RECOMMENDATION

Transforming Society to Become Resilient and Sustainable beyond Catastrophic Disasters

August, 2023

Science Council of Japan

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Subcommittee on IRDR, Committee on Civil Engineering and Architecture, Science Council of Japan

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	SATAKE Kenji	Professor, Earthquake and Volcano Information Center, Earthquake Research Institute, the University of Tokyo
	IMAMURA Fumihiko	Professor, International Research Institute of Disaster Science, Tohoku University
	OHARA Miho	Professor, Institute of Industrial Science, the University of Tokyo Adjunct Professor, The National Graduate Institute for Policy Studies
	KAZAMA Motoki	Professor, Graduate School of Engineering, Tohoku

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KOMORI Daisuke	Specially Appointed Professor, Green Goals Initiative, Tohoku University
SAITO Taiki	Professor, Department of Architecture and Civil Engineering, Architecture and Urban Design, Toyohashi University of Technology
SUZUKI Yasuhiro	Professor, Disaster Mitigation Research Center, Nagoya University
TATANO Hirokazu	Professor, Disaster Prevention Research Institute, Kyoto University
TSUKAHARA Kenichi	Professor, Faculty of Engineering, Kyushu University
NISHIJIMA Kazuyoshi	Associate Professor, Disaster Prevention Research Institute, Kyoto University
HORI Muneo	Director-General, Japan Agency for Marine-Earth Science and Technology
MIYANO Michio	Specially Appointed Professor, Urban Resilience Research Center of Osaka Metropolitan University
ONO Yuichi	Deputy Director, International Research Institute of Disaster Science, Tohoku University
NISHIKAWA Satoru	Senior Advisor, Japan International Cooperation Agency

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	KONAMI Takahiro	Director, International Affairs Office, River Planning Division, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism
	KURIBAYASHI Daisuke	Chief Researcher, International Centre for Water Hazard and Risk Management (ICHARM), Public Works Research Institute (PWRI)
	SHAW Rajib	Professor, Graduate School of Media and Governance, Keio University

TABATA Kentaro	Deputy Manager, Earthquake Disaster Mitigation Research Division, National Research Institute for Earth Science and Disaster Resilience (NIED)
NISHIGUCHI Hiro	President, Japan Bosai Platform
HIROKI Kenzo	Professor, National Graduate Institute for Policy Studies (GRIPS)
MURAKAMI Takeo	Director for International Cooperation and Partnership, Office of Director General for Disaster Management, Cabinet Office, Government of Japan
YAMAZAKI-HONDA Ritsuko	Deputy Director-General, Strategic Planning Department, National Research Institute for Earth Science and Disaster Resilience (NIED)

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Secretary	TAKAHASHI Yoshikazu	Professor, Department of Civil and Earth Resources Engineering, Kyoto University
	KOIKE Toshio	Executive Director, International Centre for Water Hazard and Risk Management (ICHARM), Professor Emeritus, the University of Tokyo Adjunct Professor, The National Graduate Institute for Policy Studies
	AMANO Reiko	Auditor, Japan Atomic Energy Agency Auditor, National Institute for Environmental Studies Special Adviser, National Research Institute for Earth Science and Disaster Resilience (NIED)
	KOMATSU Toshimitsu	Professor Emeritus, Kyushu University

KOMINE Hideo	Professor, School of Science and Engineering, Waseda University
TATANO Hirokazu	Professor, Disaster Prevention Research Institute, Kyoto University
NASU Seigo	Professor, School of Economics and Management, Kochi University of Technology Head of Entrepreneur Engineering Management Course, Graduate School, Kochi University of Technology
NISHIJIMA Kazuyoshi	Associate Professor, Disaster Prevention Research Institute, Kyoto University
HANAKI Keisuke	Professor, School of Information Networking for Innovation and Design, Toyo University
YASUFUKU Noriyuki	Professor, Geotechnical Engineering group, Faculty of Engineering, Graduate School of Engineering, Kyushu University

Subcommittee on Earth and Planetary Science Social Contribution, Committee on Earth and Planetary Science, Science Council of Japan

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	HARUYAMA Shigeko	Professor Emerita, Mie University
	OKUBO Shuhei	Professor Emeritus, the University of Tokyo Professor, Faculty Geoscience and Environment, School of Earth Science and Environmental Engineering, Southwest Jiao tong University
	KAWAGUCCI Shinsuke	Senior Researcher, Japan Agency for Marine-Earth

	Science and Technology
KIMURA Gaku	Advisor, Marine Earthquake and Volcano Division, Japan Agency for Marine-Earth Science and Technology
SASAKI Shou	Professor, Graduate School of Science, Osaka University
SATO Kaoru	Professor, Graduate School of Science, the University of Tokyo
SUZUKI Yasuhiro	Professor, Disaster Mitigation Research Center, Nagoya University
TAKAHASHI Keiko	Senior Research Fellow/Professor, Global Consolidated Research Institute for Science Wisdom, Comprehensive Research Organization, Waseda University
TANIGUCHI Makoto	Deputy Director-General/ Professor, Research Institute for Humanity and Nature, National Institutes for the Humanities, Inter-University Research Institute Corporation
ZHANG Jing	Professor, Faculty of Science, Academic Assembly, University of Toyama
TSUKUDA Eikichi	Emeritus Researcher, National Institute of Advanced Industrial Science and Technology
NIINO Hiroshi	Professor Emeritus, the University of Tokyo
NISHIYAMA Tadao	Professor, Faculty of Advanced Science and Technology, Kumamoto University
HIMIYAMA Yukio	Emeritus Professor, Hokkaido University of Education
FUJII Ryoichi	President, Research Organization of Information and Systems, Inter-University Research Institutes
YABUTA Hikaru	Professor, Graduate School of Advanced Science and Engineering, Hiroshima University
WATANABE Junichi	Professor, Inter-University Research Institute Corporation, National Institutes of Natural Sciences, National Astronomical Observatory of Japan

The following members have contributed to this Recommendation.

IGARASHI Kurumi	Headquarters of Innovation Co-Creation, National Research Institute for Earth Science and Disaster Resilience (NIED)

IKEDA Tetsuya	Japan Construction Information Center Foundation
INOGUCHI Munenari	Associate Professor, Faculty of Sustainable Design, University of Toyama
ISHII Kazu	Deputy General Manager, Corporate Planning Division, Mitsubishi Research Institute
EGAWA Shinichi	Professor, International Research Institute of Disaster Science, Tohoku University
EBINA Yuichi	Associate Professor, International Research Institute of Disaster Science, Tohoku University
OKABE Takashi	Deputy Director, International Affairs Division, Strategic Planning Department, National Research Institute for Earth Science and Disaster Resilience
KAWAUCHI Atsushi	Associate Professor, International Research Institute of Disaster Science, Tohoku University
KAWATA Yoshiaki	Executive Director, Disaster Reduction and Human Renovation Institution Director and Chair Professor, Graduate School and Research Center for Societal Safety Sciences Kansai University
GYOJI Takahiro	Director of Research, Disaster Reduction and Human Renovation Institution
SATO Daisuke	Associate Professor, International Research Institute of Disaster Science, Tohoku University
SHIMADA Kazuyoshi	Director, Washington D.C. Office, Japan Science and Technology Agency
SUGIMORI Reiko	Professor, Early Modern Materials Department, the University of Tokyo
SEKINE Hozuma	Value Creation Process Manager, Resilience Field, Corporate Collaboration Promotion Division, Resilience Field, Mitsubishi Research Institute, Inc.
TACHIKAWA Yasuto	Professor, Graduate School of Engineering, Kyoto University
HIRATA Naoshi	Emeritus Professor, the University of Tokyo
MASHINO Sonoe	Executive Director, Research Institute of Nursing Care for people and Community, University of Hyogo
MARUYAMA Yoshikazu	Disaster Medical Management Supervisor, the Japanese Red

	Cross Society Director, Domestic and International Medical Relief Department, the Japanese Red Cross Medical Center Director, Disaster Management Research Institute, Japanese Red Cross College of Nursing.
YAMAGUCHI Kentaro	Senior Research Fellow, Safety & Industry Division and Center for Policy & Economics, Mitsubishi Research Institute, Inc.
MIZUMOTO Shinichi	Former Executive Director, National Research Institute for Earth Science and Disaster Resilience (NIED)
YAMASHITA Katsuya	Senior Researcher, National Research Institute for Earth Science and Disaster Resilience (NIED)

The following officials handled administration and research in preparing this recommendation.

MATSUMURO Kanji	Director for Scientific Affairs II
SASAKI Toru	Director for Scientific Affairs II
TAKAHASHI Naoya	Deputy Director, the office of Director for Scientific Affairs II
YANAGIHARA Jyoko	Deputy Director, the office of Director for Scientific Affairs II
ISHIKAWA Eri	Specialist, the office of Director for Scientific Affairs II
IKEGAWA Yukino	Specialist, the office of Director for Scientific Affairs II
FUJITA Takashi	Specialist, the office of Director for Scientific Affairs II

Executive Summary

１ Background

To overcome catastrophic disasters such as earthquakes and tsunamis, which are almost certain to occur in the first half of the 21^{st} century, we have integrated the knowledge of various related academic fields, and recommended an overarching strategy and feasible concrete measures to overcome catastrophic disasters from an academic perspective regarding what should be done in the remaining time and after the disasters.

２ Current Status and Challenges

There is a high probability that a Nankai Trough Earthquake, which has recorded almost every century since the 7th century, will occur in the first half of the 21^{st} century. The Tokyo Inland Earthquake, which had an adjacent epicenter, may have occurred in close temporal proximity. According to damage estimates by the Japanese government, the maximum estimated damage was 220 trillion yen for the Nankai Trough Earthquake, and 95 trillion yen for the Tokyo Inland Earthquake. In summary, the estimated damage by these two earthquakes amounted to over 300 trillion JPY. Disasters that cause damages exceeding 100 trillion yen are referred to as ″Trillion-Dollar Disasters.″ In the United States, which experiences many disasters annually, large-scale disasters are referred to as "Billion-Dollar Disasters." Although there has never been a ″Trillion-Dollar Disaster″ individually or in the annual total, the coming Nankai Trough Earthquake and the Tokyo Inland Earthquake could be the first ″Trillion-Dollar Disasters″ that humanity has experienced since the Industrial Revolution. Such ″catastrophic disasters″ of unprecedented scale are definitely an apparent threat to Japan's sustainable development, and a significant threat to the sustainable development of the international community.

It is impossible to completely prevent the estimated damage in the time remaining before the disaster strikes. Accordingly, this recommendation focuses on ″resilience,″ which is the ability to comprehensively overcome a disaster, including streamlining and improving the efficiency of post-disaster emergency response and recovery/reconstruction processes, in addition to further improvement of damage deterrence. To improve resilience, it is essential to promote science and technology that aims for “consilience” of knowledge of disasters as natural and social phenomena.

３　Recommendations - What Should We Do with the Remaining Time? -

To acquire resilience to overcome catastrophic disasters of the scale estimated by the government of Japan, all stakeholders should continue putting in effort to not only prevent damage, but also focus on scientific studies and practices promoting disaster response and recovery. In the following sections, we propose measures to be taken consistent with the four priorities for action in the Sendai Framework for Disaster Risk Reduction 2015-2030.

（１）Elucidating disaster risk

・To establish science and technology for improving disaster resilience and the sustainability of societies with three ultimate goals: 1) maintaining and improving the physical, mental, and social well-being of individuals, 2) reinforcing the capacity for mutual support in communities; and 3) the coherent realization of disaster risk reduction, climate change adaptation, and sustainable development in society.

・To develop a disaster management system with an all-hazards approach, conversing multi-disciplinary knowledge covering all phases of disaster management, including forecasting, prevention/mitigation, early warning, emergency response, and recovery/restoration.

・To realize the consilience of knowledge for disaster resilience using information infrastructure to disseminate to society according to the Recommendation titled “Developing an Online Synthesis System (OSS) and fostering Facilitators to realize consilience” from the Science Council of Japan in 2020.

（２）Establishing new governance to manage disasters

・To establish the governance contributing to the transition to an autonomous, decentralized, and cooperative society as suggested by the irreversible changes caused by the COVID-19 pandemic.

・To ensure transnational resilience, where multiple countries cooperate in addition to improving the national resilience of land and sea, sovereignty, and the people of each country.
・To stimulate risk communication on catastrophic disasters nationally and globally, starting with discussions at the Science Council of Japan.

（３）Ensuring investment in financial expenditure, capacity development, and technological development during disasters

・To establish the role of investment in reducing human activities and asset accumulation at risk exposed to disasters such as medium to long-term spatial reorganization plans and maintenance of critical social infrastructure.
・To promote the concentrated investment in (1) improvement of qualitative and quantitative enhancement of market services to improve self-help capacity and (2) enhancement and diversification of insurance and mutual aid programs to provide mutual assistance aid based on the system.
・To enhance individual and grassroots community resilience capabilities to deploy strategic capacity development programs to further respond to disasters more efficiently, and effectively utilize digital transformation (DX).

（４）Establishing proactive measures to enable “Build Back Better”

・To reinforce the transformative capacity to further build a new society after a disaster with the awareness that "in an emergency, we can only do what we normally do," as well as a system that promotes proactive measures using DX.
・To present a vision of society after a catastrophic disaster (sustainability, green energy/zero carbon, national spatial planning, transition to an autonomous decentralized and cooperative community in terms of finance, economy, industry, international cooperation, etc.)

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To overcome catastrophic disasters, such as earthquakes and tsunamis, which are almost certain to occur in the first half of the 21st century, we integrate the knowledge of various related academic fields, and recommended an overarching strategy and feasible concrete measures to overcome catastrophic disasters from an academic perspective regarding what should be done in the remaining time and after the disaster. It is impossible to completely prevent the estimated damage in the time remaining before the disaster strikes. Accordingly, this recommendation focuses on "resilience," which is the ability to comprehensively overcome a disaster, including streamlining and improving the efficiency of post-disaster emergency response and recovery/reconstruction processes, in addition to further improvement of damage deterrence. To improve resilience, it is essential to promote science and technology that aims for 'consilience [1]' of knowledge of disasters as natural phenomena and that of disasters as social phenomena.

1 Background and Purpose of this Recommendation

Catastrophic disasters impede sustainable development worldwide. In 2015, the Sustainable Development Goals (SDGs) [2] were set as common achievable goals for humanity. In the same year, the Sendai Framework for Disaster Reduction [3] and Paris Agreement were established to mitigate and adapt to climate change [4]. Although these three global agendas appear independent, they should be viewed as closely interrelated systemic risks [5].

Systemic risk is a well-known economic and financial term that describes how the impact of insolvency in one place quickly spread through payment systems and markets to the global financial system during the 2008 Lehman Shock. In this recommendation, systemic risk refers to the risk that a problem in disaster risk reduction, climate change adaptation, or sustainable development that occurs in one place, will spread to other problems and regions because of their close interdependence, which will become a global challenge. This interdependency resulted from the continuation of population growth and urbanization that began with the Industrial Revolution and accelerated after World War II (WWII).

In Japan, there is a high probability that a Nankai Trough Earthquake will occur in the first half of the 21st century, as it has recorded almost every century since the 7th century [6]. The Tokyo Inland Earthquake, which had an adjacent epicenter, may have occurred in close temporal proximity. According to damage estimates by the Government of Japan, the maximum estimated damage amounted to 220 trillion yen for a Nankai Trough Earthquake, and 95 trillion yen for a Tokyo Inland Earthquake. In summary, the estimated damage caused by these two earthquakes amounted to over 300 trillion JPY. Disasters with damages exceeding 100 trillion yen are referred to as "Trillion-Dollar Disasters. In the United States, which experiences many disasters yearly, large-scale disasters are referred to as "Billion-Dollar Disasters [7]." Although there has never been a "Trillion-Dollar Disaster" individually or in the annual total, the coming Nankai Trough Earthquake and the Tokyo Inland Earthquake could be the first "Trillion-Dollar Disasters" that humanity has experienced since the Industrial Revolution. Such "catastrophic disasters" of unprecedented scale are definitely an apparent threat to Japan's sustainable development, and a significant threat to the sustainable development of the international community. This recommendation provides an overarching strategy and feasible concrete measures to overcome "Trillion-Dollar Disaster" level catastrophic disasters, which are expected to occur in future.

２ What kind of catastrophic disasters are predicted to occur in the first half of the 21st century?

Catastrophic disasters can be predicted by science alone. However, science alone cannot determine how to overcome them. Therefore, this recommendation adopts the worst-case scenario approach used in policy assumptions based on scientific predictions of the kind of disaster risk that can be scientifically predicted. We begin with the scenarios for the Nankai Trough Earthquake proposed by the Japanese government. We then moved on to the Tokyo Inland Earthquake scenario with further complications.

(1) Basic hazard scenario "Nankai Trough Earthquake

The Nankai Trough Earthquake occurs at the plate boundary located in the Pacific Ocean from Shizuoka Prefecture to Miyazaki Prefecture, where the Philippine Sea Plate is subducting at a rate of 5 cm yearly beneath the Eurasian Plate, on which western Japan rests. The strain accumulated at the plate boundary is released approximately every 100 years. In addition to the damage caused by seismic tremors, tsunamis have caused significant damage as the plate boundary is located at the bottom of the sea. Historically, the following earthquakes were recorded:

The 684 Hakuho Earthquake
The 887 Ninna Earthquake
The 1096 Eicho Earthquake
The 1099 Kowa Earthquake
The 1361 Shohei Earthquake
The 1498 Meio Earthquake
The 1605 Keicho Earthquake
The 1707 Hoei Earthquake
The 1854 Ansei Earthquake
The 1944 Showa Tonankai Earthquake
The 1946 Showa Nankai Earthquake.

Based on a time prediction model, the Headquarters of Earthquake Research Promotion (HERP) estimates the expected time interval would be 88.2 years between the Showa Nankai Earthquake and the next Nankai Trough Earthquake, with a magnitude of 8-9 earthquake. The HERP also estimates that the probability of the next earthquake occurring within ten years from 2022, within 30 years, and within 50 years is approximately 30%, 70-80%, and 90% respectively. According to this prediction, the next Nankai Trough Earthquake will occur in the first half of the 21st century.

(2) The Possibility of Nankai Trough Earthquakes and the Tokyo Inland Earthquake is linked.

The Tokyo Inland Earthquake, which had an epicenter adjacent to the Nankai Trough Earthquake, might have occurred in close temporal proximity. While predictions for the occurrence of the Nankai Trough Earthquake are based on a time prediction model, the probability of an M7-class Tokyo Inland Earthquake to occur is estimated to be 70% in 30 years, based on the Poisson process for the southern Kanto area.

Because of the different estimation methods, no attempt has been made to directly estimate the link between the Nankai Trough Earthquake and the Tokyo Inland Earthquake. However, both earthquakes occurred in adjacent areas and were caused by the same subduction of the Philippine Sea Plate. Following the 1854 Ansei Nankai Earthquake The Ansei Edo Earthquake occurred in 1855, causing extensive damage to Edo (present-day Tokyo). Although it is scientifically difficult to predict how the Nankai Trough Earthquake and Tokyo Inland Earthquake would occur in this century, we should consider the worst-case scenario, in which both earthquakes would occur in the first half of the 21st century in close temporal proximity, as a premise for disaster risk reduction policies.

(3) Potential Losses and damagees from the Nankai Trough Earthquake and Tokyo Inland Earthquake

The Government of Japan has released two damage estimates for the Nankai Trough Earthquake and the Tokyo Inland Earthquake. Regarding the Nankai Trough Earthquake, the earthquake of magnitude 9.0 was assumed to be the most significant earthquake scenario after the 2011 Great East Japan Earthquake, with the following worst-case losses and damages: 323,000 fatalities, 623,000 injuries, 1,346,000 destroyed buildings, 750,000 burnt down buildings and an economic loss of 214.2 trillion yen [8].

The worst-case scenario for the Tokyo Inland Earthquake in 2013 assumed an earthquake of magnitude of 7.3, similar to the 1995 Great

Hanshin-Awaji Earthquake, with the epicenter in the southern part of central Tokyo, causing the following worst-case losses and damages: 23,000 fatalities, 123,000 injuries, 175,000 destroyed buildings, 412,000 burnt down buildings, and an economic loss of 95.3 trillion yen. The number of evacuees is estimated to be up to 7.2 million people [9].

Given these two cases, simple total damage would result in approximately 350,000 fatalities, and more than 300 trillion-yen in economic losses. The largest disaster in Japan following natural hazards since World War II was the 2011 Great East Japan Earthquake, a landscape-scale disaster in which the Disaster Relief Law [10] was applied to 241 municipalities, resulting in 19,294 fatalities or missing people, 126,500 buildings destroyed, 400,000 people evacuated, and 17 trillion yen in direct losses. The catastrophic disasters described above would have been far greater than the 2011 Great East Japan Earthquake.

The 1923 Great Kanto Earthquake, the largest disaster in Japan's history, caused damage worth 5.5 billion yen, which is more than three times the general budget of 1.47 billion yen at the time, according to "Tokyo Daishinsairoku Zensho" (1926), edited by the Tokyo City Office. The upcoming catastrophic disasters would be comparable in scale to the 1923 Great Kanto Earthquake, where the expected damage of over 300 trillion yen is more than three times larger than the general budget for FY2022, which is 107.6 trillion yen.

(4) Effects of extreme weather owing to climate change

Weather-related disasters have become more frequent, widespread, and severe in Japan since 1980. Japan began experiencing widespread disasters such as the torrential rains in July 2018 (West Japan), Typhoon Hagibis in 2019, and the torrential rains in July 2020 [11]; consequently, the Disaster Relief Law was applied to more than 100 municipalities simultaneously.

Because unprecedented rainfall and giant typhoons owing to extreme weather may occur every year, and will continue on a global scale over a long period, they may compound and exacerbate catastrophic disasters such as the Nankai Trough Earthquake and Tokyo Inland Earthquake.

In response to increasingly frequent, widespread, and severe weather-related disasters, the Ministry of Land, Infrastructure, and Transport established reducing exposure to disasters and increasing the capacity for advanced evacuation and disaster recovery by devising land use and the way of living [12], in addition to improving local flood reservoir capacity, as new measures. Particularly in three metropolitan areas (Kanto, Chubu, and Kansai) located in zero-meter areas, it is essential to reinforce these measures to create a society that can mitigate widespread flood damage, and support recovery from catastrophic disasters compounded by significant weather-related disasters. Because recovery and reconstruction following a catastrophic disaster is a lengthy, time-consuming undertaking, there is a risk that weather-related disasters may render the recovery efforts futile. Over the next 30 years or so, extreme weather will significantly influence future catastrophic disasters.

(5) Issues related to long-term recovery and reconstruction.

The results of the coming Nankai Trough Earthquake and Tokyo Inland Earthquake are expected to cause huge losses and damages owing to shaking and tsunamis, with up to 300,000 fatalities or missing people, and more than 300 trillion yen in direct loss, mainly on the Pacific Ocean side from Kanto to Kyushu. However, we must consider the following issues that are expected to affect the recovery process from this disaster: (1) Paralysis of various functions of Tokyo as the capital of Japan, (2) disruption in east-west transportation capacity owing to the unavailability of the Tokaido Shinkansen and Tomei/Shin-Tomei Expressways, (3) decline in productivity owing to the destruction of industrial infrastructure spreading across the Tokai region, including areas around Lake Hamana, (4) increase in sovereign risk, which is a credit risk to the government, resulting in higher long-term interest rates on government bonds, and the depreciation of the yen, and (5) shortage of workers to meet reconstruction demand.

Additionally, the occurrence of an event with low probability but serious consequences cannot be ignored: (1) an eruption of Mt. Fuji, which erupted 49 days after the 1707 Hoei Nankai Trough Earthquake, or (2) an accident at the Hamaoka Nuclear Power Plant in Shizuoka Prefecture or the Ikata Nuclear Power Plant in Ehime Prefecture, as in TEPCO's Fukushima Daiichi Nuclear Power Plant in the wake of the 2011 Great East Japan Earthquake.

(6) Population decline worsens the effects of catastrophic disasters.

The world population has surpassed eight billion. Generally, the population continues to grow, mainly in developing countries, while the number of people in developed countries has declined [13]. Japan was also entering a phase of population decline for the first time, with its population peaking in 2008. While population pressure has been a fundamentally positive factor for national development in Japan, long-term population decline is expected to result in a decrease in national strength, exacerbating and prolonging the effects of catastrophic disasters.

The decreased working-age population owing to population decline makes it difficult to secure human resources to engage in disaster response and reconstruction projects. This also results in a reduction in public assistance capacity owing to lower tax revenue. Population aging, which will continue for some time, will result in a decline in self-help capacity owing to an increase in the number of people unable to act on their initiative. There are also concerns about reducing mutual help capacity through private networks owing to a decrease in the number of people who can help each other. Additionally, Japan has a high risk of low self-sufficiency in terms of food and energy, making it even more challenging to recover from catastrophic disasters.

3 What Past Catastrophic Disasters Teach Us about the Possible Impacts?

In 2018, the Japan Society of Civil Engineers (JSCE) published a "Technical Study Report on Countermeasures for Mega Disasters Causing "National Disasters" [14]," assessed the amount of possible damage, and evaluated the impact of measures on damage reduction quantitatively, by deploying social infrastructure development. Simultaneously, it listed the 1755 Lisbon Earthquake [15], the 1854 Ansei Tokai and Nankai Earthquakes followed by the 1855 Ansei Edo Earthquake, and the 1970 Bora Cyclone, as examples of past catastrophic disasters that could be described as "national disasters." In all these cases, this report claimed that the occurrence of a catastrophic disaster resulted in significant changes in the countries that followed. Therefore, we need to clarify what would happen in the "National Disasters" case to learn lessons for overcoming catastrophic disasters.

(1) Possible changes in a nation's state

According to history, there are several scenarios of changes in the state of a nation that can be expected as a result of catastrophic disasters. (1) The most serious scenario would be the "diaspora," or ethnic disintegration. The country will cease to exist, and its people will spread worldwide. (2) The second scenario would be "vassalization" or "colonization" by a significant foreign power, where the nation loses the right to govern. (3) The third scenario would be "regime change," which may result in a change in the domestic power structure, where the opponent party comes to power. (4) The fourth scenario would be "no significant change" in the nation's state, where there could be a slow and steady "decline in national power."

The 1854 Ansei Tokai/Nankai Earthquake and the 1855 Ansei Edo Earthquake were followed by a change in government, from the Edo Shogunate, to the new Meiji government. As indicated in this example, the impact of catastrophic disasters should be examined further as a background factor that facilitates the political power shift process.

(2) Decline in the relative status of nations worldwide

The 1755 Lisbon Earthquake is said to have triggered the decline of Portugal. When the disaster struck, Portugal and Spain were world champions. However, Portugal began showing a declining trend owing to economic competition with the Netherlands and the United Kingdom. As far as per capita GDP data from 1655 to 1855 are concerned, personal income was still at its economic peak even after the Lisbon Earthquake (Maddison Project Database 2020) because of the reconstruction efforts of the Marquis of Pombal, who served as the premier after the earthquake. Per capita GDP declined rapidly by less than half after he lost his position. There are various theories on Portugal's decline. We await further empirical research on the impact of the Lisbon Earthquake.

4 What is disaster resilience?

The United Nations (UN) has defined disaster resilience twice, as the ability to overcome adversity. In 2009, the UNISDR (now UNDRR) defined "disaster resilience" in a glossary [16], which was expanded at the UN General Assembly in 2017 [17]. A comparison of these two definitions reveals three basic aspects of disaster resilience. (1) What entities have disaster resilience? (2) What capabilities do the entities possess? and (3) How do these entities behave in the face of adversity? Each of these was examined sequentially.

(1) Three types of entities with resilience.

These two definitions imply that three types of entities possess disaster resilience: systems, communities, and societies. In this recommendation, systems refer to humans as indivisible entities. Communities refer to all types of organizations based on human interaction. Society encompasses impersonal entities such as cities, buildings, and infrastructure; therefore, we discuss city, building, and infrastructure resilience. These three entities are not independent of each other but are interrelated.

(2) Disaster resilience is the sum of self-help, mutual help, and public help.

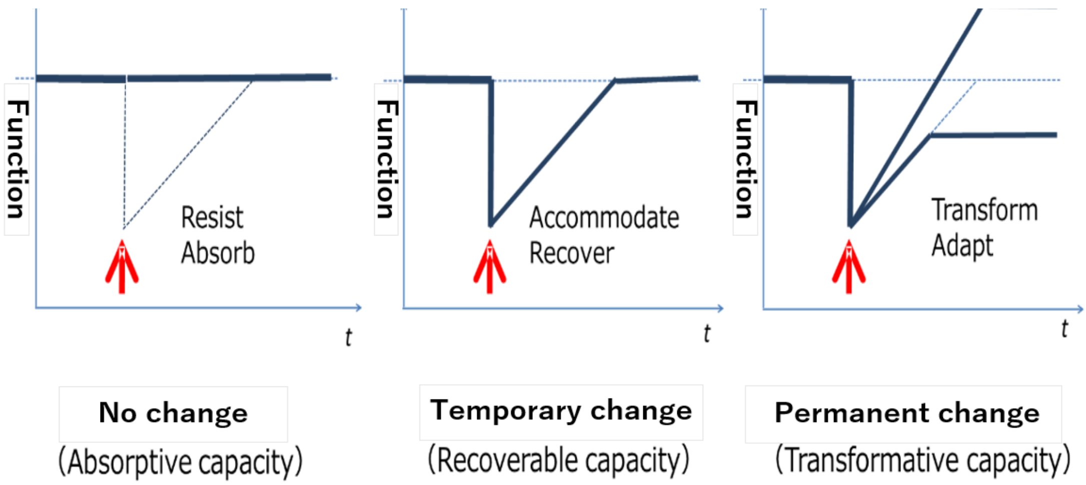
As disaster resilience is the ability of an entity to manage adversities, it consists of the interrelated capabilities of individuals, communities, and societies. In other words, disaster resilience can be operationally defined as the sum of self-help from individuals, mutual help from communities, and public help from society. The "Report of the Study Group on Community-based Comprehensive Care

[18]," which was publicized in March 2013, points out that "self-help, mutual help, and public help" have five elements. This report points out two types of mutual help: help provided through private human networks (family, relatives, friends, volunteers, etc.), and help provided through systems (insurance, mutual aid), The report also points out two types of self-help: help based on spontaneous activities of individuals, and purchasing market services. Public help is defined as help from tax money based on laws. This five-element model used in the welfare sector is relatively unique in the sense that the purchase of market services is included as a type of self-help to serve as the support to enable people to be as independent as possible. This model may be applicable to disaster resilience.

(3) The entity exhibits three types of behaviors

The UN 2017 definition lists six types of responses to a hazard: "resist, absorb, accommodate, adapt to, transform, and recover from." These six responses can be broadly classified into the three types shown in the figure below: (1) no change (resist, absorb), (2) temporary change (accommodate, recover), and (3) permanent change (adapt, transform).

Figure Three types of resilience behavior as defined by UN



(Prepared by Author based on Bruneau et al. [19])

① No change (resisting or absorbing) occurs when the entity can absorb the effects of the hazard, and no outward change appears in contact with the hazard. This is the case when disaster resilience is very high, or the hazard is not very strong. This ability is referred to as "absorptive capacity.

② A temporary change (accommodating or recovering) occurs when a temporary loss of functionality occurs in the face of adversity. This triggers activities that restore functionality as soon as possible. Such a temporary change and subsequent recovery in response to a hazard appears to be a model case of disaster resilience. This ability is referred to as ″recoverable capacity.

③ Permanent change (transforming or adapting) is a newly added behavior in the 2017 definition. An entity moves to a new state after a temporary loss of function in the face of adversity. If the hazard is too severe, the entity may not fully recover. However, it may move to a new state with improved functionality, triggered by distress, referred to as ″transformative capacity ″ [20]. One example of transformative capacity is ″Build Back Better [21]," one of the priority actions of the 2015 Sendai Framework for Disaster Reduction adopted after the 2011 Great East Japan Earthquake. Another example is ″Creative Reconstruction [22]" after the 1995 Great Hanshin-Awaji Earthquake.

Which of these three types of behaviors is manifested depends on both the hazard intensity and resilience level of the entity The identity of the entity is assumed to be maintained, regardless of the type of manifested response.

5 What Should We Do to Overcome a Catastrophic Disaster?

It is impossible to completely prevent the expected damage in the time remaining before a disaster strikes. All stakeholders must focus on ″resilience,″ which includes streamlining and improving the efficiency of emergency response, recovery, and reconstruction processes after a disaster strikes, in addition to prevention and mitigation. By maximizing the scientific and technological expertise accumulated to date, it is necessary to proactively improve preparedness to minimize suffering and enable rapid recovery after a disaster. Achieving these goals requires 'consilience' that enables the improvement of disaster resilience by integrating the knowledge of disasters as natural phenomena and that of disasters as social phenomena.

(1) Japan has high disaster prevention capabilities.

Many countries worldwide have low priorities for disaster risk reduction, believing that all they need to do is dispatch military forces to clean up the mess, and secure international assistance if a disaster strikes. Therefore, most disaster-related investments are spent on post-disaster response, recovery, and reconstruction, with only a small amount spent on proactive preparedness for disaster risk reduction (DRR). As an advanced country in the DRR, Japan has endorsed the UN's goal of improving its preparedness. Consequently, the 2015 Sendai Framework for Disaster Risk Reduction emphasizes the importance of a systematic, peacetime approach to DRR.

(2) Improve disaster resilience.

However, the devastating damage caused by the 1995 Great Hanshin-Awaji and the 2011 Great East Japan Earthquakes proved that Japan's damage deterrence capacity needs to be improved. Although seismic strengthening effectively prevents structural damage, it requires an enormous amount of time to complete. Therefore, there is a practical need to improve the "ability to overcome disasters," which includes disaster response, recovery, and restoration, namely disaster resilience, given the currently anticipated damage owing to the coming catastrophic damage.

Helping a society recover from a disaster is a matter of social phenomena that has not yet been sufficiently examined scientifically. Therefore, there is an urgent need to develop an empirical research program on "disasters as social phenomena" vigorously.

(3) Adopt an all-hazards approach

Although research on disaster forecasting and prevention has been conducted using a hazard-specific approach, perceiving disasters as natural phenomena, an all-hazards approach can be applied to the process of recovering from disasters as a social phenomenon. This is because the disaster recovery process has the following common objectives:

(1) Protecting the lives and livelihoods of affected people

(2) Maintaining important social and economic functions.

(3) Early recovery and reconstruction after physical damage.

In recovery from a disaster, there exists a case in which there is no physical damage to some hazards, as in the case of the COVID-19 pandemic.

In the all-hazards approach, disaster response is generic in terms of three common objectives that can be applied to any hazard. Specific responses are articulated depending on the events created by the nature of the hazard at stake. The all-hazards approach is considered useful for systematizing possible resulting events based on all types of past catastrophic disasters.

The first set of resulting events to be reviewed would be past examples of catastrophic earthquake disasters. In Japan, these include the 1703 Genroku Earthquake, 1707 Hoei Nankai Trough Earthquake, and Mount Fuji eruption, 1854 Nankai Trough Earthquake and 1855 Ansei Edo Earthquake. The 1923 Great Kanto Earthquake is well documented; therefore, we can comprehensively examine all the events, from the occurrence of the disaster, to the completion of long-term recovery. There are also numerous examples worldwide, including the 1755 Lisbon Earthquake, the 1906 San Francisco Earthquake, the 1948 Turkmenistan-Ashgabat Earthquake, the 1985 Mexico Earthquake, and the 2010 Haiti Earthquake.

The next set of resulting events would be lessons learned from catastrophic disasters caused by hazards other than earthquakes. For example, studies on weather-related disasters, such as the 1970 Bhola Cyclone, which led to Bangladesh's independence, can provide valuable empirical knowledge. The global coronavirus disease (COVID-19) pandemic, which began in 2020, also offers extensive knowledge regarding international-scale disasters.

In an analysis focusing on the resulting events, it is essential to examine these measures to prevent damage and comprehensively recover from the disaster. It is also important to consider them as a package of measures aimed at total optimization rather than partial optimization. It is further necessary to realize multiple lines of defense, in which various measures are integrated to work redundantly by integrating so-called "hard" measures, such as facility and equipment maintenance and stockpiling of materials and equipment, with a wide range of "soft" measures including planning, training, and human resource development.

(4) Preparing for catastrophic disasters that have never been experienced

A "Trillion-Dollar Disaster" is a devastating disaster on a scale never experienced by humanity. In other words, the question is how to prepare for a disaster that has not been experienced before.

During past earthquake disasters, enormous damage occurred when struck by unexpected or greater-than-expected hazards. An example of an unexpected hazard that resulted in a major disaster is the 1995 Great Hanshin-Awaji Earthquake, an inland earthquake near a large urban area. An example of a larger-than-expected earthquake is the 2011 Great East Japan Earthquake, which caused a massive tsunami of Mw=9.0. We must ensure the capacity to manage unexpected or greater-than-expected disasters.

In addition to hazard prediction, societal change owing to various scientific and technological innovations may result in unforeseen and devastating damage because catastrophic disasters are low-frequency, high-impact events with long intervals between them. Most of the science and technology that support society must be tested to determine the impact of catastrophic disasters. For example, the 1923 Great Kanto Earthquake demonstrated the vulnerability of Western-style brick buildings, which were believed to be the most advanced at the time, in contrast to the superior disaster resistance of reinforced concrete (RC) construction [23]. The 1995 Great Hanshin-Awaji Earthquake also demonstrated the excellent earthquake resistance of prefabricated houses [24]; the 2011 Great East Japan Earthquake further proved the effectiveness of information dissemination via the Internet in the recovery process [25]. Most of the science and technology in use currently awaits verification for catastrophic disasters with rapidly changing economic conditions, demographic trends, and international relations. It is necessary to critically evaluate scientific and technological innovations considering the possibility of a catastrophic disaster.

(5) New self-help, mutual help and public help

Public help is believed to play a major role in disaster response. There are concerns about the downward trend in future "public help because of both the huge Japanese budget deficit and decreased tax revenues owing to the decline in the working-age population. It is suggested that more active participation of all stakeholders is necessary to overcome upcoming catastrophic disasters. Accordingly, there is need to reconstruct the relationships among self-, mutual, and public help, to foster the active participation of all stakeholders.

The active participation of all stakeholders must be premised on the dignity of risk, where those who participate make decisions based on risk-informed self-determination [26]. It is important to create a society that respects this value, in the sense that everyone should make decisions based on the premise that their choices may be detrimental to them. This makes people's choices more serious and prudent. Developing disaster risk-reduction measures based on risk dignity is necessary to achieve resilience and overcome catastrophic disasters.

6 Measures to prevent catastrophic disasters from becoming national disasters

At the 3rd UN World Conference on Disaster Risk Reduction in 2015, the Sendai Framework for Disaster Risk Reduction was adopted as the primary document for global disaster risk reduction until 2030, in which four priority actions were elaborated as the basic framework for DRR measures. This study proposes recommendations for resilience and sustainability beyond catastrophic disasters based on four priority actions: (1) elucidating disaster risk, (2) establishing new governance to manage disasters, (3) investing financial expenditure, capacity development, and technological development in response to disasters, and (4) establishing proactive measures to enable "building back better". The main issues to be addressed are as follows.

(1) Elucidating disaster risk

Science aimed at disaster risk reduction has progressed steadily. One of the most prominent examples is the establishment of the Nankai Trough Seafloor Observation Network for Earthquakes and Tsunamis (commonly known as N-net). Japan deploys an observation network referred to as MOWLAS for earthquakes, tsunamis, and volcanic activity, which consists of over 2,100 observation points on both the land and seafloor [27] for real-time hazard information dissemination. The land observation network was established based on lessons learned from the 1995 Great Hanshin-Awaji Earthquake; the seafloor observation network was established following the 2011 Great East Japan Earthquake. The N-net, which will be implemented from 2019, on the seafloor of the Pacific Ocean from Kochi Prefecture to Miyazaki Prefecture, is expected to shorten earthquake and tsunami predictions by 20 seconds and 20 minutes. This is the first time that an observation network has been established in the ocean before a large-scale earthquake is expected to occur in future, to contribute to a significant reduction in tsunami damage from Nankai Trough Earthquake. This may be a significant achievement in current science and technology.

Although a dramatic reduction in mortality can be achieved, it is still necessary to reduce the direct damage to over 300 trillion yen. In addition to understanding hazards and exposures, disaster risk reduction requires measures based on the vulnerability and response capacity of individuals, communities, and societies in the affected region. The scientific community needs to identify the goals of each entity, and possible ways to ensure resilience to overcome the expected damage for each entity.

① Maintaining and improving individual well-being.

Improving resilience at the individual level will result in the maintenance and improvement of physical, mental, and social well-being, which is the goal of the Sixth Science, Technology, and Innovation Basic Plan. To achieve this goal, there is need to improve disaster preparedness skills individually by improving the ability to understand the risks posed by upcoming catastrophic disasters, and manage them appropriately, based on the dignity of risk in mind.

Ikeda et al. [28] list eight basic disaster preparedness skills that can be developed through disaster education. These skills can be classified into three categories: (i) knowledge of disasters, (ii) preparing for disasters, and (iii) acting in response to disasters.

Knowledge of disasters involves understanding them as natural and social phenomena. There are two approaches to learning about disasters as natural phenomena. It is important to have a theoretical understanding of geological disasters such as earthquakes and volcanoes because they are rare occurrences. It is important to understand meteorological disasters through what happened in past disasters because they occur almost yearly. Preparing for disasters encompasses two types of understanding of disasters as social phenomena that can be broadly classified into problems and issues that can be observed during a disaster, and the lessons learned in response to those problems and issues.

There are four types of actions to be taken in preparation for and response to disasters: (1) identification of local damage characteristics and response resources using a map, (2) damage prevention and mitigation actions before a disaster strikes, (3) how to protect oneself in the event of a disaster, and (4) mutual assistance during recovery from disasters. The systematization of empirical evidence relating to the above-mentioned eight aspects is an indispensable step for improving the basic disaster preparedness of individuals.

In a recommendation titled "Toward the Contribution of Psychology to Civil Society for the Future: Enhancement of Psychology Education in High Schools and Training of Licensed Psychologists [29]" by the Science Council of Japan (September 2020), the expectations of civil society toward psychology pointed out the need for scientific and empirical recognition of the human mind and behavior, the usefulness of psychological literacy for promoting well-being, and the importance of psychological assistance in mental health. Seligman (2001) listed disasters as a life-turning setback, in addition to childhood experiences and everyday messiness [30]. The World Health Organization (WHO) states that the well-being of a society can be determined by the extent to which it is resilient, able to act, and prepared to overcome hardship. [31] To promote understanding, preparedness, and action against disasters, the resilience of individuals within a society needs to be evaluated. Moreover, disaster education and basic disaster preparedness should be tailored to each individual.

② Reinforcing Mutual Aid Capabilities through Mutual help

To improve resilience at the community level, it is important to examine the nature of mutual support. Before the Industrial Revolution, resilience was based only on private mutual aid among people living in a community of approximately 250 people. The Industrial Revolution led to urbanization, which gave rise to a new type of mutual help for city dwellers. Ishii [32] reported that even in today's urban slums, mutual help remains at the center of resilience to support people's livelihoods.

As Japan enters a population decline and an aging phase, it is expected to become increasingly challenging to maintain the existing systems of self-, mutual, and public help. The aging population makes it difficult for individuals to engage in spontaneous activities. Population decline may directly affect mutual help through private networks. Public help is also more difficult owing to the decline in the working-age population. It is therefore necessary to reform self-, mutual, and public help. There are two promising options based on the five-element model of self-, mutual, and public help. The first is to improve self-help capabilities by enhancing the quality and quantity of market services. The other is to enrich system-based mutual aid mechanisms such as insurance and mutual assistance programs. No matter how large the upcoming catastrophic disaster will be, we have no other way except to rely on people's self-, mutual, or public help to overcome it. There is an urgent need to expand academic concerns on how to enhance new types of help consistent with societal changes.

③ Coherent solutions for disaster risk reduction, climate change adaptation, and sustainable development

The second phase of the Integrated Research on Disaster Risk (IRDR) Program [33], sponsored by the International Science Council (ISC) and the United Nations Office for Disaster Risk Reduction (UNDRR), which began in 2021, recommends the promotion of integrative science to achieve "risk-informed sustainable development and planetary health." This clearly links disaster risk reduction to sustainable development. It also expresses a sense of crisis that population growth and urbanization will exceed the limits of the Earth's capacity to absorb their impacts and ultimately undermine human health. This view reflects the basic recognition that disaster risk reduction, climate change adaptation, and sustainable development are closely interrelated at their core, to form a systemic risk, although they appear to be seemingly independent social issues.

The increase in population and urbanization has continued since the Industrial Revolution, making disaster risk reduction, climate change adaptation, and sustainable development closely interrelated social issues. Since 1980, the increase in artificial materials and massive burning of fossil fuels have caused global warming [34], biodiversity loss [35], and an increase in the number of disasters, such as floods and extreme weather events, [36]. Owing to economic globalization, the impact of disasters may not be confined to a single country; they spread instantly worldwide, posing a significant threat to sustainable development on a global scale. Therefore, there is a need for academic research that challenges the future of cities, infrastructure, and social systems by viewing disaster risk reduction, climate change adaptation, and sustainable development as interrelated social issues for a coherent solution.

Overcoming catastrophic disasters is not limited to Japanese disaster risk reduction. It is necessary to address this problem on a global scale in collaboration with researchers in the fields of climate change and sustainable development. In addition to academic collaboration among related disciplines, it is essential to work with the UN and funding agencies as an international program that explores coherent solutions to the three social challenges. As an example, the recommendation titled "Toward the Realization of a Sustainable Global Society: Promoting Future Earth [37]" by the Science Council of Japan (April 2016) stated that Japan took an active leadership role in promoting this program, with a focus on environmental issues and a system to encourage interdisciplinary and trans-disciplinary research, including collaboration among researchers, practitioners, and policymakers in the international community. Accordingly, a report on integrated global environmental change in 2023 was presented [38]. These efforts must be further promoted to resolve these three social issues coherently and simultaneously.

④ Realizing consilience through an Online Synthesis System (OSS)

To promote science that views upcoming catastrophic disasters as systemic risks, it is essential to integrate existing academic fields that have been developed separately, such as disaster risk reduction, environment, and development. Therefore, we must establish methodologies and mechanisms to enable the interdisciplinary exchange and fusion of ideas.

To forecast and prevent disaster risk, academic disciplines such as natural hazards, infectious diseases, accidents, and terrorism have been established for each hazard. In contrast, an all-hazard approach, which is generic for all hazards, is adopted for emergency response after a disaster. Recovery and reconstruction may differ depending on whether the damage results from physical destruction or from reduced human activity. Although the COVID-19 pandemic is an international disaster with severe impacts, recovery efforts have focused only on rebuilding social and economic activities because there has been no physical damage. However, disasters that entail physical damage owing to natural hazards, accidents, or terrorist attacks require physical reconstruction.

For catastrophic disasters to be systemic risks, it is indispensable to consider knowledge on post-disaster risk reduction based on an all-hazard approach in addition to integrating knowledge on predictive and preventive capabilities. It is necessary to establish web-based tools that serve as platforms for all related fields to integrate knowledge from various fields. As a first step, the recommendation titled "Building a sustainable global society by strengthening disaster resilience: Developing an "Online Synthesis System (OSS) and fostering Facilitators to realize consilience" [39] by the Science Council of Japan introduced the OSS in September 2020.

The notion of OSS was first introduced in the recommendation titled "Disaster Risk Reduction and Promotion of International Research on Disaster Prevention and Mitigation - Recommendations for Implementation of the Sendai Framework for Disaster Reduction and Tokyo Statement- " [40] by the Science Council of Japan (February 2016). This recommendation proposes that it is essential for researchers, practitioners, and policymakers to improve collaboration in their native languages in monitoring, impact assessment, and literacy activities for disaster risk reduction, and to develop domestic and international partnerships to support such activities. OSS is a system that integrates various knowledge and procedures on the cloud (a system of systems) and helps all stakeholders have an accurate and comprehensive understanding of both disaster resilience and sustainable development with a deep appreciation of the causal relationship, and an effective implementation of planning, execution, and evaluation to realize coherent solutions. A web-based OSS prototype is proposed. The use of OSS, which began mainly in the field of natural disasters, should expand into total preparedness for catastrophic disasters by disseminating comprehensive knowledge to society. Consilience in disaster risk reduction should further diffuse into society, to accelerate coherent solutions to the three societal challenges: disaster risk reduction, climate change adaptation, and sustainable development.

(2) Establishing new governance to manage disasters

Governance is primarily the notion of organizing, controlling, and managing a government or corporation, as well as the mechanisms and methods for doing so. Bevir [41] points out that the concept of governance has changed over time, from an idea initially founded on "authority" as its core, adding a "market" element, to one that emphasizes "network" owing to the expansion of geographic areas, and the diversification of issues to be addressed. In the governance of disaster resilience, it is essential to review how disaster-related laws, systems, and activities are regulated and function to reduce disaster risk. Additionally, the recommendation "Social Monitoring and Archiving: Verification of the Recovery Process and Recursive Governance" [42] (September 2020) by the Subcommittee on Issues of Social Monitoring and Recovery after the Great East Japan Earthquake for the Committee on Sociology, the Science Council of Japan, points to the importance of "recursive governance," in which policies have an inherent mechanism for making minor adjustments in response to unexpected circumstances deviating from assumptions over time.

① The New Normal Implies a Transition to an Autonomous, Decentralized, and Cooperative Society

When considering disaster risk governance, we can obtain great lessons from the global pandemic, COVID-19, which started in early December 2019. In the discussion on the world after this pandemic [43], the notion of a "New Normal" was introduced as a new and irreversible trend toward realizing a society comprising autonomous communities, which could be a turning point from the trend for urbanization and centralization since Industrial revolution. We refer to this this new society as an autonomous, decentralized, and cooperative society [44]. Therefore, future studies should examine irreversible social changes.

The introduction of the New Normal has significantly advanced the adoption of telecommuting routines, the use of online conferencing, and the expansion of e-commerce (electronic commerce). The extent to which ICT-based innovations change society remains an important question. For example, the population growth in Tokyo Prefecture, which was continuous before COVID-19, experienced a decline from 2020 to 2022. To what extent do these trends continue? The irreversibility of the trend toward an autonomous, decentralized, and cooperative society should be clarified.

In an autonomous, decentralized, and cooperative society, securing water, food, energy, and shelter, which are essential elements for survival, should be considered first. These elements must be locally produced for local consumption. We must develop measures to promote a shift in local production for local consumption from the current social structure that relies on imported food and energy.

In contrast, COVID-19 has significantly accelerated the shift to everyday life relying on ICT in life domains such as work, education, medical care, and entertainment. The use of high-speed, low-latency networks opens up the possibility of developing services on a global scale. This suggests that we may not be necessarily constrained by the notion of "national boundary" as in the past. This aspect requires further investigation.

The transition to an autonomous, decentralized, and cooperative society could be a basic framework for the future of Japan, where the population is declining. This future vision is also consistent with the Cabinet Secretariat's "Digital Garden City" Initiative [45], and the new National Land Formation Plan (National Plan) and National Land Use Plan (National Plan) approved by the Cabinet in July 2023 [46]. In the transition to an autonomous, decentralized, and cooperative society, it is necessary to realize the following points, as indicated in Section 6 of this recommendation: (i) maintaining and improving individual well-being, (ii) reinforcing mutual aid capacities through mutual help, (iii) integrated solutions for disaster risk reduction, climate change adaptation, and sustainable development, and (iv) knowledge integration through OSS.

② Appropriate urban size and function in an autonomous, decentralized, and cooperative society

The transition to an autonomous, decentralized, and coordinated society will reconsider the urbanization that has continued since the Industrial Revolution. However, it is meaningless to return to the old days before the Industrial Revolution, when people lived in settlements with a population of approximately 250, lacking the basic services necessary, and which we enjoy today in our daily lives. In an autonomous, decentralized, and cooperative society, what is the appropriate urban size, and what functions do cities have? The "Grand Design of National Land 2050, Reference Material (July 2014) [47]" compiled by the National Land Policy Bureau of the Ministry of Land, Infrastructure, Transport, and Tourism indicates the desirable size of cities as "the population size of municipalities where there is a 50% and 80% probability that a service facility will be located." Based on this, a population of 50,000 to 200,000 is recommended as the appropriate size for a city with the various urban functions necessary. This recommendation suggests different challenges for metropolitan areas, regional core cities, and depopulated areas in Japan, although the solutions to these three challenges must be coherent and simultaneous.

Metropolitan areas must be transformed into urban areas that do not require long daily commutes. The current urban structure connects large central business districts with vast surrounding suburban areas through highly developed public transportation networks. This structure should be transformed to bring work and residence closer together, which would enable lifestyles with more free time. It is proposed that the urban structure is reconfigures from the current unipolar structure to an integration of basic units with a high degree of autonomy, referred to as "Cell City" with 36 km square as the basic unit (Iwasaki, 2000) [48].

Local core cities have an urban structure that closely resembles autonomous, decentralized cities in terms of population size. There is need for further commitment to expand local production for local consumption to further meet basic survival needs. Transportation and communication networks must also be improved to enhance services in the domains of work, healthcare, education, and entertainment to further provide a higher quality of life.

Depopulated areas will increase further owing to the ongoing population decline. Consequently, the cost of maintaining social infrastructure per capita would increase in those regions. This might necessitate making strategic contraction an option for the near future. In contrast, it is desirable to improve the self-sufficiency of food and energy by transforming current agriculture, forestry, and fishery businesses into a "sixth industry" that uses the rich nature of these regions as joint social capital [48]. A similar argument was made in the recommendation titled "Creating an 'Inochi-machi' (town of life) " through national land formation utilizing green infrastructure against increasingly severe disasters caused by climate change [50] by the Science Council of Japan (August 2020).

③ Transnational resilience

There is need to need to improve the resilience of our land, sea, nation, and people to improve resilience and overcome upcoming catastrophic disasters. However, it is not necessarily a good idea to consider all the predicaments resulting from a catastrophic disaster. Instead, transnational resilience should be considered, in which multiple countries cooperate as partners. As an example, the Science Council of Japan's "International Commission on Science and Technology for a Sustainable Society, Subcommittee 2022" discussed transnational resilience, focusing on public health and social welfare during disasters under the theme of "disaster and health" [51].

Helping each other across national borders is not limited to enhancing international humanitarian aid in the emergency period immediately after a disaster strikes. The question is "Can we create a forum where many countries can collaborate to seek ways to reduce future disaster risks, adapt to climate change, and ensure global sustainability as we recover from this catastrophic disaster in

Japan?" In other words, it is an international challenge for every country that can hinder sustainable development. To have a positive answer to this challenge, Japan must become a so-called "country worth being helped." It is also necessary to increase the number of countries that assist Japan.

To realize coherent disaster risk reduction, climate change adaptation, and sustainable development, Japan must clarify its position in the world to enhance the value of coherence, and induce international governance where the international community can cooperate in times of crisis. Accordingly, Japan, in both the public and private sectors, must maintain its actions and contributions to the international community.

④ Activate risk communication

Upcoming catastrophic disasters would cause extensive physical damage in addition to emotional and socioeconomic hardship over a wide area and may prompt many people to seriously reconsider society's nature as it exists. The transition to a new society may be prescribed by the speed of the renewal of the society, which may take a long time. Opportunities for social change, such as the new normal after COVID-19, may emerge abruptly. There is a strong possibility that an upcoming catastrophic disaster will trigger the transition into a new society.

What matters is how much discussion about what kind of society people would like to have before a catastrophic disaster strike. Therefore, it is necessary to vitalize risk communication. Active and transdisciplinary discussions should be facilitated both domestically and internationally, through an inclusive process that allows people from various backgrounds and positions to participate. We began this discussion with the Japanese Science Council. This issue should be elevated to a national debate. In this discussion, we must foster facilitators and continuously consider how we can contribute from an academic standpoint, including establishing disaster risk communication science using OSS. Proactive measures must be taken to ensure better preparedness before a disaster strikes, and to ensure appropriate responses.

(2) Investing in financial expenditure, capacity development, and technological development against disasters

The third priority action of the Sendai Framework for Disaster Reduction is an investment in disaster reduction. The Framework states, "Addressing underlying disaster risk factors through disaster risk-informed public and private investments are more cost-effective than reliance on post-disaster response and recovery primary, and it also contributes to sustainable development." [52] As Japan enters a phase of population decline for the first time in modern history, there is need to reconsider our past approach to investments based on population growth. Considering the decline in the productive population, there is need to enhance the resilience of individual level to engage in disaster response efficiently and effectively, with a smaller number of people using digital transformation (DX). There is need to find ingenious ways to overcome problems caused by population decline, by considering the new areas and new way of investment.

① Decrease in human activity and asset accumulation at the risk of disaster exposure

The first question to be considered is how to actively reduce hazardous exposure. There is an urgent need to reduce and relocate human activities and asset accumulation at high risk of exposure to catastrophic disasters to safer locations, as much as possible. During rapid population growth in Japan since the Meiji restoration in 1868, human activities and asset accumulation in high-risk areas have continued owing to the scarcity of suitable residential areas. We should consider the remaining time before catastrophic disasters as an opportunity to reduce exposure at high risk using population decline.

According to available data, Nankai Trough Earthquakes have occurred almost every century since the 684 Hakuho Earthquake. This suggests that it is necessary to not only consider overcoming the disasters caused by the Nankai Trough Earthquakes in this century, but also consider the 22nd century and beyond. A medium- to long-term spatial reorganization plan should be formulated to ensure the maintenance of basic functions and the business continuity of critical social infrastructure.

Risk is defined by the following three factors: hazard, exposure, and vulnerability. Hazard prediction has become a reality in current disaster risk reduction owing natural hazards. There is need to explore the possibility of reexamining the urban structure to reduce exposure as a countermeasure that would have a wide range of long-term effects, in addition to continuing efforts to reduce vulnerability to each hazard. Future research should focus not only on seismic risk, but also on the effects of climate change by adopting an all-hazards approach.

② Greater investment by the private sector to improve resilience

The next consideration is the enhancement of investment, which directly results in improved resilience. Resilience is defined operationally as the sum of self-, mutual, and public help. This definition indicates a future direction for improving resilience in Japan in the face of population decline. First, as the Japanese population continues to age, it will become more difficult for the elderly to engage in spontaneous disaster risk reduction activities. The continuous decrease in the population makes it challenging to maintain mutual help through private networks, which is a form of benevolent assistance. Reducing tax revenues owing to the decline in the working-age population [53] also makes it difficult to maintain public help. In summary, two measures are essential to improve resilience under population decline: (1) expansion of the quality and quantity of market services that contribute to self-help and their support, and (2) enhancement, diversification, upgrading, and dissemination of insurance and mutual aid programs, which are mutual assistance through systems. Because both measures are regarded as activities mainly undertaken by the private sector, an increase in investment in these areas will be the deciding factor for the future improvement of resilience. Therefore, realizing "market" type governance is important, encompassing more active involvement of private businesses to help solve social issues.

A barrier to this is the separation of emergency situations from non-emergency situations or regular times. Therefore, products for disaster risk reduction should be used only in the event of disasters. Because the opportunities and scope of such products have limited use, it may be difficult for the private sector to invest in something that cannot be used regularly. Resilience, however, is the ability to prevent hazardous impacts as much as possible, and recover from them as quickly as possible. Resilience does not distinguish between emergency and non-emergency situations by continuously reducing the negative impacts of adversities as in the case of insurance. The rapid acceleration of the digitalization of society is promising in the sense that it links emergency situations with non-emergency situations smoothly, which may provide for the private sector to promote the notion of a ″resilient lifestyle [54]″ as a new comprehensive and sustainable business opportunity to help solve social issues and yield profits.

(4) Establish proactive measures to enable ” Build Back Better”

The final priority action of the Sendai Framework for Disaster Reduction is to achieve emergency preparedness and ″Build Back Better.” The question is, what can be done to rebuild Japan into a more resilient and sustainable country in preparation for upcoming catastrophic disasters, that is, what can be done to enhance the transformative capacity of a society facing hardship to use it as an opportunity to build a better society?

① Disasters as an opportunity to build a new society

The lesson of the 1995 Great Hanshin-Awaji Earthquake and the 2011 Great East Japan Earthquake was that ″in times of emergency, we can only do what we usually do.” This bitter lesson means that transformative capacity is the ability to solve problems with a clear and drastic plan prepared before the event strikes to create a better and different society within a short period after the onset of the event. Without such a plan, disaster victims would adhere to realizing their desire to “return to the way they were before the event."

When leaders prepare such a plan in advance, disasters may provide an opportunity to transform society. The most famous example is the proposal of the Imperial Capital Renewal Plan [55], referred to as the "Tokyo Municipal Government Outline," by the then Minister of Home Affairs Mr. Shinpei Goto at the time of the 1923 Great Kanto Earthquake. Based on the plan he formulated when he was the mayor of Tokyo, which had not yet been realized, he submitted his reconstruction plan to the Diet within the first week of the earthquake. Subsequently, his reconstruction plan was implemented, with some reductions in scope. Consequently, the basic structure of the current central Tokyo area was established at this time, and the idea is still established today, 100 years later.

Similar examples of prior preparation reflected in recovery plans include Kobe City during the 1995 Great Hanshin-Awaji Earthquake [56] and Ojiya City during the 2004 Niigata Chuetsu Earthquake [57]. In both cases, the cities were hit by earthquakes when comprehensive plans were underway. Both plans were near completion with active citizen participation in the years when the earthquakes struck. Although officials in both cities felt that all preparations for their comprehensive plans would be wasted owing to the disasters, the completed reconstruction plans showed that most of the content from the previous comprehensive plan was reflected in the recovery plan, with some additional lessons from the disasters.

In all three cases, an earthquake was used as a trigger to activate preparations. Additionally, in all three cases, the time available to freely decide the direction of recovery after a disaster was very short, only approximately the first two weeks after the occurrence of a disaster. Because the time to implement preparations is limited to a very short period, and in the early stages of disaster recovery, it is critical to determine how quickly the leadership team makes decisions for transformative recovery from the catastrophe.

In the 2022 "White Paper on Disaster Prevention," the Working Group on Pre-Disaster Prevention and Complex Disasters, consisting of experts established in the Cabinet Secretariat, made recommendations regarding future policy directions in anticipation of the coming

Nankai Trough Earthquake and Tokyo Inland Earthquake [58]. To improve transformative capacity, it might be a good starting point to critically evaluate the effectiveness of these recommendations, with the broad participation of all stakeholders as the basis for a transformative plan.

② Promote new proactive measures using DX.

If we can only do what we usually do during a disaster, we should actively consider improving our resilience through what we typically do. An upcoming catastrophic disaster will never be on a scale before that experienced by humankind, and it will be difficult to predict what may happen accurately. The use of digital twins [59], such as collecting information and data from the real world through IoT, reproducing the same conditions and situations as in the real world in digital space, and the quality of disaster response in unprecedented situations, is expected to be improved by the use of ensemble simulation [60] [61] as well as an advanced and comprehensive computational method.

Given the assumption of a generic framework for disaster response simulations, it may be useful to construct simulations based on frequently experienced weather-related disaster responses. It provides basic experiences for trainees to learn about possible resulting events through cases of high-frequency disasters. It is also important to learn about the unique consequences of earthquakes and tsunamis simultaneously.

Owing to the effects of extreme weather caused by climate change, weather-related disasters have intensified and become more widespread since the beginning of the 2010s. Wide-area weather-related disasters that simultaneously affect multiple prefectures have been occurring every yearly: 110 municipalities were affected by torrential rains in western Japan in 2018, and 390 municipalities by Typhoon Hagibis in eastern Japan in 2019 in terms of the number of municipalities to which the Disaster Relief Act was applied. It is estimated that the Disaster Relief Law will be applied to 707 municipalities in the coming Nankai Trough Earthquake, and that we should actively apply the experiences gained through weather-related disasters to upcoming wide-area earthquake disasters.

It is necessary to standardize disaster response to make nationwide mutual support possible to realize effective disaster response in a wide-area disaster where multiple prefectures are affected simultaneously. This suggests that the national government of Japan should build on the progress of ICT, to establish a nationwide standardized disaster response system to further implement an emergency response DX on the cloud. Over 1,700 municipalities can use this system for real disaster responses as well as drills and exercises. Using this cloud system, all municipalities can conduct coordinated, effective, and efficient disaster responses and exercises. By utilizing this system for frequent weather-related disasters that have occurred in recent years, disaster response can be continuously upgraded by common visualization of the damage, common disaster response, and a real compilation of actions, questions, and answers in the database as the source for further decision-making. Promoting the creation of a nationwide ICT environment is indispensable as an effective and proactive measure to respond to upcoming catastrophic disasters.

③ Advance Presentation of Recovery Vision

By citing the examples of Tokyo City after the Great Kanto Earthquake, Kobe City after the Great Hanshin-Awaji Earthquake, and Ojiya City after the Chuetsu Earthquake in the Niigata Prefecture, we introduced the importance of preparing for the physical reconstruction of impacted areas. We showed that the large-scale destruction caused by catastrophic disasters creates new social structural realizations. However, in each case, the time available to step into this transformation was limited to the short period immediately after the disaster. Preparation before a disaster strike is essential to make use of this limited opportunity. Moreover, there is need to establish a system to ensure and improve transformative capacity that can use disasters as an opportunity to build a new society.

To this end, it is essential to present a vision of society that should be realized after a catastrophic disaster (sustainability, green energy/zero carbon, national land planning, transition to an autonomous, decentralized, and cooperative society that leads to the realization of fiscal, economic, industrial, and international cooperation, etc.). It is necessary to construct and clarify a vision for reconstruction that is consistent with the social vision presented above beforehand, and all relevant organizations need to start preparations for its realization.

７　Recommendations - What Should We Do with the Remaining Time? -

To acquire resilience to overcome catastrophic disasters of the scale estimated by the government of Japan, all stakeholders should continue their efforts not only to prevent damage, but also to focus on scientific studies and practices promoting disaster response and recovery. In the following sections, we propose measures to be taken consistent with the four priorities for action in the Sendai Framework for Disaster Risk Reduction 2015-2030.

（１）Elucidating disaster risk

・To establish science and technology for improving disaster resilience and the sustainability of societies with three ultimate goals: 1) maintaining and improving the physical, mental, and social well-being of individuals, 2) reinforcing the capacity for mutual support in communities, and 3) the coherent realization of disaster risk reduction, climate change adaptation, and sustainable development in society.

・To develop a disaster management system with an all-hazards approach, conversing multi-disciplinary knowledge covering all phases of disaster management, including forecasting, prevention/mitigation, early warning, emergency response, and recovery/restoration.

・To realize the consilience of knowledge for disaster resilience using information infrastructure to disseminate to society according to the Recommendation titled “Developing an Online Synthesis System

(OSS) and fostering Facilitators to realize consilience” from Science Council of Japan in 2020.

（２）Establishing new governance to manage disasters

・To establish the governance contributing to the transition to an autonomous, decentralized, and cooperative society as suggested by the irreversible changes caused by the COVID-19 pandemic.
・To ensure transnational resilience where multiple countries cooperate in addition to improving the national resilience of land and sea, sovereignty, and the people of each country.
・To stimulate risk communication on catastrophic disasters nationally and globally, starting with discussions at the Science Council of Japan.

（３）Investing in financial expenditure, capacity development, and technological development during disasters

・To establish the role of investment in reducing human activities and asset accumulation at risk exposed to disasters such as medium to long-term spatial reorganization plans, and maintenance of critical social infrastructure.
・To promote the concentrated investment in the (1) improvement of qualitative and quantitative enhancement of market services to improve self-help capacity and (2) enhancement and diversification of insurance and mutual aid programs, to further provide mutual assistance aid based on the system.
・To enhance individual and grassroots community resilience capabilities to deploy strategic capacity development programs to respond to disasters more efficiently, and effectively utilizing digital transformation (DX).

（４）Establishing proactive measures to enable “Build Back Better”

・To reinforce the transformative capacity to build a new society after a disaster with the awareness that "in an emergency, we can only do what we normally do," as well as a system that promotes proactive measures using DX.

・To present a vision of society after a catastrophic disaster (sustainability, green energy/zero carbon, national spatial planning, transition to an autonomous decentralized and cooperative community in terms of finance, economy, industry, international cooperation, etc.)

Glossary

(1) Ensemble simulation

Ensemble modeling is a process in which multiple diverse models are created to predict an outcome using either many different modeling algorithms or different training datasets. The ensemble model then aggregates the predictions of each base model, resulting in a final prediction of the unseen data. The motivation for using ensemble models is to reduce the generalization error of the prediction. If the base models are diverse and independent, the prediction error of the model decreases when the ensemble approach is used. This approach seeks the wisdom of crowds when making predictions. Although the ensemble model has multiple base models within the model, it acts as a single model. Most practical data mining solutions utilize ensemble modeling techniques.

Reference: Vijay Kotu: Bala Deshpande PhD, in Predictive Analytics and Data Mining, 2015

(2) Well-being

Well-being is a positive state experienced by both individuals and society. Similar to health, it is a resource for daily life and is determined by social, economic, and environmental factors. Well-being encompasses quality of life and the ability of people and societies to contribute to the world with a sense of meaning and purpose. Focusing on well-being supports tracking the equitable distribution of resources, overall thriving, and sustainability. A society's well-being can be determined by the extent to which it is resilient, builds a capacity for action, and prepares to transcend challenges.

Reference: WHO: Glossary of Terms, 2021.

(3) All-hazard Approach

An all-hazard approach addresses capabilities-based preparedness to prevent, protect against, respond to, and recover from terrorist attacks, major disasters, and other emergencies.

Reference: FEMA, National Preparedness Guidelines, September 2007

(4) Disaster risk governance

・The system of institutions, mechanisms, policy and legal frameworks, and other arrangements to guide, coordinate, and oversee disaster risk reduction and related areas of policy

・Annotation1: Good governance needs to be transparent, inclusive, collective, and efficient to reduce existing disaster risks and avoid creating new ones. The system of institutions, mechanisms, policy, legal frameworks, and other arrangements to guide, coordinate, and oversee disaster risk reduction and related areas of policy.

・Annotation2: Good governance needs to be transparent, inclusive, collective, and efficient to reduce existing disaster risks and avoid creating new ones.

Reference: UNDRR Terminology,
https://www.undrr.org/terminology/disaster-risk-governance

(5) Green Energy

Green power is generated from renewable energy sources that satisfy the following conditions.

The details are based on the methodology (Methodology for Green Power Type) separately determined by the committee.

(a) Power generation must not be based on fossil fuels such as oil, coal, or natural gas.

(b) Electricity shall not be generated by nuclear power.

(c) The emissions of greenhouse gases and toxic gases such as sulfur and nitrogen oxides during power generation must be zero or significantly less.

Currently, power generation methods that satisfy the above conditions are as follows:

(i) Wind-power generation

(ii) Photovoltaic Power Generation

(iii) Biomass power generation

(iv) Hydroelectric power generation

(v) Geothermal power generation

(vi) Fossil-fuel-biomass co-firing power generation

Reference: Agency for Natural Resources and Energy: Green Energy CO2 Reduction Equivalent Certification System Operation Rules, 2021. https://www.enecho.meti.go.jp/category/saving_and_new/green_energy/newenergy/geco2_iinnkai/31ref1.pdf (Japanese)

(6) Systemic risks

Systemic risk refers to the risk that the insolvency of an individual financial institution or dysfunction in a particular market or settlement system will spread to other financial institutions, markets, or the financial system overall.
Individual financial institutions are interconnected through various transactions and fund settlements in the settlement network.

Reference: Bank of Japan: What is systemic risk？
https://www.boj.or.jp/about/education/oshiete/kess/i06.htm (Japanese)

(7) Zero Carbon

The term "zero carbon" refers to the overall reduction of greenhouse gas emissions, such as carbon dioxide (CO_2), and methane (CH_4), which are gases that help keep the earth warm, and are emitted when we produce electricity and drive gasoline-powered vehicles.

Reference: Kansai Electric Power Group. What is Zero Carbon?
https://media.kepco.co.jp/_ct/17528022 (Japanese)

(8) Sovereign Risk

Sovereign Risk refers to the credit risk of a nation (country), specifically the possibility that government bonds or agency debt will be downgraded or defaulted. When this risk increases, it affects the supply-demand balance for government bonds and other securities, causing long-term interest rates to rise, often resulting in a decline in investment and consumption.

Nomura Securities Co., Ltd.: Sovereign Risk, Glossary of Securities Industry Terminology
https://www.nomura.co.jp/terms/japan/so/s_risk.html

(9) Digital Transformation

Digital transformation refers to how a company responds to disruptive changes in its external ecosystem (customers and markets), while driving changes in its internal ecosystem (organization, culture, and employees).

The third platform (cloud, mobility, big data, analytics, and social technologies) drives new products, services, and business models through online and real-world applications.

Transform customer experiences online and in the real world through new products, services, and business models.

(big data, analytics, and social technologies) to create value and establish competitive advantage by transforming the customer experience online and in the real world through new products, services, and business models.

Reference: Ministry of Economy, Trade and Industry Study Group for Digital Transformation: DX Report, 2018
https://www.meti.go.jp/shingikai/mono_info_service/digital_transformation/pdf/20180907_03.pdf (Japanese)

(10) The New Normal

The spread of the new coronavirus infection has causes significant changes in the social economy of Japan. The rapid spread of the new coronavirus infection and the declaration of a state of emergency issued on April 7, 2020, triggered the rapid development of telework, telemedicine, and distance education. Under these circumstances, the transition to the "new normal," a new way of life in the so-called "with Corona" and "after Corona," came to be called for.

The "with Corona" and "after Corona" lifestyles, or the "new normal," were being sought. However, when the emergency was lifted on May 25, 2020, there was a movement to return to the "old normal.

Cabinet Secretariat, Advisory Council on the Use of IT in the New Normal Era: Advisory Council on the Use of IT in the New Normal Era Final Report, 2020.
https://www.cas.go.jp/jp/seisaku/new_normal_it/pdf/saishuuhoukokusho.pdf (Japanese)

(11) Facilitator

In the narrowest sense, it means "a person who works to make a meeting effective, who facilitates the smooth running of the meeting, and who manages the process of proceedings." In the broadest sense, it means "a person who works to support and facilitate an organization's creation, change, problem-solving, consensus building, and learning while creating opportunities for knowledge creation of all kinds and facilitating the process of such creation. A person who promotes the process.

Reference: NPO Japan Facilitation Association,
https://www.faj.or.jp/facilitation/application/ (Japanese)

Catalytic presence that integrates the functions of a moderator, problem-solving facilitator, and expert advisor in the field.

Reference: Science Council of Japan, Committee on International Cooperation for Promoting Science-Based Disaster Risk Reduction: Recommendation " Building a sustainable global society by strengthening disaster resilience: Developing an "Online Synthesis System (OSS)" and fostering "Facilitators" to realize consilience, 2020.

(12) Planetary health

Planetary health is a nascent concept focused on the interdependence of human, animal, and environmental health.

Defined as the health of human civilization and the state of the natural systems on which it depends, planetary health calls for urgent attention to the extensive degradation of our planet for human advancement. This concept focuses on reversing this trend by better balancing human needs with the preservation of the Earth to sustain the health and well-being of future generations. This will require a multi-disciplinary, cross-sector, and cross-border approach to change mindsets and behaviors at every level, from global to local.

Reference: The Rockefeller Foundation Planetary Health 101; Conversations on Planetary Health, 2017

1) The concept of planetary health is based on the understanding that human health and civilization depend on thriving natural systems and wise management of those natural systems. However, natural systems have been degraded more than ever in human history.
2) Environmental threats to human health and civilization are characterized by surprise and uncertainty. Our society faces clear and powerful dangers that require urgent and transformative action to protect present and future generations.
3) Current governance systems and the organization of human knowledge are inadequate to address threats to planetary health. We seek to improve governance to support the integration of social, economic, and environmental policies, and to create, integrate, and apply interdisciplinary knowledge to improve planetary health.
4) Solutions are within reach and should be based on a redefinition of prosperity that focuses on improving quality of life and health while respecting the integrity of natural systems. Therefore, societies must take the initiative to address the drivers of environmental change by promoting sustainable and equitable consumption patterns, controlling population growth, and harnessing the power of technology.

Reference: Sarah Whitmee 他：Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation-Lancet Commission on planetary health, Lancet 386, 10007 (2015).

(13) Poisson process

A Poisson process can be considered a mathematical description of a random phenomenon waiting to occur, such as waiting for a telephone call, where the course of events before a specific point in time does not affect future occurrences, and the process is uniform in time. It is a stochastic process X (t, w) ($t \geq 0$) with a continuous time variable t, where X(t+h)-X(t) is independent of the past X(s) ($s<t$) and follows a Poisson distribution with mean λh when the current time is t and $h>0$. Therefore, its sample function (which considers the number of observations as a function of t) is a monotonically non-decreasing staircase function with a jump of one.

Reference: Heibonsha: The Encyclopedia, 2nd edition, Poisson process.

(14) Risk communication

Activities to share diverse information and perspectives through dialogue, co-consideration, and collaboration among various segments of society for more appropriate risk management

Reference: Ministry of Education, Culture, Sports, Science, and Technology, Committee on Safety, Security, Science, Technology, and Social Cooperation, Measures to Promote Risk Communication, 2014.

(15) Resilience

The concept of resilience, or the ability to overcome hardship, was defined by the United Nations (UN) in 2009 by the UNISDR (now UNDRR) in a glossary of terms [15]. In 2017, the UN General Assembly expanded its definition [16] as follows (underlining was added to the 2017 definition):

"The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including the preservation and restoration of essential basic structures and functions through risk management."

Reference: UNISDR:2009 UNISDR Terminology on Disaster Risk Reduction, 2009.
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Deliberation process

2021	
July 30	Subcommittee on IRDR, Committee on Civil Engineering and Architecture and Working Group on IRDR Activity Promotion (joint meeting) (25th Term, 4th Meeting): Activity plan for the 25th term
October 21	Subcommittee on IRDR, Committee on Civil Engineering and Architecture and Working Group on IRDR Activity Promotion (joint meeting) (25th Term, 5th meeting): Draft framework of recommendations
November 9	25th Term, 5th meeting, Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture: Reports from each WG
November 6	Public Symposium: "What is Resilience to Overcome National Disasters in the 21st Century: Strategies for Building Consilience for Disaster Risk Reduction "
December 25	25th term, 3rd meeting, Subcommittee on Social Contribution to Earth and Planetary Science, Committee on Earth and Planetary Science: "How to Ensure Resilience to Overcome National Disasters"
2022	
January 6	25th term, 6th meeting, Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture: Reports from each WG
March 3	Subcommittee on IRDR, Committee on Civil Engineering and Architecture and Working Group on IRDR Activity Promotion (joint meeting) (25th Term, 6th meeting): Draft framework of recommendations

March 8	Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th term, 7th meeting): Reports from WGs
March 17	Committee on Civil Engineering and Architecture (25th Term, 8th meeting): Status of activities of committees and subcommittees
May 16	Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th term, 9th meeting): Reports from each subcommittee
May 23	Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th Term, 8th meeting): "Expression of Interest" of IRDR Subcommittee
July 7	Academic Forum "How to Ensure Resilience to Overcome National Disasters," hosted by the Science Council of Japan and co-hosted by Committee on Civil Engineering and Architecture
August 2	Subcommittee on IRDR, Committee on Civil Engineering and Architecture, and Working Group on IRDR Activity Promotion (joint meeting) (25th period, 7th meeting): Draft framework of recommendations
August 8	Committee on Civil Engineering and Architecture (25th Term, 10th meeting): Reports from Working Group and Working Subcommittee
October 17	Advice from the Scientific Advice and Response Committee
October 22	Public Symposium "How to Ensure Resilience to Overcome National Disasters that are Expected to Occur in the First Half of the 21st Century," hosted by Subcommittee on IRDR, Committee on Civil Engineering and Architecture

November 1 Subcommittee on IRDR, Committee on Civil Engineering and Architecture, and Working Group on IRDR Activity Promotion (joint meeting) (25th Term, 8th meeting)

Recommendation matters

(1) Responses from the Committee on Response to Recommendations, etc.

(2) Deliberations by the Subcommittee on Advanced Infrastructure and the Subcommittee on Social Contribution, Committee on Earth and Planetary Science

(3) Holding of JHoP Responsible Persons Meeting

(4) Discussion on the framework of recommendations

December 15 Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th Term, 11th meeting): “Expression of Interest″ of the IRDR Subcommittee

December 27 Subcommittee on Earth and Planetary Science Social Contribution, Committee on Earth and Planetary Science, (25th Term, 4th meeting): Discussion on the draft of Expression of Intention ″How to Ensure Resilience to Overcome National Disasters.”

2023

February 28 2023 Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th Term, 12th meeting)

Draft ″Expression of Intention (Recommendation) “ jointly signed by″ Subcommittee on IRDR, Subcommittee on Advanced Infrastructure, and Subcommittee on Earth and Planetary Science Social Contribution, Committee on Earth and Planetary Science.

March 1 Subcommittee on IRDR, Committee on Civil Engineering and Architecture and Working Group on IRDR Activity Promotion (joint meeting) I (25th term, 9th meeting)

(5) Domestic Component 3) Approval of Draft Recommendations related to Recommendations

August 29 Science Council of Japan Executive Committee Meeting (351st meeting)
Approved the recommendation "How to Ensure Resilience to Overcome Catastrophic Disasters."