and presentations to the review. GOSAT-2 successfully started its extended operation in November 2023.

A paper on the consistency of GHG concentrations between GOSAT and GOSAT-2 was published in August 2023³⁾. In this paper, GHG concentration data obtained by

two satellites were compared to evaluate their quality. We found that the data were generally consistent within 1%, with slight regional differences (Fig. 3). This study will help to promote the combined use of these data in scientific applications.

Fig. 3 Comparison of GOSAT and GOSAT-2 synchronous observation data. Two-dimensional frequency distribution of (a) CO₂ concentration over land and (b) CH₄ concentration over land. Dashed lines indicate a range of $\pm 1\%$. “#” is the number of data, and “AVG” and “STD” are average and standard deviation, respectively. “ r ” is correlation coefficient, and “G1” and “G2” are GOSAT and GOSAT-2, respectively.



3. GOSAT-GW

In FY2023, manufacturing and testing of the Total Anthropogenic and Natural emissions mapping SpectrOMeter-3 (TANSO-3) and related ground systems, including NIES’s GOSAT third-generation Data Processing/operating System (G3DPS) and the GOSAT-GW Nitrogen dioxide (NO₂) Data Processing System (GNDPS), were continued by JAXA, NIES, and their contractors. Installation of the G3DPS hardware at the University of Tsukuba was completed, and the procurement contract of the GOSAT Operational and research Computing Facility (GOCF) was concluded. Planned procurement and installation of the ground-based observation instruments for validation of the TANSO-3 products was completed. Observations at Downtown Tokyo and at Yokosuka, which were in preparation as of FY 2022, became operational in FY 2023.

A special issue of the *Journal of the Remote Sensing Society of Japan* covering TANSO-3 onboard GOSAT-GW was published⁴⁾. It consists of 11 original articles describing the mission concept of TANSO-3 and giving overviews of the GOSAT-GW satellite and TANSO-3 instrument, the ground data processing systems, retrieval algorithms, validation, and data applications.

4. GOSAT-GW Follow-on

The fourth generation of GOSAT, or GOSAT-GW follow-on, has been considered at NIES since FY2023. The scientific mission objective and measurement strategies of the mission have been discussed among researchers at NIES and at other institutions or universities. The mission objective has been defined as “Improvement of global GHG flux estimates”. Three requirements for the GHG concentration product have been proposed under this objective: 1) reduction of

bias in the concentration product; 2) an increase in the number of data covering the tropics; and 3) continuity of the product from GOSAT. Three measurement concepts have been proposed to meet these requirements. The first is the use of an imaging spectrometer, which has almost the same optical specifications as the Fourier transform spectrometer on board GOSAT, with the addition of a 1.27- μm band. The second and the third are the use of a combination of an imaging spectrometer and an aerosol lidar and the combination of an imaging spectrometer and a GHG lidar.

5. Collaboration with Other Organizations

Research Announcements on the GOSAT Series have been issued three times jointly by MOE, JAXA, and NIES since 2018 to solicit research proposals covering GOSAT and GOSAT-2 from around the world. Those proposals that are evaluated as appropriate by the GOSAT Series Research Announcement Selection and Evaluation Committee are adopted to conclude joint research agreements. A total of 41 joint studies have been conducted and eight studies are ongoing.

In response to the agreements concluded with the US National Aeronautics and Space Administration, the European Space Agency, le Centre national d'études spatiales (CNES), and the German Aerospace Center (das Deutsches Zentrum für Luft- und Raumfahrt), several informal meetings were held virtually. The contract with CNES was renewed in December 2023.

6. Hosting of Meetings

NIES, with support from MOE and JAXA, will host the 21st International Workshop on Greenhouse Gas Measurements from Space (IWGGMS-21) in June 2025. NIES hosted IWGGMS-18 in 2022, mostly as an online meeting because of COVID-19. IWGGMS-21 will be the first face-to-face meeting to be held in Japan in 6 years, since IWGGMS-15 in Sapporo in 2019.

7. Participation in International Events

In November 2023, SOC participated in GEO Week 2023 and a Ministerial Summit held in Cape Town, South Africa. These events were hosted by the Group on Earth Observation (GEO) and covered almost all aspects of Earth observation, including climate change and biodiversity. SOC joined the Japan GEO Exhibit and gave an on-site short lecture on the achievements and future prospects of GOSAT Series (Fig. 4, left).

In December 2023, SOC participated in the 28th session of the Conference of the Parties (COP28) to the UNFCCC (United Nations Framework Convention on Climate Change) in Dubai, United Arab Emirates, by means of an official hybrid-style side event, an official exhibit, an on-site seminar at the Japan Pavilion, and

participation in the Virtual Japan Pavilion. The official side event, “Earth observations in support of mitigation actions towards the Paris climate goal and SDGs [Sustainable Development Goals]” (Fig. 4, right) was hosted jointly by NIES and the Universities Space Research Association (USRA). Its primary objective was to showcase advancements in space-based CO₂ and CH₄ observations from Earth Observation (EO) satellites and in the emission-monitoring capabilities expected from the next-generation satellites. Another objective was to discuss the use of EO in deriving “actionable” information to monitor and guide climate mitigation efforts in support of the Paris Agreement and towards SDGs.

Fig. 4 Left: Japan GEO Exhibit at GEO Week 2023. Right: A panel discussion at the official side event at UNFCCC COP28.



8. Press Releases

SOC issued the following three press releases in FY 2023:

- 1) “Update on the analysis method to estimate the greenhouse gas concentrations from GOSAT” (April 2023)
See <https://www.nies.go.jp/whatsnew/2023/202304181-e/20230418-e.html>
- 2) “Study on consistency of greenhouse gas concentrations between GOSAT and GOSAT-2 - Efforts to develop long-term data sets on greenhouse gas concentrations using the GOSAT series” (September 2023)
See <https://www.nies.go.jp/whatsnew/2023/20230911-e/20230911-e.html>
- 3) “Detecting drought impact on grassland via GOSAT ‘Ibuki’ satellite-observed chlorophyll fluorescence” (October 2023)
See <https://www.nies.go.jp/whatsnew/2023/20231016-e/20231016-e.html>

References:

- 1) Someya Y. et al. (2023) Update on the GOSAT TANSO-FTS SWIR Level 2 retrieval algorithm, *Atmospheric Measurement Techniques* 16(6), 1477–1501.
<https://doi.org/10.5194/amt-16-1477-2023>
- 2) Kiyono T. et al. (2023) Regional-scale wilting point estimation using satellite SIF, radiative-transfer inversion, and soil-vegetation-atmosphere transfer simulation: a grassland study. *Journal of Geophysical Research: Biogeosciences* 128(4), e2022JG007074. <https://doi.org/10.1029/2022JG007074>
- 3) Yoshida Y. et al. (2023) Quality evaluation of the column-averaged dry air mole fractions of carbon dioxide and methane observed by GOSAT and GOSAT-2. *Scientific Online Letters on the Atmosphere* 19, 173–184.
<https://doi.org/10.2151/sola.2023-023>

4) Miscellaneous (2024) Special Issue for GOSAT-GW TANSO-3, *Journal of the Remote Sensing Society of Japan* 44(2), 89–176

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, which is located in the National Center for Child Health and Development and provides medical expertise.

1. Aim

The aim of JECS is to identify environmental factors that affect children's health in order 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 or 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 planned to follow their children until they reach 13 years of age. The study protocol has now been updated to keep following the children until they reach at least 40 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.

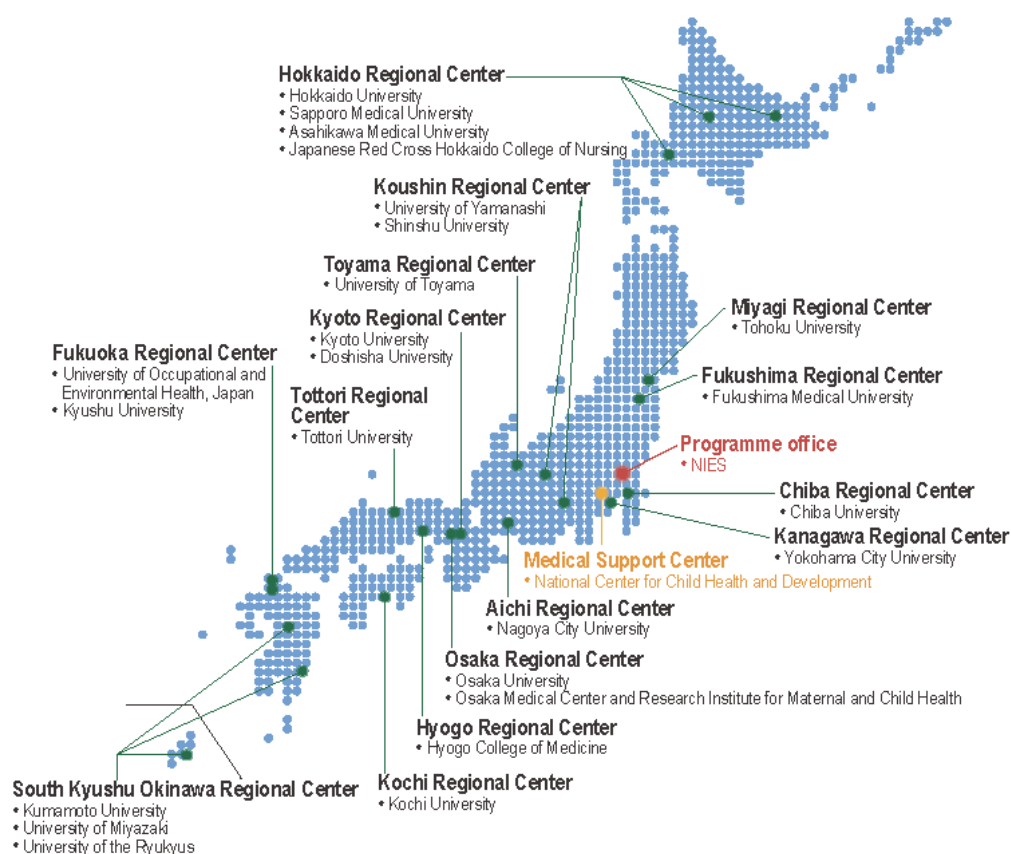
3. JECS study organization and role of the Programme Office

The Programme Office plays key roles in ensuring appropriate data collection and analysis, 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

2. Japan Environment and Children's Study Programme Office

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 protocols

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

1. Kawamoto T., Nitta H., Murata K. et al. (2014) Rationale and study design of the Japan environment and children's study (JECS). *BMC Public Health* 14, 25. doi:10.1186/1471-2458-14-25
2. Michikawa T., Nitta H., Nakayama S.F. et al. (2018) Baseline profile of participants in the Japan Environment and Children's Study (JECS). *Journal of Epidemiology* 28(2), 99–104. doi:10.2188/jea.JE20170018

3. Sekiyama M., Yamazaki S., Michikawa T. et al. (2022) Study design and participants' profile in the Sub-Cohort Study in the Japan Environment and Children's Study (JECS). *Journal of Epidemiology* 32(5), 228–236. doi:10.2188/jea.JE20200448

5. Activity report for FY 2023

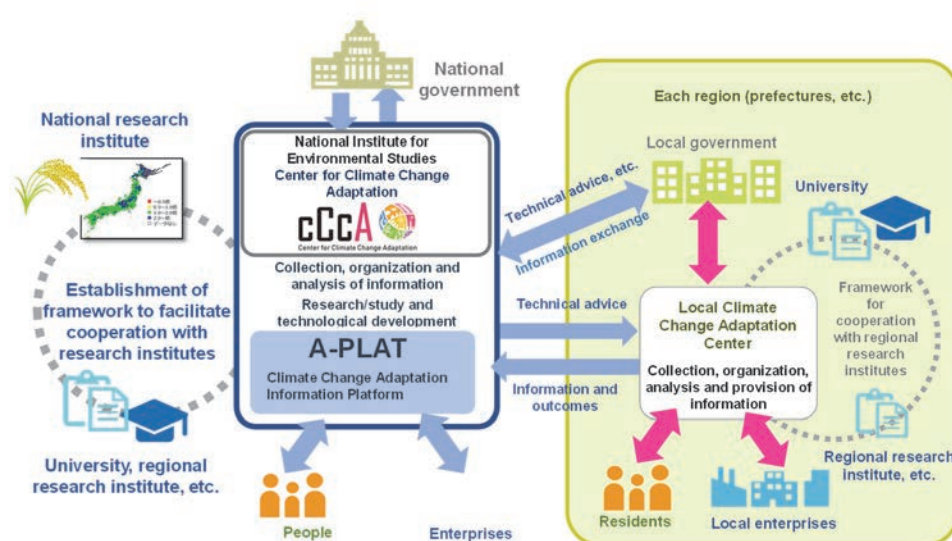
The children participating in the Main Study reached the ages of 9 to 12 years in FY 2023. We continued to administer questionnaires to participants to collect a wide range of information on the children's health and development and their exposure to environmental factors. We analyzed 5000 maternal urine samples for organophosphate flame retardants, 5000 maternal blood samples for acrylamide adducts, and 2500 paternal blood samples for metal elements. As part of the Sub-Cohort study, about 2200 ten-year-old participants were tested developmentally and examined by pediatricians. Blood and urine samples were also collected and tested.

Promotion of Climate Change Adaptation

Center for Climate Change Adaptation

Under the Climate Change Adaptation Act enforced in December 2018, NIES is designated as the core information platform for climate change adaptation in Japan. NIES established the Center for Climate Change Adaptation (CCCA) 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 2023 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 governments

We provided various forms of technical advice and help to prefectures, municipalities, and LCCACs to promote the development of regional climate change adaptation plans and adaptation measures by local governments. Some of the specific activities are summarized below.

We conducted an e-learning training program for newly appointed local government officials from April to June 2023. In August 2023, we co-hosted a training course for local government officials with the Ministry of the Environment to provide basic knowledge for formulating regional climate change adaptation plans, with a total of 135 participants in two sessions. We also collaborated with the Ministry of the Environment's Regional Environment Offices to conduct face-to-face training, including workshops, on the formulation of local climate change adaptation plans at six locations nationwide (Hokkaido, Tohoku, Chubu, and three prefectures in

Kyushu). We held regular online meetings once every 2 months and an in-person roundtable meeting in December with LCCACs across Japan (Fig.2) to share knowledge of the activities of LCCACs and to exchange information and opinions among them.

We gave lectures at various meetings at the request of local governments and other entities and provided knowledge on climate change adaptation to a total of approximately 9800 people in FY 2023, thereby contributing to human resource development in local communities. In addition, as part of the development of environmental research and technical help to local communities, we conducted “Joint Research on Climate Change Adaptation with LCCACs” on seven themes.

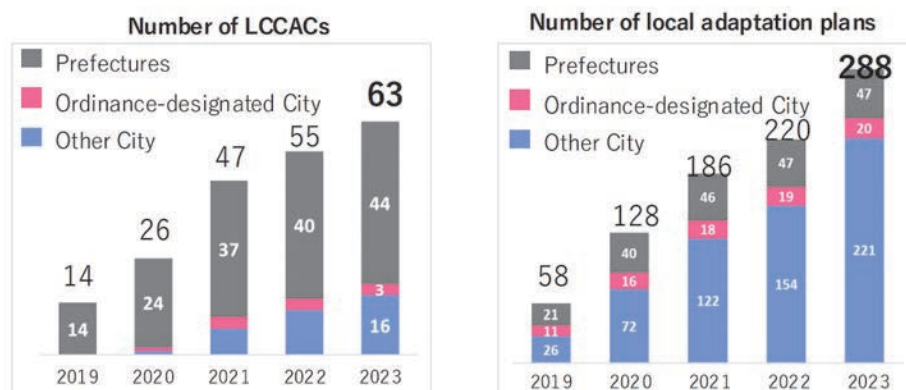
We held a symposium and umbrella meetings of the “Study Group on Climate Change Adaptation” in December 2023, with the participation of national research institutes of various ministries and LCCACs, to discuss the feasibility of tangible collaboration (social implementation) among national research institutes on the basis of local needs.

Fig. 2 LCCAC discussion meeting in 2023.



As a result of our continued support for local communities, the number of local adaptation plans and LCCACs has been increasing (Fig. 3). As of 31 March 2023, local adaptation plans have been formulated in all 47 prefectures, and regional adaptation centers have been established in 44 prefectures.

Fig. 3 Numbers of local adaptation plans (left) and LCCACs (right).



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

The Climate Change Adaptation Information Platform (A-PLAT), which provides comprehensive information on adaptation to the effects of climate change, was operated to disseminate information on various events and initiatives of government ministries and agencies, national research institutes, local governments, LCCACs, businesses, and others. Because a great deal of content has accumulated in the 5 years since its establishment, and the web page structure has become complicated, we revised the entire site structure and some of the content to improve usability. In addition, information dissemination on recent topics on A-PLAT was strengthened, including the release of a page related to heat stroke and “Nature Positive and Climate Change Adaptation.” In FY 2023, the number of web page views was approximately 1.05 million (target: over 500,000), and there were 1040 SNS transmissions (X, Facebook, Instagram, LinkedIn, and Twitter) (target: more than 100). Both of these figures substantially exceeded the target values.

To monitor the status of public awareness of climate change adaptation, we have conducted a web-based questionnaire survey annually since FY 2021. The survey covers items such as awareness of climate change effects and adaptation, sufficiency of information provided, and areas of interest in each of the seven regions of Japan.

To enhance public awareness of climate change adaptation, we developed and lent out educational tools (e.g., *Gacha*, a capsule toy machine, and *Sugoroku*, a board game), produced a video version of A-PLAT Kids for children (“Hello, Adaptation Measures”), and disseminated information and exchanged opinions through educational seminars in collaboration with JCCCA (Japan Center for Climate Change Actions), the ESD (Education for Sustainable Development) National Forum, and the Children's Eco-Club National Festival 2024.

To promote the utilization of climate change data, we promoted the activities of the Roundtable on Scenarios and Data for Climate Change Risk and Opportunity Assessment, which was established by the relevant ministries and agencies (including NIES) for the purpose of close exchange of information and opinions between data providers and users. In FY 2023, we conducted interviews with companies (the users of data) through the activities of the Roundtable, and by identifying the issues and needs we created a Climate Change Risk Analysis Information Site and made it available on A-PLAT.

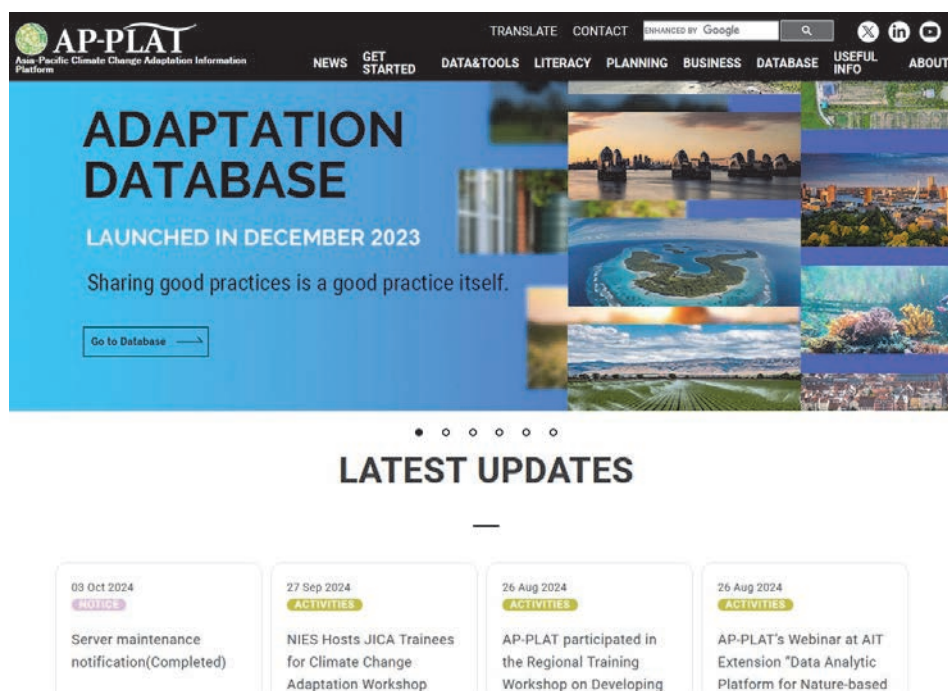
1.3 International contributions to the development of an information platform for the Asia-Pacific region

The Asia-Pacific Platform for Climate Change Adaptation (AP-PLAT) (Fig. 4), which is being developed as an information platform to support adaptation measures in developing countries in response to the Paris Agreement, developed, implemented, and released an Adaptation Database, which collects and organizes information on good practices, case studies, and organizations related to adaptation.

We signed a Memorandum of Agreement on joint research with the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) to strengthen AP-PLAT's international collaboration.

We helped promote adaptation policies in the Asia and Pacific region by sending a member to the Capacity Development Committee of the Asia-Pacific Network for Global Change Research (APN) to contribute to the development of human resources for global change research in the Asia-Pacific region; by collaborating with relevant domestic and international organizations such as PCCC (the Pacific Climate Change Centre) and ADB (the Asian Development Bank); by organizing an international workshop on scientific tools at the 28th Conference of the Parties (COP28) to the UNFCCC (United Nations Framework Convention on Climate Change); and by making presentations on AP-PLAT at the APAN (Asia-Pacific Climate Change Adaptation) Forum and other forums.

Fig. 4 home page of the AP-PLAT website (<https://ap-plat.nies.go.jp/>).



1.4 Contribution to climate change policy

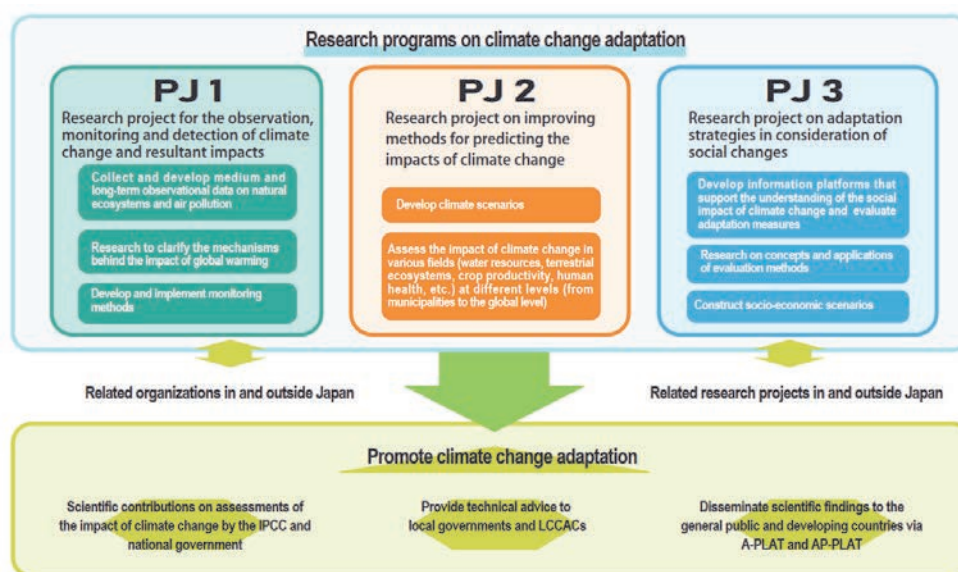
We contributed to discussions on climate change risks and adaptation measures and the promotion of adaptation-related projects of the government by sending members to 82 committees and working groups. This included working with the Subcommittee on Climate Change Impact Assessment and Adaptation of the Global Environment Committee of the Central Environment Council (an advisory council to the Minister of the Environment) and sectoral Working Groups. We also held monthly exchanges of opinions with the Climate Change Adaptation Office of the Ministry of the Environment. In particular, we contributed to the Subcommittee's discussion on the implementation status of the Climate Change Adaptation Act in its fifth year of implementation by responding to its hearings and reporting on achievements and challenges, as well as on the future direction of our research and technical support activities.

2. Climate Change Impact and Adaptation Research

To promote adaptation-related research throughout the country, NIES takes the lead in managing liaison councils and study groups consisting of research institutes from various ministries and agencies, and we work closely with these research institutes.

To promote important adaptation measures, NIES conducts research on various fields and items, including ecosystems, the air and water environments, and health impacts such as heat stroke. We aim to detect and predict the effects of climate change, evaluate the effects of adaptation measures to reduce the impacts, and develop policy research and the methods needed to formulate and implement adaptation measures on the basis of our findings. These studies are largely divided into “Strategic Research Programs” and “Basic Research and Research Infrastructure Development.” Figure 5 summarizes the main topics for FY 2023 in the three research projects that comprise the Strategic Research Program: PJ1, impact assessment; PJ2, improvement of assessment methods; and PJ3, adaptation strategies.

Fig. 5 Structure of our research projects.



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

In this project, we elucidate the impacts of climate change on terrestrial, terrestrial–water, and coastal ecosystems, as well as on inland bay environments, heat, and health by using observation data in priority target areas. We also provide useful information for planning and promoting adaptation measures. Information on detected climate change impacts, as well as monitoring data that are useful for detecting climate change impacts, will be made public through A-PLAT and AP-PLAT, with the aim of helping to plan and promote regional and local adaptation measures.

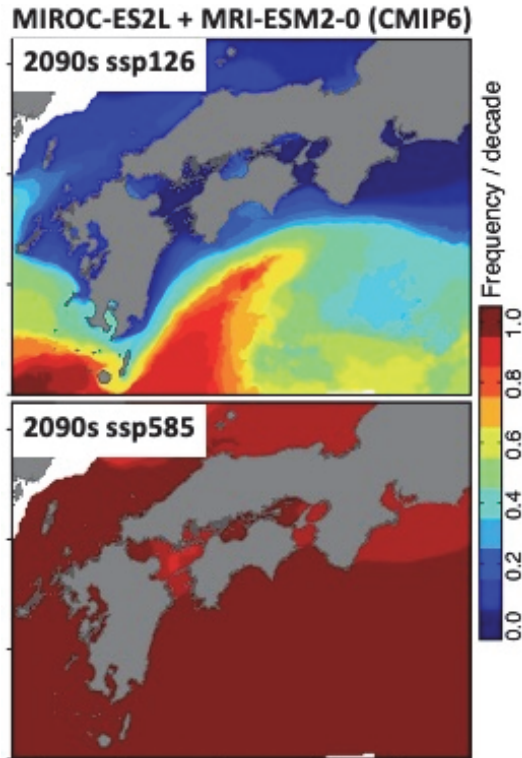
Heat stroke was also a topic studied in 2023. Noting that heat stroke incidence rates vary regionally, even for the same heat index—the wet bulb globe temperature (WBGT)—we conducted a time-series analysis of the association between the number of heat stroke cases and daily maximum WBGT in 47 prefectures, controlling for confounding factors such as seasonality and long-term trends, and we analyzed regional characteristics. The results indicated that there was an association of both age group and severity of illness with regional climate. In addition, the health impacts of hot nights (days when the minimum nighttime temperature does not drop below 25 °C, i.e., “Nettaiya”) on mortality were analyzed. The results showed an association between the occurrence of hot nights and the number of deaths, suggesting the need for health measures against hot nights.

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

In PJ2, we are conducting climate change impact assessments by using the latest climate scenarios and socioeconomic scenarios. We are also evaluating impacts with and without adaptation measures by upgrading future climate change impact assessment methods for multiple sectors and scales (global, Asia-Pacific region, and Japan). The purpose of this project is to help advance climate change impact assessment methods and the consideration of adaptation measures, such as the identification of priority areas. The project also aims to contribute to our understanding of climate change risks in society by publishing the climate scenarios that are developed, as well as the results of the impact assessments obtained from them through A-PLAT and AP-PLAT.

The results related to the thermal impact on coral and macroalgal communities in the seas around Japan are shown in Figure 6. In a study of corals and macroalgae, we analyzed the thermal impacts of marine heatwaves. The Japanese warm temperate zone has been expected to play a role as a refuge for corals at the expense of macroalgal communities under the climate change. However, our analyses of thermal impacts revealed that not only macroalgae but also corals failed to persist against the 2013 marine heatwave in the Japanese warm temperate zone. Furthermore, our future projections showed that macroalgal loss and coral bleaching would occur every year at the end of the century under SSP585 (a scenario that emits greenhouse gas maximally under fossil fuel-dependent development without climate policy), but remained at the current levels under SSP126 (a scenario that limits temperature rise below 2.0°C under sustainable development) (Fig. 6)

Fig. 6 Future projections of simultaneous occurrence of macroalgal loss and coral bleaching under SSP126 and SSP585 in 2090s. See text for the scenario descriptions. The climate projection was based on the MIROC-ES2L and MRI-ESM2.0 climate models.

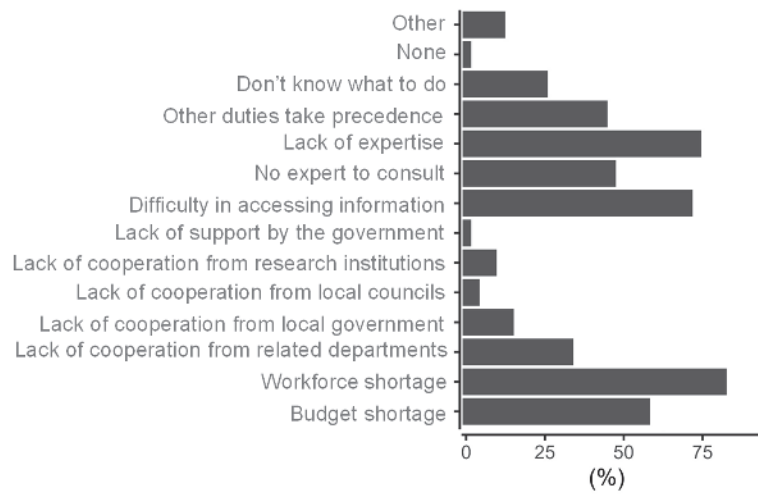


2.3 Adaptation strategies in consideration of social changes (PJ3)

In collaboration with PJ1 and PJ2, this project aims to identify gaps and impediments among climate change impact projections, adaptation planning, and adaptation practices, as well as to develop models and methods to ameliorate them. The topics for 2023 included results on the challenges of promoting adaptation in local communities.

In Japan, local governments are encouraged to establish LCCACs tasked with collecting, evaluating, and disseminating information on climate change impacts and adaptation strategies. To clarify the status of the activities and challenges of LCCACs in performing their expected roles, we conducted a questionnaire survey among the LCCACs (Fig. 7). We found discrepancies in the activities of LCCACs compared with their expected roles. Many LCCACs acknowledged the importance of roles such as projecting the impact of climate change. However, the number of centers with practical experience in these roles was limited. The challenges identified include a lack of expertise, as well as inadequate personnel and budgets.

Fig. 7 Challenges local climate change adaptation centers face in performing their duties.



Environmental Information Department

Environmental Information Department

The Environmental Information Department provides information technology (IT) support for research and related functions at NIES and collects, processes, and disseminates environmental information to the general public.

In the fifth mid-to-long-term plan, NIES formed the PMO (Portfolio Management Office) responsible for IT project management within the organization. Additionally, with the goal of leading data utilization and data-driven science in the environmental research field in the future, as well as establishing an internal IT infrastructure and a support team to support the use of information and data in research activities, a substantial reorganization of the department was considered and implemented. In 2021, the Information System Strategy Working Group (WG) was established to discuss the efficient use of computational resources and a new research data infrastructure. In 2022, the public affairs team in the Department was transferred to the Public Relations Office in the Planning Department. In October 2023, the Information Management Office was reorganized into the Information System Infrastructure Office, and the Information Development Office was reorganized into the Research Information Office. The work content was also revised to further strengthen the system for supporting research activities and enhancing the dissemination of environmental data.

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, the 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 (LAN) called NIESNET was established at NIES in 1992. NIESNET was replaced in March 2021. We are improving user convenience by expanding the wireless LAN usage area and strengthening security by introducing an authentication function.

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 2023, 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 Preparation for next-generation research computing infrastructure

We started planning to upgrade to the next computer system for research; the upgrade should be completed by February 2026. On the basis of discussions by the WG and a survey of opinions across the Institute, a committee to consider the next research computing infrastructure was launched in 2023. As the WG and committee secretariat, the Department compiled opinions on specifications and conducted hearings with IT vendors.

As a result of the review of the next research computing infrastructure, we newly adopted a virtualization computational infrastructure to meet user needs broadly. For the feasibility study of this infrastructure, we started using “mdx”, a platform for building a data-empowered society (<https://mdx.jp/en>), and we are working to resolve technical issues and consider operating rules.

1.4 Library services

As of March 2024, the NIES library (Fig. 2) held 75,670 books, 7489 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. We have also introduced a web-scale discovery service, Primo (Ex Libris). It has the capacity to more easily connect researchers with the library's vast amount of information held in physical holdings, digital collections, and various repositories.

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.



1.5 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 and papers written by our researchers. Accordingly, we have set up a system for publishing URLs (metadata) associated with DOIs on the NIES website, as well as an institutional repository (see below).

The government's 5-year Japanese Science and Technology Basic Plan calls for efforts to promote open science. A working group was established at NIES, and we examined the introduction of an archiving system (institutional repository) to be operated and constructed by NIES. As a result of the group's discussion, it is now possible for us to release articles and assign DOIs in response to requests from our researchers. In addition, we joined JPCOAR (the Japan Consortium for Open Access Repository), and in May 2022 we started to operate JAIRO Cloud, a cloud-based institutional repository-environment provision service. It is now possible for us to release articles and assign DOIs in response to requests from our researchers. In February 2023, the repository module was changed to the WEKO3 data publishing program to enable the registration of various content types.

In addition, NIES is using the CHORUS Institution Dashboard Service to monitor and understand the status of our researchers' products and activities. A seminar based on the monitoring results was held at NIES in December 2023 to explain the current situation of open access. We are continuing discussions on the information infrastructure required to support the promotion of open science.

1.6 Collection, processing, and dissemination of environmental information

One of NIES's major tasks is the collecting, processing, and disseminating 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).

1.6.1 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 environmental issues in Japan and across the globe, descriptions of key environmental technologies, environmental

information via GIS, and other content to aid environmental learning.

1.6.2 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 the Ministry of the Environment (MOE). These processed data can be accessed through the database on the NIES website. A lending service is also available.

1.6.3 Provision of environmental information via GIS

The Department, in cooperation with 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 easily understand the status of the environment. The system has been publicly available through the Internet since July 2010 and has since been updated as needed in response to user requests. The cloud-based GIS data platform can also be linked to the integrated GIS infrastructure system promoted by MOE, and we plan to share mutual data in the future.

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Inquiries:

International Coordination Office
Facsimile: +81-29-851-2716
E-mail: international@nies.go.jp

National Institute for Environmental Studies
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