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S-4 Comprehensive Assessment of Climate Change Impacts to Determine the Dangerous Level of Global Warming and Appropriate Stabilization Target of Atmospheric GHG Concentration

Global Warming Impacts on Japan
－Latest Scientific Findings －

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Introduction

This report is a compilation of the research results for the first three years (fiscal 2005-2007) of the Global Environment Research Fund Strategic R&D Area Project entitled “S-4 Comprehensive Assessment of Climate Change Impacts to Determine the Dangerous Level of Global Warming and Appropriate Stabilization Target of Atmospheric GHG Concentration” (abbreviated title: “Project for Comprehensive Projection of Climate Change Impacts”) being implemented by the Ministry of the Environment, Japan. This ongoing research project, initiated in 2005, has a total term of five years comprising the first period of three years followed by the second, two-year period.

Widespread impacts of climate change are appearing in the world, as described in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) released in 2007. Discussions on medium- to long-term measures to deal with these impacts have now become a focus of global attention, including at the G-8 Summit in Toyako, Hokkaido, in July 2008. For the planning of such measures, future impact projections and a clear determination of the dangerous level of global warming based on these projections are indispensable. By combining impact studies by field and synthesizing these studies using an integrated model, the objective of this report is to provide information essential for discussions on climate policies currently in progress; that is, the projection of climate change impacts on Japan and scientific findings concerning the dangerous level of global warming.

In the first part of the research term up to fiscal 2007, targeting the period up to the end of the present century while focusing on the period up to around 2050, we have made projections of climate change impacts on Japan as well as economic assessments in key fields such as water resources, forests, agriculture, coastal zones, and human health. We have also developed an integrated assessment model in order to comprehensively analyze and assess the impacts and risks, and conducted quantitative studies to elucidate the levels and regional distributions of impacts occurring in Japan as well as their rate of appearance in Japan. The results of these studies reveal that although the level of impact and rate of increase vary according to the field, severe impacts will also appear in Japan even with a relatively low temperature increase and that while impacts will vary by region, there are especially vulnerable regions for each field. These results provide the latest comprehensive findings concerning the dangerous level of global warming not only for Japan but globally as well. It is our hope that these results will be utilized on a broad scale for studies on both mitigation measures and adaptation measures, as well as for promoting widespread understanding of global warming. In the next two-year period, we will make efforts to provide even more useful findings by further improving the projection of impacts on Japan and conducting impact projections for the Asia-Pacific regions.

On behalf of the Project Team for Comprehensive Projection of Climate Change Impacts

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Contents

Introduction
Contents ···································· 3
Main Research Results ························· 4
Objectives of This Report ······················ 6
Outline of This Report ························· 6
Climate Change Impact Studies in the World ········ 9

I . Climate Change Impacts by Field

1. Impacts on Water Resources ················· 11
   - 1.1 Outline ···························· 11
   - 1.2 Targets and Methods of Impact Assessment ··· 11
     - (1) Floods ·························· 11
     - (2) Slope disasters ··················· 12
     - (3) Sedimentation ···················· 12
     - (4) Snow water resources ·············· 12
     - (5) Water supply and demand ··········· 13
   - 1.3 Future Projection of Water Resources Impacts ·· 14
     - (1) Future projection of floods ········ 14
     - (2) Future projection of slope disaster ···· 15
     - (3) Future projection of sediment disasters ·· 16
     - (4) Future projection of snow water resources · 17
     - (5) Future projection of water supply and demand ······ 19
2. Impacts on Forests ······················· 20
   - 2.1 Outline ···························· 20
   - 2.2 Objectives and Methods of Impact Assessment ·· 20
     - (1) *Fagus crenata* (Siebold's beech) forests ··· 20
     - (2) Pine wilt ························ 21
     - (3) *Sasa kurilensis* (Chishima dwarf bamboo) ·· 21
     - (4) Mountain bogs ···················· 21
     - (5) *Pinus pumila* (subalpine stone pine) ··· 22
     - (6) *Abies veitchii* (Veitch's silver fir) ···· 22
   - 2.3 Future Projection of Impacts on Natural Forests ·· 22
     - (1) *F. crenata forests* ················ 22
     - (2) Pine wilt ························ 28
     - (3) *S. kurilensis* ···················· 29
     - (4) Mountain bogs ···················· 30
     - (5) *P. pumila* ······················· 31
     - (6) *A. veitchii* ······················ 32
3. Impacts on Agriculture ····················· 34
   - 3.1 Outline ···························· 34
   - 3.2 Targets and Methods of Impact Assessment ·· 34
     - (1) Rice production in Japan ············ 34
     - (2) Outlook of impacts of global warming by world food model 36
   - 3.3 Future Projection of Agricultural Impacts ··· 38
     - (1) Rice yield in Japan ················ 38
     - (2) Outlook of impact of climate change by world food model 43
4. Impacts on Coastal Zones ················· 47
   - 4.1 Outline ···························· 47
   - 4.2 Object and Methods of Impact Assessment ·· 49
     - (1) Storm-surge flooding ·············· 49
     - (2) River levee ······················ 49
     - (3) Economic value of sands ············ 49
     - (4) Economic value of tidal flats ········ 49
     - (5) Variation of liquefaction risk ········ 50
     - (6) Risk of slope disaster ·············· 50
   - 4.3 Estimation of Future Effects on Coastal Zone ·· 51
     - (1) Estimation of future storm surge flooding damage 51
     - (2) Future estimate of vulnerability of river levee 54
     - (3) Economic value of sand beaches ····· 56
     - (4) Economic value of tidal flats ········ 58
     - (5) Variation of liquefaction risk ········ 59
     - (6) Risk of slope disaster ·············· 61
5. Impacts on Human Health ················· 63
   - 5.1 Outline ···························· 63
   - 5.2 Targets and Methods of Impact Assessment ·· 63
     - (1) Heat stress mortality risk ··········· 63
     - (2) Heatstroke ························ 63
     - (3) Atmospheric pollution risk ·········· 64
     - (4) Dengue, malaria, and Japanese encephalitis · 64
   - 5.3 Future Projection of Health Impacts ····· 65
     - (1) Mortality risk due to heat stress ···· 65
     - (2) Future projection of heatstroke ····· 66
     - (3) Atmospheric pollution risks ········· 67
     - (4) Future projection of dengue and malaria · 70
6. Comprehensive Assessment of Impacts by Field ·· 78

II. Adaptation Measures and Future Tasks

1. Impacts on Water Resources ·············· 81
2. Impacts on Forests ······················ 82
3. Impacts on Agriculture ··················· 82
4. Impacts on Coastal Zones ················· 83
5. Impacts on Human Health ················ 85

Reference Material ························ 87
References ······························· 90
Members and Contacts ····················· 93

Main Research Results

1. While impact levels and rates of increase will vary by region, there are especially vulnerable regions for each field.

A number of risk maps have been presented showing the regional distribution of climate change impacts on five fields: water resources, forests, agriculture, coastal zones, and human health. In these fields, a wide range of impacts will appear such as increases in flood and landslide disasters, northward migration and decline of forests, impacts on rice production, increases in storm surge disasters as well as the risk of liquefaction in coastal zones, increases in the number of heatstroke cases, and increases in the potential risk of infectious diseases. Moreover, while there are regional differences, some of the impacts will be extremely severe when the country is examined as a whole.

2. Although the level of impact and rate of increase vary according to the field, Japan will also experience significant impacts even with a relatively low temperature rise.

Climate change impact functions elucidating the relationships between the temperature rise and the concurrent levels of impact have been developed and utilized for the comprehensive study of how the impacts on Japan will intensify under a climate scenario in which global warming progresses up to 2100. The results show that even with a relatively low temperature rise, severe impacts will also appear in Japan.

3. In view of the fact that the impacts of climate change have been appearing in various fields in recent years, the immediate planning of appropriate adaptation measures is necessary.

The approaches toward adaptation measures necessary to control these adverse impacts and the direction of measures to be taken in each field have been consolidated.

Water resources	• Although the increase in torrential downpours due to global warming varies according to the region, torrential downpours will tend to increase more in mountainous regions. • The damage caused by floods resulting from increased torrential downpours due to global warming is expected to be approximately 1 trillion yen annually. • The danger of slope collapses due to torrential downpours will become evident in areas closer to the outskirts of cities. • Dam sedimentation will be accelerated due to global warming. • Decreases in snow water resources are expected to reach two billion tons or more in regions with large decreases. • There is a possibility of shortages in agricultural water supplies during the time of plowing and irrigation of fields. • There will be increasing occurrence of water shortages in southern Kyushu in 100 years’ time.
Forests	• Suitable habitats for *Fagus crenata* (Japanese beech) forests will sharply decrease due to global warming. • *F. crenata* forests in the Shirakami mountain range are also vulnerable to global warming. • The migration of *F. crenata* at the northern limit of distribution in response to global warming is difficult. • Pine wilt damage will expand due to global warming. • *Sasa kurilensis* (Chishima dwarf bamboo) is vulnerable to global warming in low-altitude areas. • With the trend toward mild winters and decreases in snow, mountain bogs have been shrinking.

	・ *Pinus pumila* (subalpine stone pine) in the Tohoku region is vulnerable to global warming. ・ *Abies veitchii* var. *reflexa* (Shikoku *shirabe,* a variety of Veitch's silver fir) is feared to become extinct due to global warming.
Agriculture	・ Rice yields will increase in northern Japan, while yields in western Japan will be roughly the same as at present or will show a trend of slight reduction. ・ In the area centering around western Japan, average agricultural yields will decrease and a trend toward greater year-by-year changes in yields will also be evident in the same area. ・ The rate of growth in output of major cereals by the U.S. will decrease up to the 2030s due to climate change. ・ Although the impact on the supply of food to Japan will be small during this period, the rate of growth in the supply of maize will decrease.
Coastal zones	・ As a result of rising sea levels and increasing storm surges due to global warming, the areas and populations affected by flooding caused by storm surges will increase. These areas and populations will gradually increase further with the progress of global warming. ・ The areas and populations affected by storm-surge flooding due to global warming in western Japan will be greater in semi-enclosed sea areas such as the Seto Inland Sea, inlets, etc. ・ With the progress of global warming, the risk of storm-surge flooding will be particularly high in land areas bordering the inner parts of Japan's Three Big Bays which are old landfills reclaimed long ago, as well as their environs. ・ Saltwaters in rivers will expand as a result of rising sea levels due to global warming, leading to a weakening of river embankments. ・ The economic value of sand beaches is about 12,000 yen/m^2. The value of sand beaches lost by a 30 cm sea-level rise will reach about 1.3 trillion yen. ・ The economic value of tidal flats is about 10,000 yen/m^2. The economic loss will reach as much as 5 trillion yen assuming tidal flats throughout Japan are impacted by sea-level rise. ・ Rising sea levels and extreme rainfall events will raise groundwater levels and expand the size of areas subject to ground disaster due to liquefaction at the time of earthquakes. ・ Slope disaster risks will become greater as a result of global warming. Studies employing a risk index will be important for slope restoration plans.
Human health	・ With rising temperatures, the mortality risk due to heat stress will increase. ・ The incidence of heatstroke will drastically increase as the daily maximum temperature becomes higher. A steep increase in cases is seen in people aged 65 years or older on days when the temperature exceeds 35°C. ・ Accompanying the changes in weather due to global warming, higher concentrations of photochemical oxidants and consequent increases in mortality are expected. However, the impact of this will be smaller than that resulting from an increasing occurrence of transboundary photochemical oxidant pollution. ・ The potential distribution range of the yellow fever mosquito *(Aedes aegypti*), a vector for dengue, will expand to a wide area encompassing the southern part and the eastern and western coastlines of Kyushu, Kochi Prefecture, the southern part of the Kii Peninsula, Shizuoka Prefecture, Kanagawa Prefecture, and the southern part of Chiba Prefecture by 2100. ・ The distribution range of the Asian tiger mosquito *(Aedes albopictus)* has now reached Iwate and Akita prefectures, and by 2100 it will expand to the whole of the Tohoku region and some part of Hokkaido. ・ The possibility of a new malaria epidemic due to global warming is low.

Objectives of This Report

The impacts of global warming are already appearing in various regions of the world. Arctic sea ice is shrinking at a greater speed than expected and glaciers in the Himalayas and South America are also significantly receding. Including the effects of Hurricane Katrina, damage caused by typhoons, torrential downpours, and drought is occurring throughout the world. In Japan as well, impacts of global warming including changes in agriculture, fisheries, alpine vegetation, etc. are now frequently reported. As a result of these trends, there is a strong need for information on projected environmental conditions in 2030, 2050, and beyond in order to determine what types of impacts will appear in Japan.

The target of global warming mitigation measures is to suppress global warming/climate changes to below the level that would be dangerous to the sustainability of human society and the global environment. The ultimate objective of the United Nations Framework Convention on Climate Change, which forms the basis for global warming mitigation measures, stipulates "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) released in 2007 pointed out that, based on the assessment of climate change impacts and vulnerability, even a 2-3°C temperature increase compared to the 1990 level will lead to negative economic impacts on a global scale. Clear findings have not yet been obtained, however, concerning the dangerous level of global warming based on the characteristics of each country and region, and of each field affected. Therefore, now that the formulation of medium- to long-term policies for implementation after the first commitment period of the Kyoto Protocol has become a pressing issue, scientific studies on the dangerous levels of global warming and concentration stabilization have become an urgent and critical task.

This report describes the results achieved so far in Global Environment Research Fund Strategic R&D Area Project S-4, which was inaugurated in fiscal 2005 by the Ministry of the Environment, Japan, entitled "Comprehensive Assessment of Climate Change Impacts to Determine the Dangerous Level of Global Warming and Appropriate Stabilization Target of Atmospheric GHG Concentration" (abbreviated title: "Project for Comprehensive Projection of Climate Change Impacts").

With the above as a background, this research project has the following two objectives:

1) To obtain as much quantitative knowledge as possible on climate change impacts in key fields such as water resources, forests, agriculture, coastal zones/disaster prevention, and human health in the Asian regions including Japan, targeting the period up to the end of the present century while focusing on the period up to around 2050.

2) To comprehensively grasp the impacts on Japan and elucidate the relationships with the level of global warming.

Risk maps (nationwide as well as regional assessments) showing the level and distribution of these impacts, created from the research results obtained using quantitative assessments by field and collating the parts related to Japan, are presented in this report. Moreover, the report describes climate change functions that have been developed to show the relationships between the progress of global warming/climate change and impact levels, as well as the comprehensive studies on the increasing impacts on Japan when global warming proceeds under a certain climate scenario using these functions.

Such comprehensive impact assessments represent an almost unprecedented achievement not only for Japan, but for worldwide. We believe that they will be of assistance to administrators, corporations, and citizens, enabling them to more concretely visualize and give considerations to environmental changes caused by global warming.

Outline of This Report

Composition of the Report

This report consists of two parts. In Part I, the results concerning physical impacts and economic impacts are introduced focusing on the five fields of water resources, forests, agriculture, coastal zones/disaster prevention, and human health. Simple impact information, risk maps, and other facts are enumerated for each field. In addition to these research results, other important topics are introduced in column reports. The results of the comprehensive impact assessment are summarized at the end of this part.

Part II provides a summary of the respective adaptation measures for adverse impacts, and future tasks.

Impact Assessment Methodology

The following is a description of the

methodology adopted to project the impacts of progressing global warming.

(1) Multiple cases for future world socioeconomic development (population, economy, technologies, etc.) are assumed, and greenhouse gas (GHG) emissions under each assumption are estimated (preparation of socioeconomic/emissions scenarios).
(2) With the emissions scenarios as preconditions, the future climate is simulated using a climate model and future temperature and precipitation changes are projected for various regions in the world (preparation of climate scenarios).
(3) With the socioeconomic/emissions scenarios as well as the climate scenarios mentioned above as preconditions, an impact assessment model by field/by event is used to project what types of impacts will occur in the future (implementation of impact projection).

The emissions scenarios, climate models and climate scenarios, impact assessment models, and integrated assessment model as well as climate change impact functions used in this study are described below.

(1) Socioeconomic/emissions scenarios

The IPCC Special Report on Emissions Scenarios (SRES) are used as socioeconomic/emissions scenarios. These scenarios were released by IPCC in 2000 for use as standardized preconditions in climate/impact projection studies. The SRES scenarios describe four different storylines concerning the future world development, showing socioeconomic factors (population / economy / technologies, etc.) as well as quantitative scenarios of GHG emissions corresponding to each storyline. Incidentally, none of the SRES scenarios include policies (mitigation measures) to mitigate global warming. The four storylines (A1, A2, B1, and B2) and their scenarios are as follows.

A1: The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are the convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

A2: The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than other storylines.

B1: The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2: The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

(2) Climate models and scenarios

For future climate changes, which serve as the input data for climate change impact assessments, the scenarios calculated by a climate model (global climate model: GCM) and a regional climate model (RCM) are used. In the climate model, the atmosphere and the ocean are expressed as a grid with horizontal and vertical divisions (grid cells). The climate scenarios used for impact assessment work in this study are summarized below.

(a) MIROC3.2 (hires)

This is a global climate scenario developed from a climate projection experiment using the Earth Simulator, the world's largest supercomputer, by a joint research team of the Center for Climate System Research (CCSR) of the University of Tokyo, the National Institute for Environmental Studies (NIES), and the Frontier Research Center for Global Change (FRCGC) of the Japan Agency for

Marine-Earth Science and Technology. The model used for the projection experiment is the MIROC3.2 (hires) high-resolution coupled atmosphere-ocean model with a horizontal resolution of 1.125° (approx. 100 km) developed by CCSR, NIES, and FRCGC. The SRES-A1B scenario is assumed as the emissions scenario. **Figure 1** shows the rises in temperature and changes in precipitation from 1990 to 2100 both in Japan and globally.

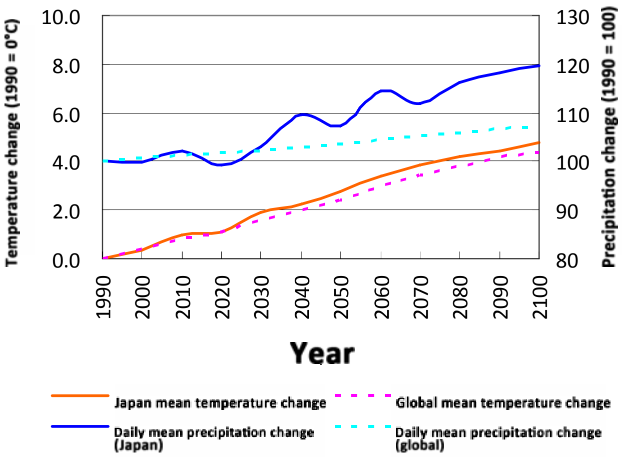


Fig.1 Global and in Japan rises in temperature and changes in precipitation from 1990 to 2100 (MIROC)

Table 1

MIROC temperature rise/sea-level rise scenario

	Japan mean temperature change	Global mean temperature change	Sea-level rise
1990	0.0℃	0.0℃	0cm
2000	0.3℃	0.4℃	2cm
2030	1.9℃	1.6℃	11cm
2050	2.8℃	2.4℃	18cm
2100	4.8℃	4.4℃	38cm

Base year: 1990

(b) RCM20 (coupled atmosphere-ocean general circulation model)

This is a regional climate scenario developed by the Meteorological Research Institute (MRI) of the Japan Meteorological Agency targeted at Japan. The model used for the projection experiments is the RCM20 regional climate model with a horizontal resolution of 20 km developed by MRI (output of a global coupled atmosphere-ocean model (CGCM2, horizontal resolution approx. 280 km) as a boundary condition, with Japan downscaled). SRES-A2 is assumed as the emissions scenario.

(3) Impact assessment models

In the impact assessments by field described in sections I.1 to I.5 of this report, future impacts of global warming are estimated by field/index using various models (physical model, process type model, statistical model, economic model, etc.). The method and model used for each estimation are explained in a subsection entitled “Targets and Methods of Impact Assessment” provided in each section by field.

(4) Integrated assessment model and climate change impact functions

The AIM/Impact[Policy] integrated assessment model has been developed in this project in order to integratedly analyze and assess emission reductions necessary for achieving climate stabilization targets as well as the impacts and risks occurring under such stabilization targets. In the development of AIM/Impact[Policy], using some of the detailed impact assessment models by field described in (3) above (hereafter referred to as “detailed models”), multiple simulations were performed while altering key factors such as temperature, precipitation, etc. in sensitivity analysis, and climate change impact functions were developed through mean aggregation of the output by region. The impact functions were implemented in the integrated assessment model, and integrated assessments of the impacts in multiple fields were performed. Incidentally, the impact functions described here can be regarded as simplified impact assessment models that emulate the detailed models.

Climate Change Impact Studies in the World

IPCC and former U.S. vice president Al Gore were the joint recipients of the 2007 Nobel Peace Prize. The Prize was awarded to them “for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change.” IPCC is a United Nations organization established in November 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The mission of IPCC is not to plan or implement global warming studies but to carry out scientific, technical, and socioeconomic assessments concerning global warming by scientists recommended by the governments of individual countries, with the latest findings obtained there to be used on a broad scale including by policymakers. Its organization consists of the IPCC Plenary, which is the highest decision-making body; three Working Groups; and the Task Force on National Greenhouse Gas Inventories.

At the 27th Plenary Session of the IPCC from November 12-17, 2007, the Synthesis Report of the Fourth Assessment Report (AR4) was adopted. This, together with the reports of the three Working Groups that had already been released in the same year, completed the compilation of AR4. The preparation of AR4 took more than four years, with the participation of more than 450 lead authors and 800 contributing authors and peer reviews by more than 2,500 expert reviewers from more than 130 countries.

Working Group I (WGI), which evaluates the physical science basis of climate change, reported that warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Moreover, WGI reported that the temperature increase observed during the 100 years from 1906 to 2005 was 0.74°C, with a linear warming trend of 0.13°C/decade for the 50 years from 1956 to 2005, nearly double that for the 100 years from 1906 to 2005. The report stated that the global average temperature rise observed from the mid-20th century onward was very likely due to anthropogenic GHG increase, going one step further than the expression “likely” used in the Third Assessment Report (TAR).

Similarly, Working Group II (WGII), which evaluates impacts on and adaptation measures in ecosystems, socioeconomic spheres, etc., reported that observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. This is based largely on data sets that cover the period since 1970, with the number of studies reporting such data having increased greatly since the release of TAR in 2001 and the quality of the data sets having also improved. In concrete terms, this is based on more than 29,000 observational data from 75 studies that met the criteria of (1) ending in 1990 or later, (2) spanning a period of at least 20 years, and (3) showing a significant change in either direction as assessed in individual studies that show significant change in many physical and biological systems. Ninety percent of 28,671 observational data in the biological environment and 94% of 765 observational data in the physical environment were reported to have been affected by global warming. The major impacts of global warming that have already manifested are described below.

Snow, ice, and frozen ground: (1) enlargement and increased numbers of glacial lakes; (2) increasing ground instability in permafrost regions, and rock avalanches in mountain regions; and (3) changes in some Arctic and Antarctic ecosystems (including those in sea-ice biomes, and also predators high in the food chain).

Hydrological systems: (1) increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and (2) impacts on water quality due to warming of lakes and rivers in many regions.

Terrestrial biological systems: (1) earlier timing of spring events (such as flowering, leaf unfolding, bird migration, and egg laying); (2) poleward and upward shifts in ranges of plant and animal species; and (3) based on satellite observations since the early 1980s, the appearance of a trend in many regions toward earlier “greening” of vegetation in the spring linked to longer thermal growing seasons due to recent warming.

Marine and freshwater biological systems: (1) shifts in ranges and changes in algal, plankton, and fish abundance in high-latitude oceans; (2) increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and (3) range changes and earlier migrations of fish in rivers.

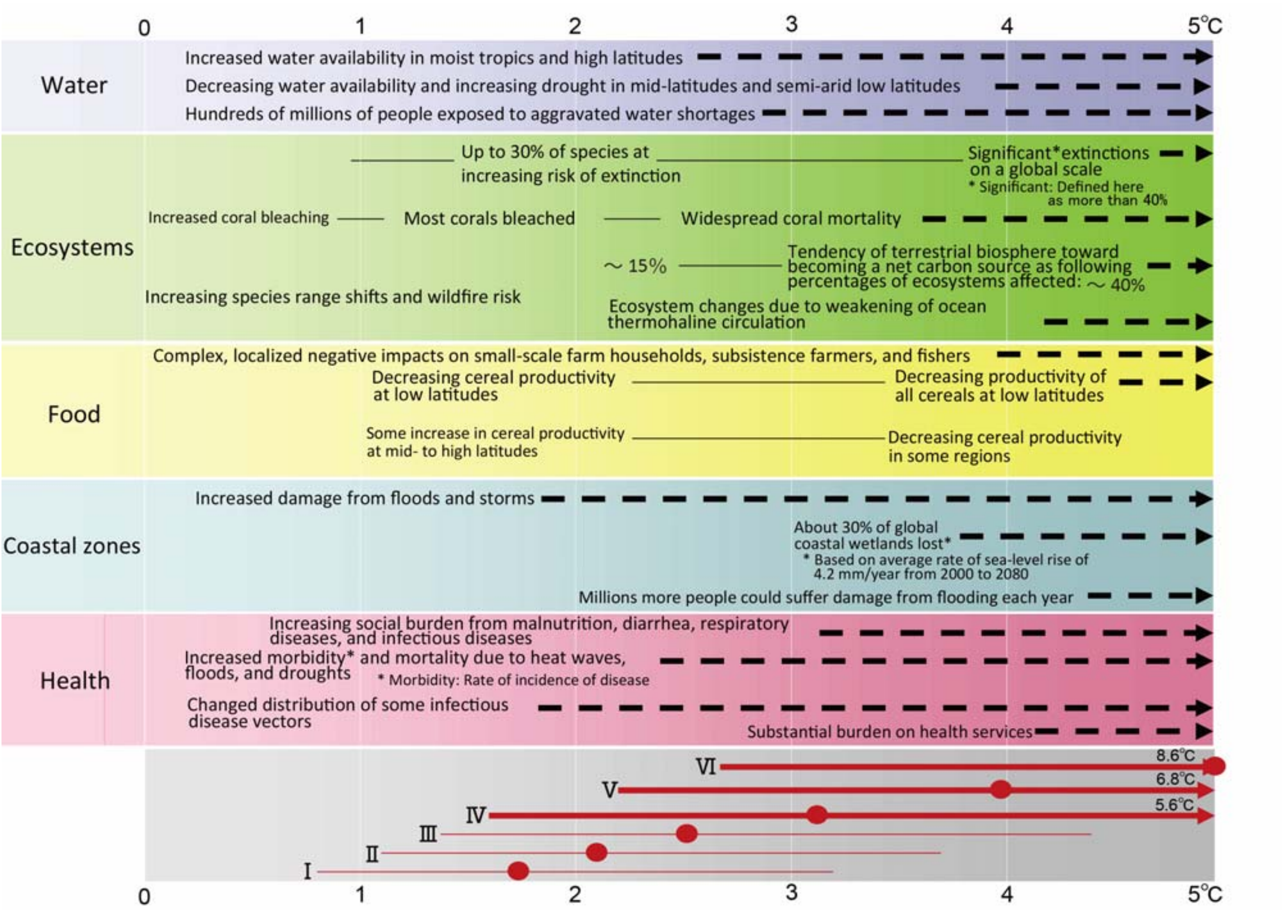
With regard to the impacts on human society, although it is difficult in many cases to specifically and quantitatively show a relationship with temperature increase because non-climate factors are also intricately intertwined, WGII reported the following impacts: (1) agriculture and forestry: earlier spring planting of crops at Northern Hemisphere higher latitudes, and alterations in disturbance regimes of forests due to fires and pests; (2) human health: heat-related mortality in Europe, infectious disease risk due to vectors, and allergenic pollen in Northern Hemisphere high and mid-latitudes; and (3) direct impact on human activities: hunting and travel over snow and ice in the Arctic, mountain sports in lower-elevation alpine areas, etc.

Since the publication of TAR in 2001, the results of studies conducted in regions that had previously been little researched have provided a more systematic understanding of how the timing and magnitude of impacts may be affected by changes in climate and sea level associated with differing amounts and rates of change in global average temperature. Global future impacts by field reported by WGII in AR4 are shown in **Table 2**. The black lines indicate linkages between impacts, and the dotted arrows indicate impacts continuing with increasing temperature. The left-hand side of the description indicates the approximate point of onset of a given impact. Note, however, that the effects of adaptation to climate change are not included in these estimations.

This table provides an overview of what types of impact appear at certain points in time and the extent of these impacts with increasing temperature. Moreover, as shown in the lower part of the table, by combining this information with stabilization levels, useful scientific findings are obtained for discussing the extent to which GHGs are reduced at certain points in time in order to achieve the target. For example, when category II climate stability is achieved (temperature rise of 2.4-2.8°C), it can be seen that most corals will be bleached and an increasing risk of extinction of species will emerge. Such scientific findings are a highly effective resource to assist policymakers in taking appropriate measures against the risks of climate change.

Table 2 Key impacts of global mean temperature increase

(IPCC 2007. Climate Change 2007: Impacts, adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report for the IPCC. M.L. Parry, O.F. Canziani, J.P. Palutkikof, P.J. van der Linden & C.E. Hanson (eds). Cambridge University Press, Cambridge, UK, 976pp.)



I. Climate Change Impacts by Field

1. Impacts on Water Resources

1.1 Outline

The impacts of global warming on water resources can be roughly divided into torrential downpours and water shortages. According to several general circular models (GCMs), the intensity of torrential downpours and an increase in the number of days without rainfall due to global warming have become conspicuous. The term *torrential downpour* refers to rainfall with such strong precipitation intensity that it can cause a disaster. Both torrential downpours, which bring about various disasters, and lack of rainfall, which limits water use, result in economic losses. This report presents assessments of increased flood damage and slope disasters as well as reservoir sedimentation problems as future impacts of increased torrential downpours, and assessments of changes in water supply and demand as future impacts of increased frequency of water shortages. In addition, an assessment of decreased snow water resources accompanying increased temperatures is also presented.

In this section, the method of impact assessment is described. The data on torrential downpours used here are based on the present statistical values of daily maximum rainfall. The estimation of future statistical values using results obtained from a GCM is difficult because of limitations in terms of spatial and temporal resolution. It is therefore necessary to note the possibility that the data on torrential downpours used for assessment may result in an overestimate or underestimate depending on the region. Since the data were obtained according to statistical values, the periods of the data used and the points observed are limited, local phenomena cannot be represented due to rough spatial resolution when distribution data are prepared, and the temporal statistical values are not necessarily complete. The possibility also exist that future statistical values may change. The rainfall data therefore contain uncertainties. For details, refer to 1.3 (1).

1.2 Targets and Methods of Impact Assessment

(1) Floods

Various measures against floods (flood control) have been taken in the past in Japan. As a result, floods have now become less frequent. With the greater severity of torrential downpours accompanying climate change, however, water levels projected in the past will be exceeded and the risk of floods will increase.

In the present study, two methods were combined in order to investigate the economic damage resulting from floods. First, floodwater depths and flooding periods were estimated by obtaining the areas of flooding using an inundation model without taking flood control improvements into account. Then, by assigning asset values according to land use, the amount of damage caused by floods was calculated. This approach conforms with that in the flood control economy investigation manual of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Flood damage was calculated by means of these two methods.

Using the inundation model, the areas of flooding due to torrential downpours occurring with a probability of once every 50 years (a 50-year return period) and those occurring with a probability of once every 100 years (the 100-year return period) were calculated, and the difference between the amounts of flood damage caused by these two types of torrential downpours was obtained. The assumption was made that flood control improvement work in Japan protects against damage from torrential downpours that occur once every 50 years. On this basis, our study considered the expansion of damage if the frequency of torrential downpours that currently occur once every 100 years increases to around once every 50 years due to global warming. The reason for targeting torrential downpours that occur once every 100 years is that improvement work for most Class A rivers (rivers designated as important water systems administered by MLIT) is aimed at the level of the 100-year return period. The spatial distribution of rain in the study was set on the basis of torrential downpours occurring simultaneously throughout Japan. The maximum values of potential damage accompanying floods were therefore obtained in the analysis.

(2) Slope disasters

Among the consequences of torrential downpours are collapses of land and slope failures exemplified by landslides. With its steep geographical features and extensive mountainous areas, Japan continues to suffer from slope disasters. Slope disasters cause not only damage to human life and property but also economic losses due to the disruption of transportation links. As it is impossible to take measures covering the entire country, the specification of priority areas has been necessary. Therefore, in the present study, slope disaster probabilities were obtained using digital map information, and risk maps were prepared accordingly.

Slope disaster probability can be estimated from two variables: relief energy (the difference in altitude between the highest and the lowest points in the digital map mesh) and the hydraulic gradient of groundwater (groundwater flow velocity). The disaster probability can be constructed by a logistic function with these two variables. Constants were obtained to give agreement with past records of actual disasters, and the function was estimated for each geological feature. The hydraulic gradient of groundwater, which is a variable as mentioned above, was obtained from the subsurface flow generated by the infiltration of rainfall. That is, by inputting data on torrential downpours that occur once every 30 years, the probability of a slope disaster of the type that occurs once every 30 years can be obtained. An area with an 80% probability of slope disaster referred to here means that if such rainfall occurs during a 30-year return period, 80 out of 100 sites will collapse.

This method only considers data at the time of disasters due to short-term rainfall. Many sites will not collapse in such a case compared with the case of torrential downpours occurring over a long period, and therefore the actual probability will increase. On the other hand, land use that inhibits ground infiltration such as vegetation, roads, etc. was not taken into account, and decreases in the hydraulic gradient of groundwater due to the effects of evaporation and infiltration were therefore not considered. The probability of slope disasters thus contains uncertainty due to these factors.

(3) Sedimentation

When slope failure progresses due to torrential downpours, sediment production will increase as a result. Excessive sediment production causes riverbed rise, leading in turn to an increase in flood risk. Moreover, as sedimentation increases in dams and weirs, their water storage capacity is diminished. The deterioration of water quality due to turbid runoff accompanying sedimentation is also a source of concern. Increased sediment production thus makes it difficult to secure good-quality water resources.

Using the slope disaster probability described above, sedimentation data for 52 dam lake sites throughout Japan and the average values of slope risk were compared. As a result, it was found that both can be represented by an exponential function and that they show a high correlation coefficient. This relationship can be used to estimate the distribution of sediment production throughout Japan. Moreover, since slope disaster risk incorporates rainfall as a variable, sediment production due to changes in rainfall accompanying climate change can be estimated.

The estimated relationship between sedimentation and slope disaster is the average value for the 52 dam lake sites calculated as a long-term trend, and does not take the effects of sediment control works and short-term sediment runoff into account.

(4) Snow water resources

The impact of global warming on water resources appears most conspicuously with respect to snow. In view of its role as a form of water storage in mountainous areas during the winter season, snow is also referred to as “white dams.” Snowmelt is a valuable water resource in the spring, providing irrigation to vast expanses of paddy fields. On the other hand, not only agricultural water but also water for other uses is disrupted in years with little snow, with rivers often drying up and ecosystems affected as well.

A snow accumulation and snow melt model was used to estimate snow water resources. In this model, snowfall distribution data are prepared using data on rainfall, temperature, and altitude throughout Japan, and snowmelt distribution is estimated using the temperature data. By combining these two, snow depth is calculated. A constant for this model was obtained to give agreement with the snow distribution obtained from satellite images and that obtained by calculation. Using this method, simulations were performed setting 2000 and 1993 as representative years, which were average years of heavy snow and little snow, respectively, during the past 20 years. Moreover, the vulnerability of snow water resources was investigated by comparing differences in snow water resources on February 15, just before snowmelt starts.

The situation of snow following the progress of global warming will not necessarily coincide with the present condition of little snow, because snowfall will change to rainfall and other changes in precipitation will occur. It is therefore necessary to conduct detailed studies on the combination of future temperature and snowfall obtained by GCMs.

(5) Water supply and demand

Longer periods of drought increase the risk of water shortages. In the case of future reductions in the area of paddy fields and in population, however, water utilization can also be expected to decrease. Future projection of water shortage risk is therefore complicated. To investigate the future directions of water use to cope with these changes as well as water resource policies, the relationship between the present water supply and demand balance and social conditions throughout Japan at the level of common water usage areas (catchment basins) was elucidated, and with reference to this, the future water supply and demand balance was estimated using the RCM20 regional climate model based on the SRES A2 climate scenario. The future water supply and demand balance was assessed by calculating the water shortage index (Number of days with a shortage of dam water x Maximum volume of dam water shortage) from the future volumes of water supply and demand by common water usage area (catchment basin), and comparing this with the water shortage index for the present conditions. With regard to future water supply and demand, due to a lack of data projecting population, number of people covered by waterworks, area of paddy fields, and industrial output 100 years into the future, simple estimations were made from the existing data. The number of people covered by waterworks was estimated from the trend of future population projections (final year of projection: 2030), the area of paddy fields was estimated from the trend of the cultivation abandonment rate (final year of projection: 2015), and industrial output was estimated from the projected values of labor productivity (final year of projection: 2050) and future population projections. The water demand was estimated from the relationships between these data and present water use, while the water supply was estimated in terms of the potential use of water from the values for rainfall, evapotranspiration, and snowmelt obtained by GCM. The ratios of changes in the water shortage index were represented in this way, taking future social changes and climate change into account.

Since these estimates incorporate social changes projected from past data, significant variations may occur depending on policies that are adopted and on the environment. In particular, agricultural policies such as the reduction of rice acreage under cultivation, food self-sufficiency policies, etc. will have a major effect.

1.3 Future Projection of Water Resources Impacts

(1) Future projection of floods

Although the increase in torrential downpours due to global warming varies according to the region, torrential downpours will tend to increase more in mountainous regions.

The GCM and the concept of rainfall probability were used to assess the increase in torrential downpours due to global warming. **Figure I-I-1** shows the changes in future rainfall (daily rainfall) throughout Japan obtained by GCM.

Data on torrential downpours were prepared using the following process. (1) The maximum value each year of 24-hour rainfall observed at rainfall observation sites in Japan over the past 50 years was obtained. (2) These maximum values were subjected to frequency analysis. This involved obtaining the probability density function (frequency function) of each annual maximum value of 24-hour rainfall. The probability density function represents the probability of occurrence of maximum 24-hour rainfall during a year. Here, the generalized extreme value (GEV) distribution function was used. (3) The functions thus obtained were permuted to the relationship between the annual maximum 24-hour rainfall and cumulative probability. The cumulative probability means the nonexceedance probability, and the function of the annual maximum 24-hour rainfall and nonexceedance probability is referred to as the distribution function. The nonexceedance probability shows the probability that a particular amount of rainfall will not be exceeded. (4) The exceedance probability is obtained by subtracting the nonexceedance probability from 1.0 (100%). The distribution function is reexpressed as the relationship with the exceedance probability. This shows the probability of annual maximum 24-hour rainfall exceeding a certain value. (5) The reciprocal of the exceedance probability of annual maximum 24-hour rainfall obtained here is the return period (RP; also known as recurrence interval) (unit: years). For example, if the return period of an annual maximum 24-hour rainfall of 100 mm is 30 years, this can be described as “rainfall exceeding 100 mm occurs once every 30 years in term of probability.”

The analysis results presented in **Fig. I-I-1** were obtained from the statistical values of present rainfall, showing the difference between torrential downpours that occur once every 50 years and those that occur once every 30 years. The obtained values represent daily rainfall. This is roughly equivalent to the difference between the present climate and the climate around 2030 according to the MIROC climate scenario, showing that torrential downpours will increase due to climate change. The areas with high values are those in which the increase in torrential downpours is greater than that in other areas. As can be seen in this figure, there are significant differences in the level of increase in torrential downpours according to the area, with a larger increase in torrential downpours seen along the Pacific coast and mountainous regions. This indicates the possibility of a greater increase in the occurrence of disasters due to climate change in these areas compared with other areas, pointing to a greater necessity to make preparations for climate change in these areas.

Incidentally, the future climate modeled by the GCM described here is viewed from the perspective of average values, and changes in the probability density function were not taken into account. When the rainfall conditions shown in **Figs. I-I-2** and **I-I-3** are examined, the dispersion values are very large. It should therefore be noted that the degree of uncertainty is high.

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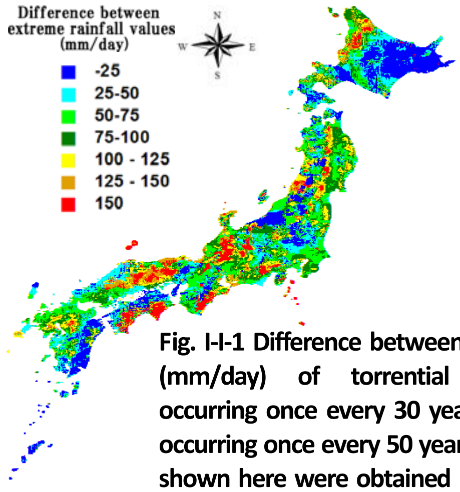

Fig. I-I-1 Difference between daily rainfall (mm/day) of torrential downpours occurring once every 30 years and those occurring once every 50 years. The results shown here were obtained using present statistical values.

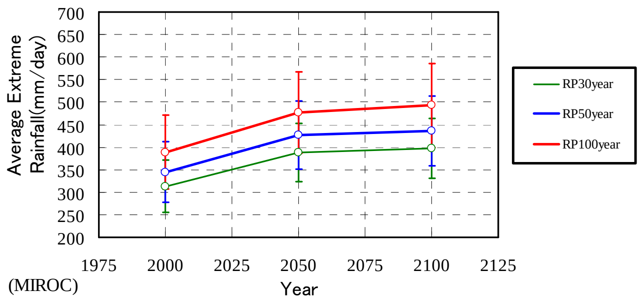

Fig. I-I-2 Rainfall conditions in the near future (2030-2050) and around 2100 (2080-2100) obtained by MIROC. The mean of the values throughout Japan over a 20-year period and the standard deviations (vertical lines) are shown.

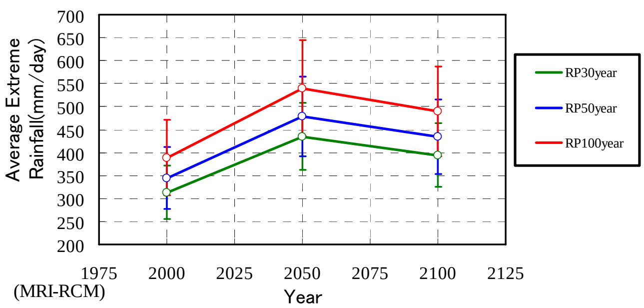

Fig. I-I-3 Rainfall conditions in the near future (2030-2050) and round 2100 (2080-2100) by RCMver2.0. The mean of the values throughout Japan over a 20-year period and the standard deviations (vertical lines) are shown.

The damage caused by floods resulting from increased torrential downpours due to global warming is expected to be approximately 1 trillion yen annually.

In order to assess the economic impact of floods due to global warming, the amount of damage caused by floods was calculated using flood calculations (assessment of floodwater depths and areas) and the flood control economy investigation manual of MLIT (assessment of asset values). The amount of damage if the frequency of torrential downpours that currently occur once every 100 years increases to around once every 50 years due to climate change was estimated. According to the MIROC model, this change can be considered to be the condition until around 2030.

A distribution map of the amount of damage per square kilometer is shown in **Fig. I-I-4**. It can be seen that expensive measures are necessary in the regions centering around the Three Big urban areas that have extensive lowlands and flatlands and high levels of economic activity. Although the damage does not exceed 20 billion yen/km^2 in many areas of the country, in Osaka and Nagoya and their vicinities there are areas with damage exceeding 40 billion yen/km^2. In Tokyo and its vicinity, damage amounting to 100 billion yen/km^2 is seen. Nationwide, damage may total approximately 1 trillion yen annually (expected amount), and under conditions in which the provision of sufficient budgets is difficult, measures such as the construction of early warning systems and flood-withstanding type housing differing from the conventional water control improvement measures typified by large dams, super-embankments, etc. will be necessary.

It can be considered that, in areas with a large amount of damage, water control by conventional types of facilities that contain floodwater (embankments, dams, underground conduits) should be given priority, while in areas with less damage, priority should be given to land use management and risk management response type adaptation measures; for example, the construction of early warning systems, promotion of flood-withstanding type housing, restrictions on new development in specified areas, etc. (Ministry of Land, Infrastructure, Transport and Tourism, 2007).

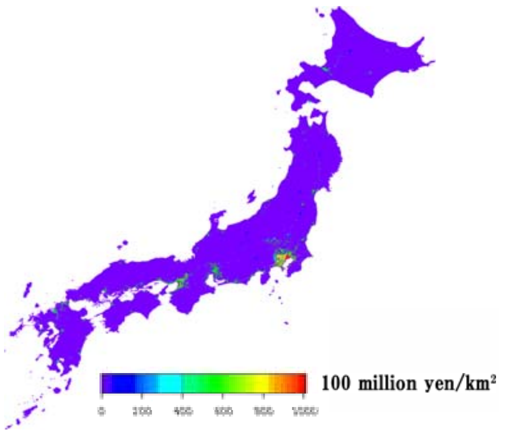

Fig. I-I-4 Distribution of increased damage if the intensity of extreme rainfall changes from that of 50-year return period to that of 100-year return. The differences between the amounts of damage incurred by the two types of torrential downpours were calculated.

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(2) Future projection of slope disasters

The danger of slope failures due to torrential downpours will occur in areas closer to the outskirts of cities.

To clarify how the areas with the greatest likelihood of slope failure change according to changes in rainfall patterns accompanying climate change, the probability of slope disasters due to torrential downpours was studied using values from the MIROC climate scenario as input values. It was assumed that only the average intensity of torrential downpours will shift in 2050 (near future). Climate change also affects statistical values such as dispersion, etc., but this was not taken into account (refer to 1.3 (1)). **Figure I-I-5** shows the probability of slope failure due to torrential downpours that occur once every 30 years. The areas considered to be dangerous are distributed even to the vicinity of flatlands. In particular, the outskirts of urban areas in the Chugoku and Tohoku regions show a high probability of close to 100%. Most mountainous areas also show a high probability approaching 100%. Since the occurrence of debris flow due to slope disasters is also a source of concern in the case of mountainous areas, not only are sites with high probability indicated but it is also assumed that they extend to their downstream areas. It is therefore necessary to consider disaster prevention systems from the perspective of the entire basin.

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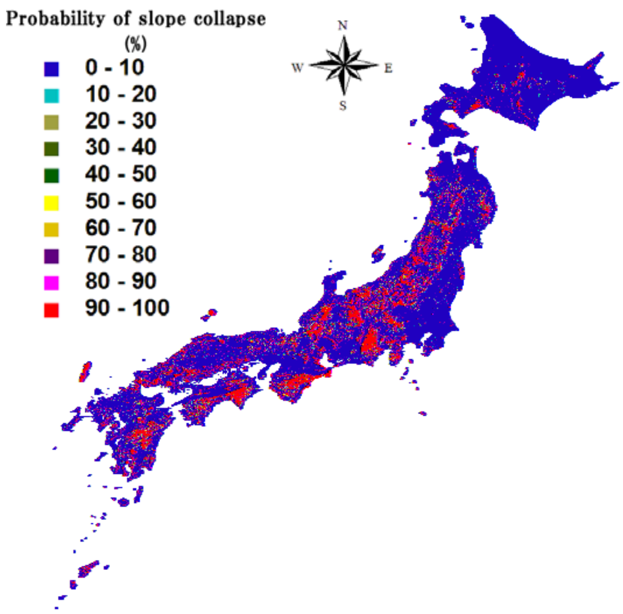

Fig. I-I-5 Probability of slope failure due to extreme rainfall that occur once every 30 years in the climatic conditions of 2050. Since the probability of torrential downpours has a high level of uncertainty, the results shown here are likely to be overestimated values.

(3) Future projection of sediment disasters

Dam sedimentation will be accelerated due to global warming.

To assess the impact of global warming on sediment production, the distribution of sediment production was estimated using the values obtained for slope disaster risk. The relationship between the amount of sedimentation in dam lakes and the slope disaster risk (described in (2) above) in the dam lake catchment basins was calculated. The result revealed that sedimentation increases exponentially with the risk. This, in turn, shows that sedimentation increases at an accelerated pace with the rate of increase in torrential downpours. Using this relationship, the slope disaster risk distribution map was converted to a sediment production distribution map, shown in **Fig. I-I-6.** Areas of large sediment production extend along the Median Tectonic Line, which is a major fault line that runs through southwestern Japan from the Kanto region to Kyushu. Areas in which the production of sediment was originally high show larger amounts of sediment production. In particular, the increase in sediment production in the area extending from the Northern Japan Alps to the Southern Japan Alps is a source of concern. Sediment production in mountainous areas also promotes sedimentation in dam lakes. It is inferred that the impact of this will not only reduce flood adjustment capacity but also accelerate the deterioration of water quality accompanying the runoff of nutrient.

Countermeasures that can be considered include sediment control works and the construction of pre-dams (dams for sedimentation built around the mouth of a river flowing into a dam lake), dredging and flushing operations to remove sedimentation. Sand bypasses (to move sedimentation downstream) and flushing operations are important for the stabilization of riverbeds and coastlines, but careful planning is necessary because their impacts on downstream areas are large.

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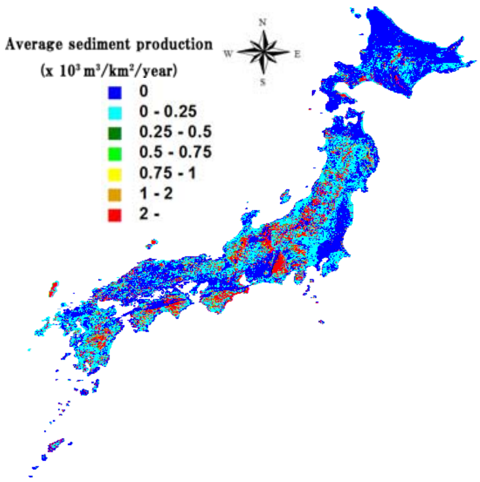

Fig. I-I-6 Map of sediment production distribution accompanying slope disasters. The data were calculated from the relationship between slope disaster risk and dam sedimentation.

The cost of water purification will increase as a result of global warming.

The results of modeling with numerous GCMs indicate that periods without rainfall will become longer due to climate change. This will also have an impact on water purification processes. It is known that a longer period without rainfall gives rise to increased turbidity at the time of rainfall. This is because of the immediate runoff of sedimentation accumulated over a prolonged period from atmospheric deposition. By representing deposition in terms of land use, an exponential function model using the period without rainfall as a variable was prepared and the parameter was identified with regard to representative rivers for which complete data exists. Here, by statistical analysis of present data, periods without rainfall that occur every year and those that occur once every 100 years (once-in-a-century droughts) were calculated. The method of calculating the return period is the same as that used for torrential downpours in 1.3 (1). The ratio of turbid runoff in the case of a once-in-a-century drought to the value in an average year was obtained, as shown in **Fig. I-I-7**. The larger the value, the greater the increase in the turbidity of that area due to climate change. Among the targeted catchment basins, the Shinano river system shows the greatest rate of increase in turbidity at more than 5%. Although the period without rainfall is the longest in the Ishikari river catchment basin, the Shinano river catchment basin shows the largest increase due to the effects of land use. Increased turbidity becomes a factor pushing up water treatment costs in water purification plants.

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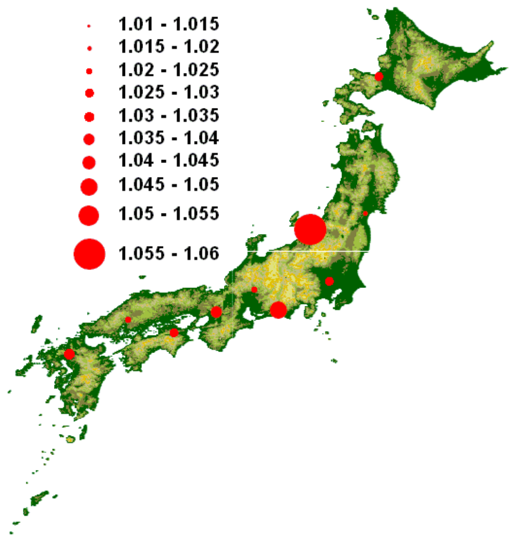

Fig. I-I-7 Rate of increase of turbid runoff in the case of a once-in-a-century drought to the value in an average year.

(4) Future projection of snow water resources

Decreases in snow water resources are expected to reach two billion tons or more in regions with large decreases.

In order to assess the impacts of global warming on snow water resources, the amount of decrease in snow was estimated using numerical calculation. A comparison of the amounts of snow in representative years with abundant snow and with little snow showed that Niigata and Akita prefectures have a difference in water equivalent height of 1,000 mm or more (**Fig. I-I-8**) (see Topic: "Ski industry"). Global warming promotes not only decreases in snow but also increase in evapotranspiration, thereby accelerating the decrease in water resources. These prefectures are areas of thriving rice production. Since snowmelt water is used during the time of plowing and irrigation of fields, there is a possibility of rice production being hindered by water shortages accompanying global warming. In order to support the extensive areas of paddy fields, storage facilities having the same function as snow will become necessary.

Although no simple measures for adaptation are available, such adaptation measures as reviewing agricultural water rights, changing the time of rice planting, etc. can be considered. Moreover, the use of snow dams, which can concurrently serve as a measure against avalanches, is also a method of enhancing the storage effect.

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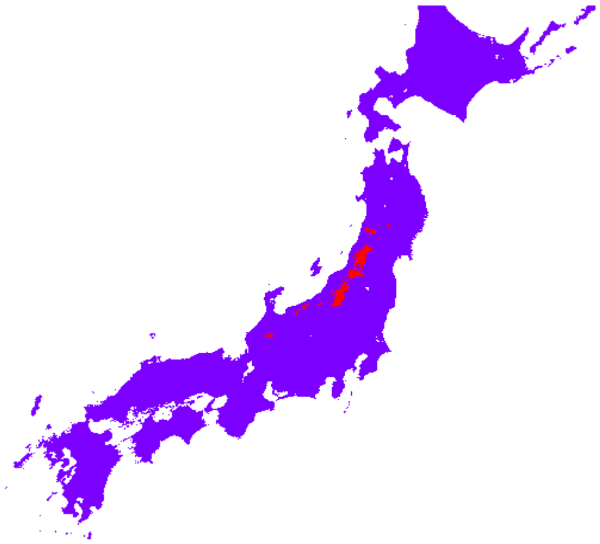

Fig. I-I-8 Areas with a decrease in snow water of 1,000 mm or more in years with little snow (areas colored red). The difference between the value in 2000, which was an average year with abundant snow, and that in 1993, which was an average year with little snow, was calculated.

There is a possibility of shortages in agricultural water supplies during the time of plowing and irrigation of fields.

Tohoku is the region with the largest rice production in Japan, accounting more than one-quarter of the country's overall rice yield. It is snowmelt that supports this vast expanse of paddy fields. The ratio of snow water resources used for irrigation in the springtime in past years with little snow and with abundant snow was investigated for representative catchment basins of rice production. The three catchment basins of the Mogami, Kitakami, and Shinano rivers were targeted for study. Each of these river catchment basins has extensive areas of paddy, and snow accumulated during winter plays a highly important role as agricultural water.

In all of the catchment basins, the amount of snow water per area under cultivation in a year with abundant snow was more than double that in a year with little snow. In the case of the Kitakami River, since it is located on the Pacific Ocean side and the total amount of snow water is low, the amount of snow water per area under cultivation is small even in a year with abundant snow.

In the case of general irrigation for normal cultivation of paddy rice, the amount of irrigation water required for paddy fields during one irrigation period is 1.5 m^3 per 1 m^2. A comparison was made between this value and the amount of snow water per area under cultivation. **Table I-I-1** shows the ratios of snow water resources in the respective catchment basins accounted for by irrigation water during the time of plowing and irrigation of fields. A ratio of less than 1 indicates a shortage. It is found that in the Shinano River basin, sufficient agricultural water can be obtained from snow both in years with little snow and years with abundant snow. In the Mogami River basin, although snow water resources amount to about three times the amount required for irrigation in years with abundant snow, the amount of snow water is less than that required for irrigation in years with little snow, with the result that it is difficult to secure agricultural water from snow alone. In the Kitakami River basin, sufficient agricultural water cannot be obtained from snow both in years with little snow and years with abundant snow. In years with abundant snow, about 30% of the snow water is used for irrigation, but this figure falls to 10% or less in years with little snow.

In the case of the Shinano River, although the decrease is large, snow water resources can still be considered to be sufficient. In catchment basins on the Pacific Ocean side such as the Kitakami River, on the other hand, there is a possibility that sufficient agricultural water may not be available during the time of plowing and irrigation of fields due to changes in the amount and timing of snowmelt accompanying global warming in the future. To deal with this issue, in addition to previous section, the establishment of new agricultural water rights will become necessary.

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Table I-I-1 Amount of snow water accounted for by irrigation water during the time of plowing and irrigation of fields

		Amount of snow water (m^3)	Area under cultivation (km^2)	Amount of snow water per area under cultivation (m^3/m^2)	Ratio of irrigation water required for paddy fields during one irrigation period
Mogami River	Little snow	8.83×10^8	717 (Yamagata Prefecture)	1.23	0.82
	Abundant snow	32.0×10^8		4.46	2.97
Kitakami River	Little snow	0.96×10^8	795 (Miyagi Prefecture)	0.12	0.08
	Abundant snow	4.05×10^8		0.51	0.33
Shinano River	Little snow	32.1×10^8	1210 (Niigata Prefecture)	2.65	1.76
	Abundant snow	78.5×10^8		6.49	4.32

(5) Future projection of water supply and demand

There will be increasing occurrence of water shortages in southern Kyushu in 100 years' time.

Targeting common water usage areas (catchment basins) throughout Japan, the future balance of water supply and demand and risk of water shortages were assessed by a simple estimation of water demand according to future social changes and the calculation of water supply using the RCM20 climate scenario.

Regional differences were clearly revealed when the balance of water supply and demand in 100 years' time was calculated using estimated values of future demand (**Fig. I-I-9)**. In Hokkaido and the east coast of the Tohoku region, the balance of water supply and demand is projected to become tighter compared with the present condition, with water resources in southern Kyushu and in Okinawa becoming particularly strained. This is due to a significant decrease in rainfall and a significant increase in evaporation accompanying temperature rise. Various future social conditions were projected from present changes for this calculation. Although the degree of uncertainty is large, southern Kyushu can be cited as an area where the securing of water resources will become relatively difficult.

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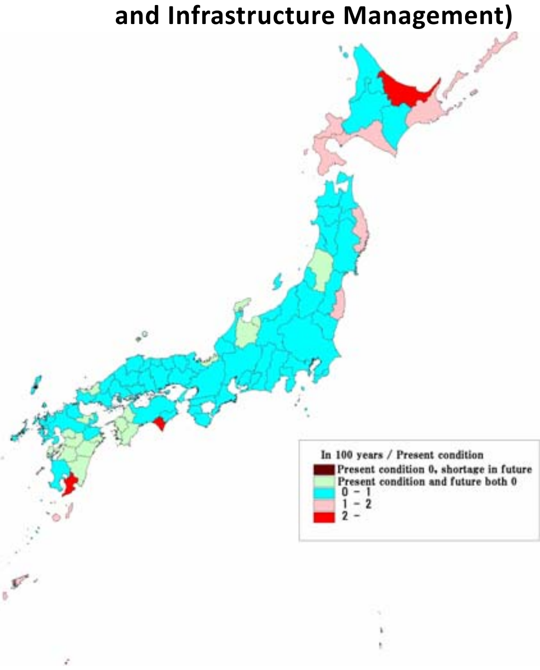

Fig. I-I-9 Rate of change of water shortage index. The figure shows the ratio of the water shortage index in 100 years' time based on projected water demand to the present water shortage index.

Topic

Ski industry

Skiing and snowboarding are among the typical winter recreational activities. With the increase in tourists visiting Japan in recent years from areas without snow in Taiwan and southern China, the ski industry has become important. If operating periods become shortened due to global warming, however, the ski industry is expected to suffer from an accelerating state of decline. Skiers and snowboarders who tour various countries are clearly aware of the decrease in snow, and the ski industry has also begun to address the issue of global warming.

The *Asahi Shimbun* website (asahi.com) published the following remarks on March 19, 2007:

"If global warming progresses, snow will decrease and skiing will become impossible. In response to successive cancellations of ski tournaments in various locations around the world due to shortages of snow, competitors including both Aiko Uemura (women's mogul) and Kentaro Minagawa (men's slalom) of the Ski Association of Japan visited Minister of the Environment Masatoshi Wakabayashi on the 19th and pledged that they would make widespread public appeals for the prevention of global warming. The association started PR activities this year such as using panels and numbers on athletes' uniforms with the logo 'Stop global warming' in tournaments, etc. Visiting the Ministry of the Environment in Kasumigaseki, Tokyo, Minagawa stated, 'Over the past 10 years, I have really felt the impacts of global warming such as the rising altitude of training locations year after year.' Uemura asked, 'What will we do when children who don't know what snow looks like someday?' The environment minister replied, 'A popular movement is necessary for the prevention of global warming. I would like you to continue making strong appeals in the future as well.'"

Ski grounds constitute an important industry in mountainous areas and are an important source of income in the agricultural off-season. The decline of the ski industry will accelerate the increase in depopulated communities and have major social and cultural effects on local areas. Global warming should be taken into consideration as an issue in national land planning for the future.

So KAZAMA (Tohoku University)

2. Impacts on Forests

2.1 Outline

Japan's vegetation zones correspond to the country's climate and are classified into subtropical forests, warm-temperate lucidophyll forests, intermediate temperate forests, cool-temperate deciduous broadleaf forests, subalpine conifer forests, sub-boreal forests, alpine vegetation, etc. Projected changes in the potential distribution of vegetation zones throughout Japan when the annual mean temperature is increased by 1, 2, and 3°C as a result of global warming have been reported (Tsunekawa et al., 1996). It is necessary, however, for such changes in the distribution of vegetation due to the impacts of global warming to be projected by species, because responses to temperature and precipitation differ depending on species. Moreover, since various climate scenarios have been created, projections of the distribution under each scenario are also necessary at the same time.

2.2 Objectives and Methods of Impact Assessment

(1) *Fagus crenata* (Siebold's beech) forests

Fagus crenata (Japanese name: buna) forests are typical Japanese natural forests whose importance has been increasingly recognized in recent years, particularly for their watershed protection function and as habitats for wildlife. *F. crenata* is distributed from Kuromatsunai in southern Hokkaido to the Takakuma mountains in Kagoshima Prefecture and its forests cover an area of 23,000 km^2, accounting for 17% of the country's total area of natural forests. *F. crenata* forests are widely distributed in southern Hokkaido, Tohoku, and the Sea of Japan side of Honshu, but their range is limited to the higher elevations of mountainous areas on the Pacific Ocean side of Honshu, Shikoku, and Kyushu. The Shirakami mountain range in northern Honshu with its large area of preserved *F. crenata* forests, a rarity in the world, was registered as a World Natural Heritage site in 1993.

Climate change greatly affects the forest ecosystem. Studies to project impacts of climate change on the distribution of plant species have recently been progressing. By developing a model projecting areas suitable for the distribution of species (i.e., suitable habitats) under the present climate and environmental factors, suitable habitats under future climate conditions can be projected based on a climate change scenario. This methodology makes it possible to assess changes in the size of suitable habitats due to climate change, areas that will continue to be suitable for plant species after climate change, areas that will no longer be suitable habitats due to climate change, etc. The results are expected to be used for the formulation of conservation management plans for plant populations in the era of climate change.

To assess the impacts of climate change to the F. crenata forests in Japan, a classification tree model (ENVI model) in the national scale was established (Matsui et al. 2004) by conducting the classification tree analysis which is one of the statistical models, employing the spatial resolution of third ordered mesh (approximately 1km x 1km), using four climate variables and five land variables as the explanatory variables and the existence of F. crenata distribution as the objective variable. The four climatic variables were: warmth index (yearly accumulated monthly average temperature above 5°C), average of daily minimum temperatures of the coldest month, precipitation in summer (May to September) and precipitation in winter (December to March), and the five land variables were: geology, soil, large terrain, slope orientation and slope gradient. The present climate variables were calculated using the old mesh climatic data (normal values in 1953-1982 for the temperature and normal values in 1953-1976 for the precipitation, JMA 1996) for the model establishment, and were calculated using the new mesh climatatic data (normal values in 1971-2000, JMA 2002) for the projection. Mesh climatic data are a type of climate normals (the value obtained by averaging data for about 30 years). Monthly mean values or monthly total values of weather factors were interpolated by taking the topography, etc. into account, where no meteorological observatory or Automated Meteorological Data Acquisition System (AMeDAS) observatory exist. Land variables were based on the Digital National Land Information. Data on the distribution of *F. crenata* forests and other natural vegetation were extracted from the Third Mesh Vegetation Database (MVDB) based on the Third National Survey on the Natural Environment (NSNE).
Incorporating the present climate (JMA, 2002) and two climate change scenarios for two period, RCM20 and MIROC (2031-2050 and 2081-2100),

into the ENVI model, the present and future probability of occurrence of *F. crenata* forests was projected. Compared with the present climate, the annual mean temperature will increase by 2.1 and 2.7°C, respectively, in the case of RCM20 (2031-2050 and 2081-2100), and by 2.3 and 4.3°C in the case of MIROC (for the same two periods). Hence, from the perspective of temperature increase, RCM20 represents a low-level and MIROC a high-level global warming scenario, and the use of both scenarios has significance in that it shows the variation of impact projections.

(2) Pine wilt

Pine wilt disease can be cited as an example of the conspicuous impacts of global warming on forests through biological damage. As it is known that pine wilt due to the pinewood nematode (*Bursaphelenchus xylophilus*) does not occur in cool climate conditions, there is a concern that global warming will expand the areas at risk of this disease.

To assess the impacts of global warming on pine wilt, using the mesh climatic data (JMA, 2002) for monthly temperature, the accumulated temperature with a threshold of 15°C (MB index), which serves as the index for pine wilt risk, was calculated for every 1°C temperature increase, and after taking the present forms of land use into account, the distribution of the area at risk of pine wilt at the time of global warming was calculated. The results are presented in the form of Third Mesh risk area maps, showing the calculated changes in the size (number of mesh cells) of the areas at risk of pine wilt at the time of global warming.

(3) *Sasa kurilensis* (chishima dwarf bamboo)

Sasa kurilensis, known as chishima dwarf bamboo or nemagari dwarf bamboo, belongs to the subfamily Bambusoideae and is distributed from Sakhalin and the Kuril Islands to Shimane Prefecture. It is a dominant species in forest floor vegetation from the cool-temperature zone to the sub-boreal zone in areas of heavy snowfall on the Sea of Japan side. As regards the reason for the strong correlation between the distribution of *S. kurilensis* and snow depth, it is known that snow is essential for the survival of this plant, which is evergreen and puts out winter buds above ground, by protecting its epigeal part from damage caused by the cold and dry conditions of winter. As a dominant species on the forest floor it hinders the regeneration of trees; however, its vegetation cover, rhizomes, and root systems are useful for soil conservation in mountainous areas.

S. kurilensis is distributed only in the areas with heavy snowfall and has a slow rate of migration, so it is expected to be greatly affected if snow decreases due to global warming. A classification tree model was used to project suitable habitats for *S. kurilensis* and the impacts of global warming on its distribution. Using data on the distribution of *S. kurilensis* extracted from the Phytosociological Relevé Database (PRDB; Tanaka et al., 2005), which integrates data on relevés (vegetation survey plots) reported in the literature, etc., as well as four climatic variables (warmth index, daily minimum temperature of the coldest month, summer precipitation, and winter precipitation) calculated from the present climate (JMA, 1996), a model was prepared to project probability occurrence of *S. kurilensis* from the climatic variables. By incorporating the present climate data (JMA, 2002) the two climate scenarios, RCM20 and MIROC (2031-2050 and 2081-2100) into this model, present and future suitable habitats for *S. kurilensis* were projected.

(4) Mountain bogs

Bogs are vegetation formed in wet locations with late snow release, and consist of various plant species corresponding to differences in temperature, moisture, and nutritional conditions. The Sea of Japan side of the country is an environment of heavy snowfall that is uncommon in the world. In mountainous areas of this region, many bogs have developed in flat and gentle slopes that are conserved by snow and rainfall only. Plant species growing in such bogs adapt to the wet and low-temperature environment. As these bogs are directly affected by the impacts of global warming including decreased snowfalls in recent years, their condition is considered to be deteriorating. Therefore, past changes in bogs located on a flat area around the summit of Mt. Hiragatake on the border between Gunma and Niigata Prefectures, which is a representative mountainous area with heavy snowfall, were studied based on aerial photographs from 1971 to 2000. Aerial photographs taken every five years during this period were digitized and distortions in the photographs were corrected (orthorectified), making it possible to compare the positions with radius 30cm accuracy. From the images of the bogs, the boundaries between the bogs and surrounding dwarf-bamboo thickets and forests were mapped, and changes in the bog area over the years were compared. In addition, weather data for the past 80 years were gathered from three meteorological observatory stations in the surrounding area, and changes of climatic factors including the amount of snow were analyzed.

(5) *Pinus pumila* (subalpine stone pine)

Pinus pumila (Japanese name: haimatsu) belonging to the family of Pinaceae is a prostrating shrub that is widely distributed in the northeastern regions of the Eurasian Continent. In Japan, it is distributed from Hokkaido in the north to the Akaishi Mountains in the south and Mt. Hakusan in the west. It is dominant in the alpine zone higher than the forest line in mountainous areas. Due to its distribution restriction to the higher elevations of mountainous areas, this species is considered to be vulnerable to global warming as its suitable habitats can be expected to shrink or disappear. To assess the impacts of global warming on the distribution of *P. pumila*, data on its distribution extracted from PRDB and four climatic variables (warmth index, daily minimum temperature of the coldest month, summer precipitation, and winter precipitation) calculated from the present climate data (JMA, 1996) were used to prepare a classification tree model that projects occurrence probability of *P. pumila* from climatic variables. By incorporating the present climate data (JMA, 2002) and two climate scenarios, RCM20 and MIROC (2031-2050 and 2081-2100) into this model, present and future suitable habitats for *P. pumila* were projected. At this juncture, since there are mountainous areas that are climatically suited to but actually have no distribution of *P. pumila* such as Mt. Fuji, the areas of actual distribution of *P. pumila* were mapped based on the survey data of Hayashi (1954), and suitable habitats after global warming in the areas of actual distribution of *P. pumila* were projected.

(6) *Abies veitchii* (Veitch's silver fir)

Abies veitchii (Japanese name: shirabe; also known as shirabiso) is an evergreen conifer that is dominant in the subalpine zone from Fukushima Prefecture in Honshu to Shikoku. In Shikoku, it is distributed only around the summits of Mt. Ishizuchi and Mt. Tsurugi, and it is sometimes distinguished as its variety, *Abies veitchii* var. *reflexa* (shikoku shirabe). To assess the impacts of global warming on the distribution of *A. veitchii*, data on distribution of the species including *A. veitchii* var. *reflexa*, extracted from PRDB, as well as four climatic variables (warmth index, daily minimum temperature of the coldest month, summer precipitation, and winter precipitation) calculated from the present climate data (JMA, 1996), were used to prepare a classification tree model that projects occurrence probability of *A. veitchii* from the climatic variables. By incorporating the present climate data (JMA, 1996) and two climate scenarios, RCM20 and MIROC (2031-2050 and 2081-2100) into this model, present and future suitable habitats for *A. veitchii* were projected.

2.3 Future Projection of Impacts on Natural Forests

(1) *F. crenata* forests

Suitable habitats for *F. crenata* forests will sharply decrease due to global warming.

The impacts of climate change on potential habitats of *F. crenata* forests in Japan were projected using Third Mesh climatic data (JMA, 2002) for the present climate, the RCM20 and MIROC climate scenarios for the future climate, and Digital National Land Information for land variables. As mentioned above, RCM20 and MIROC represent a low-level and a high-level in global warming scenarios, respectively.

Suitable habitats (probability of occurrence: 0.5 or more) in the areas of actual *F. crenata* forest distribution are projected to decrease to 65% and 44% in 2031-2050, and 31% and 7% in 2081-2100, by the RCM20 and MIROC climate scenarios, respectively, compared with under the present climate (**Table I-II-1**, **Fig. I-II-1**). In either scenario, *F. crenata* forests in western Japan and on the Pacific Ocean side of Honshu, where almost all of the suitable habitats will disappear, are considered to be vulnerable.

Following global warming, low-altitude areas will become unsuitable for the formation of *F. crenata* forests and there is a possibility that *F. crenata* will be replaced by other tree species distributed in these areas. *F. crenata* trees may be replaced by deciduous trees such as *Quercus serrata* (konara oak), *Quercus crispula* (mizunara oak), and *Castanea crenata* (kuri chestnut) in low-altitude areas on the Sea of Japan side of Honshu, and by evergreen oaks (mainly *Cyclobalanopsis* spp.) and *Abies firma* (momi fir) in addition to these deciduous tree species in Kyushu and Shikoku and on the Pacific Ocean side of Honshu. Since the life span of *F. crenata* is 200-400 years and they will probably not decline and die due to global warming; however, with the decline of old *F. crenata* trees, the replacement of tree species are expected to gradually progress. It is important in the future to monitor whether the replacement of tree species is smoothly progressing after the decline of *F. crenata*.

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Table I-II-1 Changes in suitable habitats for *F. crenata* forests (probability of occurrence ≥ 0.5) under climate change scenarios. The values indicate the number of Third Mesh cells (1 km2 grid cells).

Climatic data	Suitable habitats*	Suitable habitats with *F. crenata* forests**
Present climate (1971-2000)	22,314	11,869
RCM20(2031-2050)	20,102	7,720
RCM20(2081-2100)	7,353	3,644
MIROC(2031-2050)	10,215	5,170
MIROC(2081-2100)	5,197	798

* Number of cells of suitable habitats throughout Japan,

** Number of cells of suitable habitats in areas of actual distribution of *F. crenata* forests.

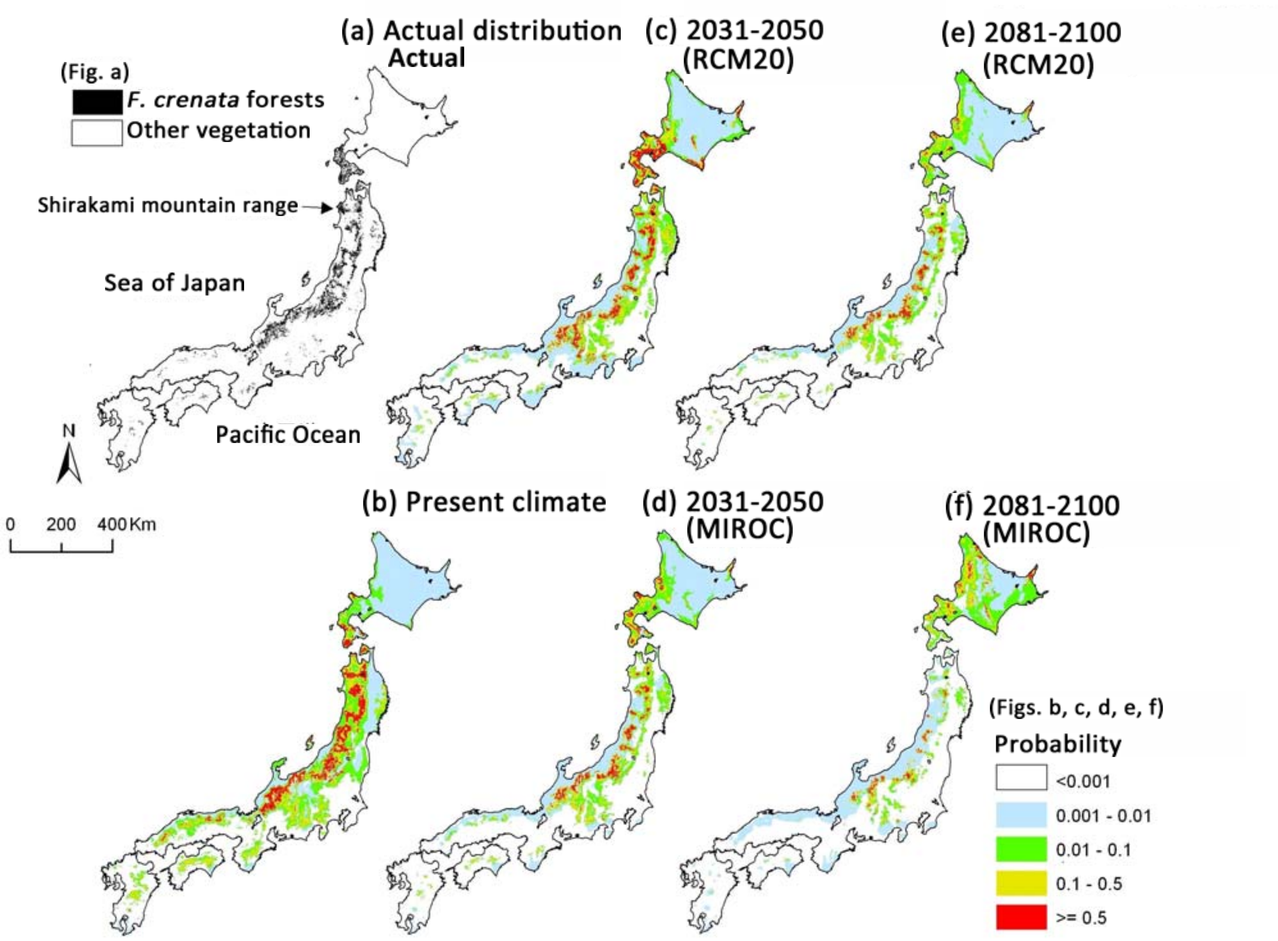

Fig. I-II-1 (a) Actual distribution and (b)-(f) projected probability of occurrence of *F. crenata* forests under each climate condition

F. crenata forests in the Shirakami mountain range are also vulnerable to global warming.

The Shirakami mountain range has been registered as a World Natural Heritage site due to natural *F. crenata* forests covering a wide area. To project the impacts of global warming on *F. crenata* forests in this area, the model projecting the *F. crenata* forest distribution (ENVI model), which was developed for the whole of Japan, was zoomed and focused on the Shirakami mountain range (**Fig. I-II-2**). The model revealed that *F. crenata* forest distribution in the Shirakami mountain range is mainly affected by the winter precipitation and warmth index among the four climatic variables (Matsui et al., 2007). Since there is little change in winter precipitation in the two climate scenarios used (RCM20 and MIROC), the main factor impacting the future distribution of *F. crenata* forests is heat amount indicated by the warmth index. Suitable habitats with a occurrence probability of 0.5 or more account for 77.0% of the area of this World Natural Heritage site under the present climate, but this figure decreases to 44.3% under RCM20 and to 2.9% under MIROC in 2031-2050, and further to 3.4% under RCM20 and 0.0% under MIROC in 2081-2100. According to the Forest Management Plan Map, about 80% of the World Natural Heritage area were covered by the forests at an age of 150-200 years, so a large number of *F. crenata* trees will be reaching their prime or the end of their life span by 2100. There is a possibility that accompanying global warming, deciduous broadleaf trees such as *Q. crispula*, *Q. serrata*, etc. will increase from the low-altitude limit areas of the *F. crenata* forests after *F. crenata* trees die and that the density of *F. crenata* trees will decrease.

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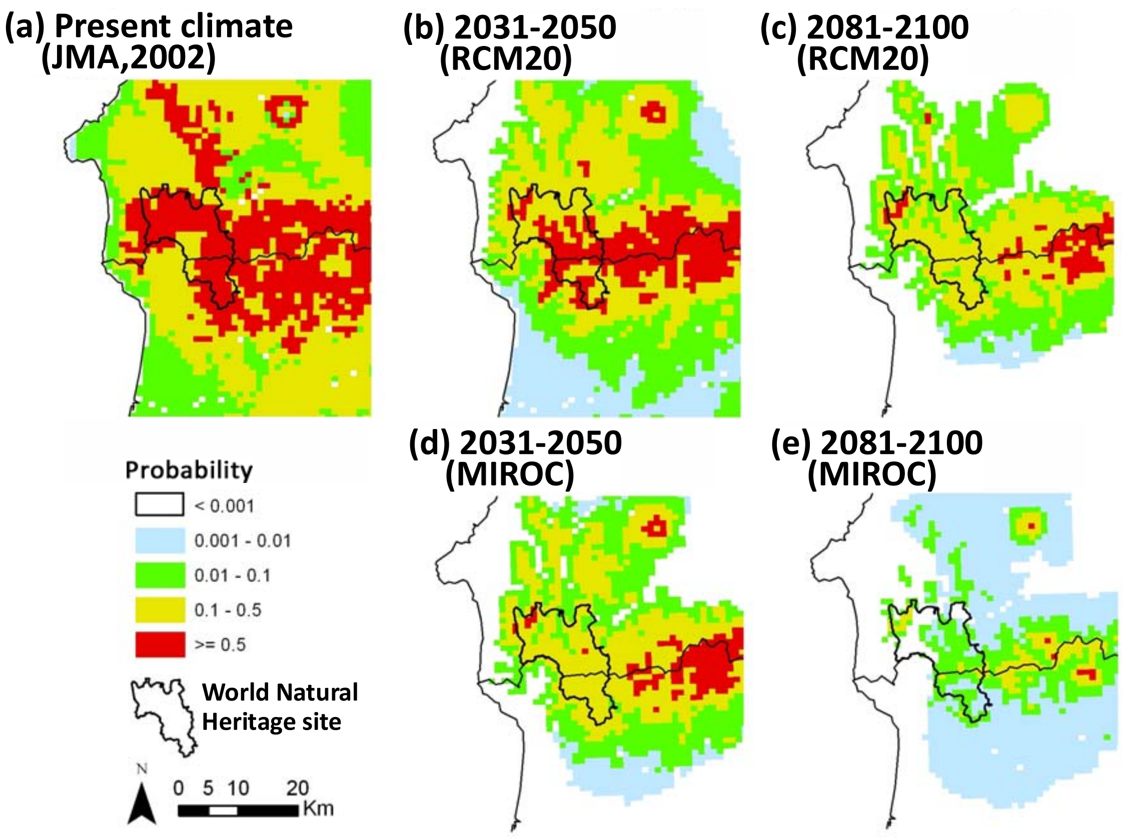

Fig. I-II-2 Projected changes in probability of occurrence of _F. crenata_ forests in the Shirakami mountain range under global warming scenarios

The migration of *F. crenata* in response to global warming at the northern limit of distribution is difficult.

The northern limit of present *F. crenata* forests is around the Kuromatsunai lowland on southwestern Hokkaido. To assess impacts of global warming on the northern limit, changes in suitable habitats for *F. crenata* forests were studied with the *F. crenata* forest distribution model based on climatic variables of the Third Mesh. According to the two climate scenarios (RCM20 and MIROC), the distribution of suitable habitats will expand northeastward beyond the Kuromatsunai lowland (**Fig. I-II-3**). It can therefore be projected that the opportunity for *F. crenata* to migrate to the northeastern area beyond the current northern limit will increase with global warming. Based on pollen analysis, the speed of the northward migration of *F. crenata* since the last glacial period has been estimated as a maximum of 233 m/year in Honshu and 11-20 m/year in Hokkaido. The distance of the northward migration of the minimum temperature of the coldest month in Hokkaido under the RCM20 and MIROC scenarios is 10-50 km over a period of 100 years, with the figure differing according to the area. Even assuming the rate of migration of *F. crenata* as the past maximum value of 233 m/year, the migration distance will be no more than 23.3 km over a period of 100 years. If global warming progresses as in these scenarios, it can be fully expected that the migration of *F. crenata* will not be able to keep pace with the temperature rise.

Contiguous natural forests are necessary for *F. crenata* to migrate smoothly, but natural forests are divided by artificial forests, agricultural lands, cities, etc. under present land use so the migration of *F. crenata* will not be easy. In particular, the Ishikari lowland, which is not a suitable habitat due to their high temperature and dry conditions, will create a wide division in the suitable habitats even after global warming, with the result that the migration of *F. crenata* is expected to be hindered.

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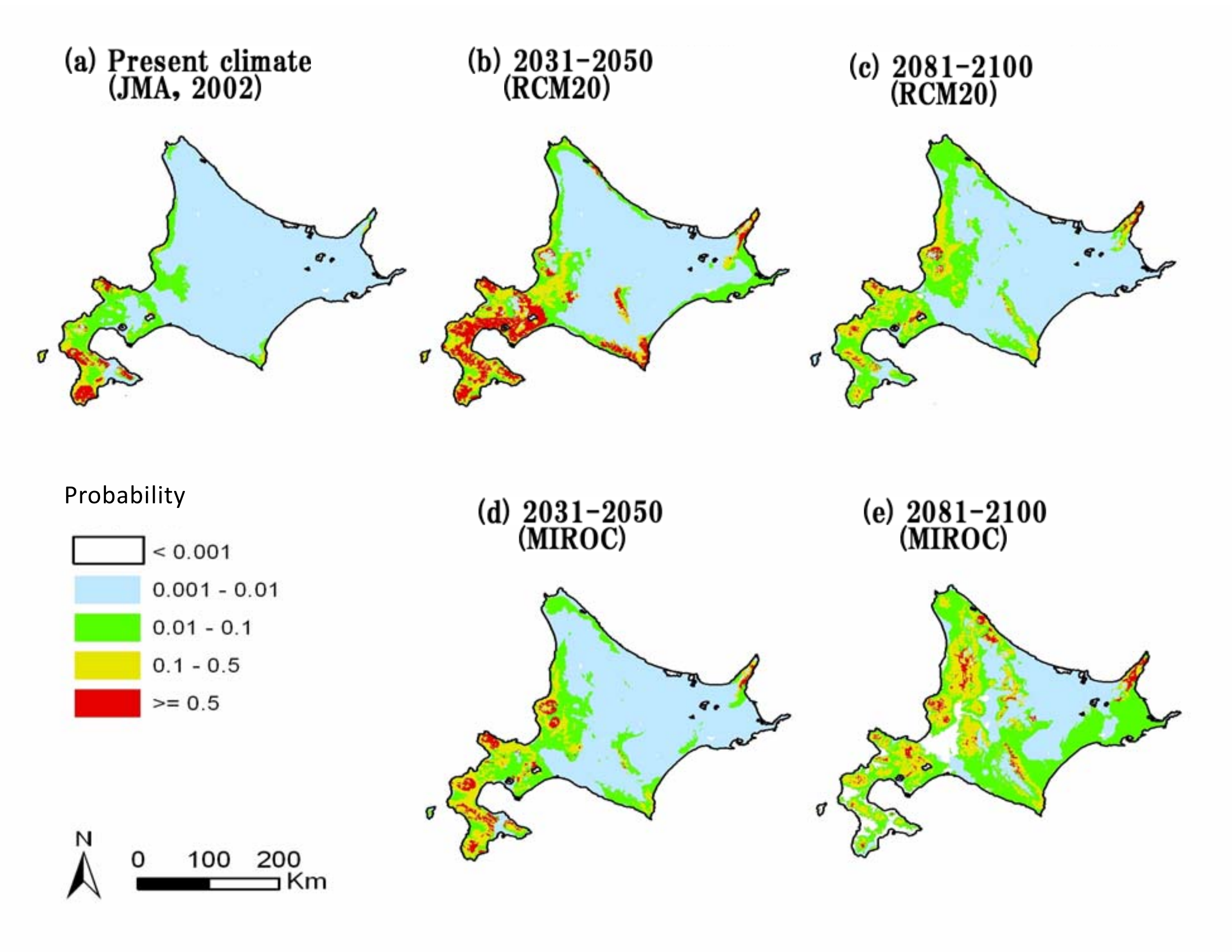

Fig. I-II-3 Changes in probability of occurrence of *F. crenata* forests in Hokkaido following global warming

Projection of suitable habitats for *F. crenata* forests corresponding to various climate changes

The probability of occurrence of *F. crenata* forests under 110 different climate conditions was projected using the *F. crenata* forest distribution projection model (ENVI model) with gradually changing precipitations in the range of -50% to +50%, and temperatures in the range of -2°C to +7°C from the present state (**Figs. I-II-4** and **I-II-5**). These climate change conditions cover almost the entire scope of changes in temperature and precipitation of the various climate change scenarios, making it possible to project the probability of occurrence of *F. crenata* forests under any type of climate change scenario without complex calculations.

When the projected changes in the present areas of *F. crenata* forests are examined, in the case of a 2°C rise in temperature compared with the present together with a concurrent 40% increase in precipitation, suitable habitats will decrease to 60% of the present level; conversely, if precipitation decreases by 40%, suitable habitats will be reduced to less than 20% of the present level. Even if the temperature rises by 4°C with precipitation increase by 40%, suitable habitats will be reduced to only 10%. These results show that not only temperature increase but also precipitation decrease greatly lower the probability of occurrence of *F. crenata* forests.

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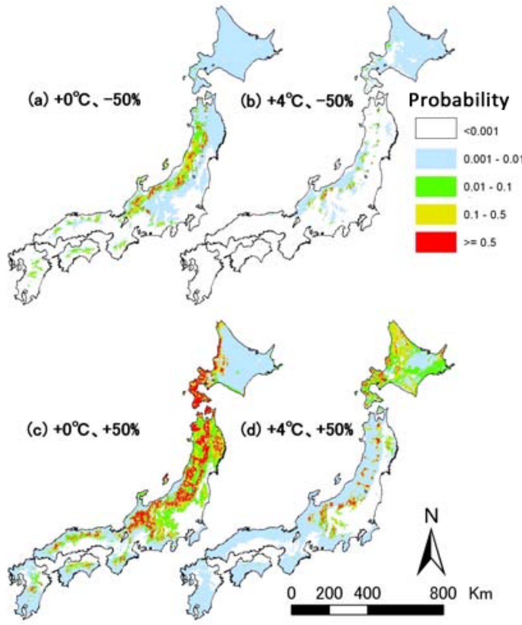

Fig. I-II-4 Projection of changes in occurrence probability of *F. crenata* forests when the temperature and precipitation are uniformly changed throughout Japan from the present climate to: (a) temperature change of +0°C and precipitation change of -50%, (b) +4°C and -50%, (c) +0°C and +50%, (d) +4°C and +50%

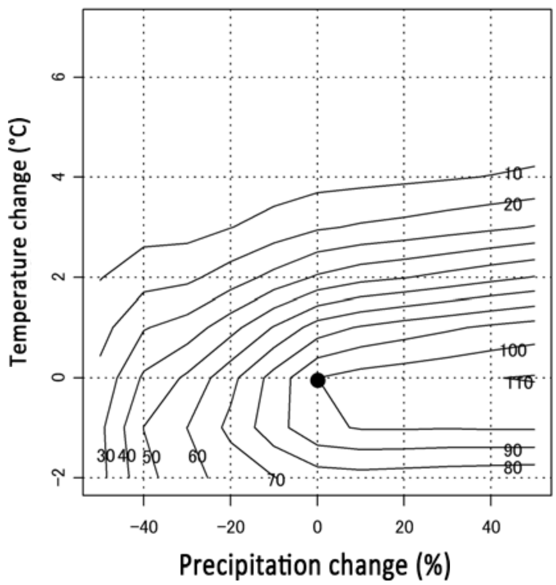

Fig. I-II-5 Ratio (%) of suitable habitat cells (probability of occurrence ≥ 0.5) for *F. crenata* forests to the mesh cells of existing *F. crenata* forests when the temperature is changed in 1°C increments between -2°C and +7°C and precipitation in 10% increments between -50% and +50% from the present climate. The isolines represent the ratio under the different combinations of temperature and precipitation. The black solid circle (coordinate 0,0) indicates the position of the present climate.

Topic

Economic value of *F. crenata* forests for the whole of Japan: 6.2 trillion yen

In December 2007, a “Survey on Attitudes toward the Conservation of Forest Ecosystems” was conducted with the participation of 84 students at the Faculty of Urban Science of Meijo University in an attempt to assess the economic value of *F. crenata* forests. The objective of the assessment, performed with the contingent valuation method (CVM), was to determine the value of *F. crenata* forests which preserve the biodiversity and cover approx. 23,000 km^2 throughout Japan. As a result of this assessment, the amount of willingness to pay (WTP) to avoid the destruction of *F. crenata* forests was found to be 1,954 yen/year/person. When this numerical value is converted to the present value using a social discount rate of 4% per year, the economic value of *F. crenata* forests becomes 48,861 yen/person. When this basic unit is multiplied by the total population of Japan, 127,740,000, the economic value of the 23,000 km^2 of *F. crenata* forests throughout Japan becomes 249.7 billion yen/year (present value: 6,241.5 billion yen).

Since the above results are based on the data from 84 students only, they cannot be considered to be fully reliable. From past experience, however, no major differences are found between the results of preliminary surveys conducted on a scale of around 100 students, such as the present survey, and actual nationwide surveys with a scale of around 1,000 adult males and females. Therefore, the economic value of *F. crenata* forests shown in the present survey can be considered to be an adequate rough estimation.

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(2) Pine wilt

Pine wilt damage will expand due to global warming.

To assess the impacts of global warming on pine wilt, the changes in areas of damage were projected using the accumulated temperature with a threshold of 15°C (MB index). Pine wilt damage has expanded as the pinewood nematode (*Bursaphelenchus xylophilus*) has spread from its original habitat of North America to all parts of the world through trade in timber, etc. The activity of the pinewood nematode and its vector the Japanese pine sawyer (*Monochamus alternatus*) is restricted by low temperature. Therefore, areas of pine forests at high risk of pine wilt can be estimated by the MB index. The MB index was developed from the growth characteristics of the pinewood nematode and the Japanese pine sawyer in order to project areas of the occurrence of pine wilt disease in *Pinus densiflora* (Japanese red pine; Japanese name: akamatsu) forests. Areas with an MB index exceeding 22 are areas at risk of pine wilt, those with an index of less than 19 are areas of naturally suppressed pine wilt, and those with an index of 19-22 are boundary area between these two areas. Present pine wilt damage has been observed in the plains on the Sea of Japan side up to Happo Town in Akita Prefecture (a town bordering Aomori Prefecture), in the Kitakami lowlands up to Shiwa Town in Iwate Prefecture, and in the Sanriku coast up to Ofunato City in Iwate Prefecture.

The risk of pine wilt damage will increase with global warming. **Figure I-II-6** shows the calculated areas at risk of pine wilt, areas of naturally suppressed pine wilt, and boundary areas, with taking land use into account when the monthly mean temperature rises by 1°C from the present temperature. With a 1-2°C temperature rise, the area at risk is expected to expand even to the plains of Aomori Prefecture, where there is currently no damage. Moreover, if the temperature rise exceeds 2°C, it is feared that pine wilt will devastate the *P. densiflora* forestry and matsutake mushroom production in the inland area of Iwate Prefecture. There are areas such as the Tsugaru Plain where pine wilt risk is expected under the present temperature conditions but damage has not yet been observed, leading to concern over the northward expansion of damaged areas.

In response to an outbreak of pine wilt disease in the northern limit area of Akita Prefecture in the summer of 2005, the prefectural authorities of Aomori implemented intensive monitoring of the zone extending 6 km north to south in the coast of the Sea of Japan, and established a protection zone against the spread of pine wilt that extended for 2 km at both the northern and southern ends in which all of live pine trees were clearly cut to eliminate trees with the potential to become newly infected. The experience obtained through such control operations provides useful information when considering adaptation measures at the time of global warming.

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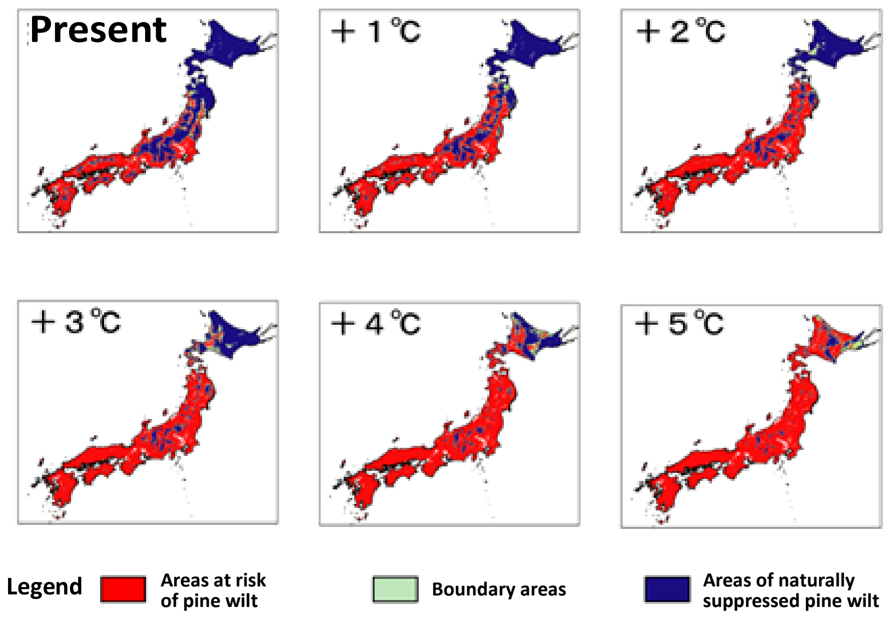

Fig. I-II-6 Projection of areas at risk of pine wilt at present and at the time of global warming (+1 to +5°C)

(3) *S. kurilensis*

***S. kurilensis* is vulnerable to global warming in low-altitude areas.**

Using data on the distribution of *S. kurilensis* extracted from the PRDB, the present climate data (JMA, 2002), and two climate change scenarios (RCM20, MIROC), the suitable habitats for *S. kurilensis* at present and after global warming (2031-2050) in eastern Honshu were projected (**Fig. I-II-7**).

Suitable habitats for *S. kurilensis* are located in cold areas with a large amount of winter precipitation, and their distribution under the present climate centers along the Sea of Japan side of the country from the Tohoku region to Niigata Prefecture. After global warming, reductions in such habitats centering in low-altitude areas are projected under both the RCM20 and MIROC scenarios, with present suitable habitats shrinking to 54% in the case of RCM20 and to 45% in the case of MIROC. In areas that are no longer suitable habitats, *S. kurilensis* may decline under global warming. A particularly vulnerable area is Sadogashima (Sado Island), where suitable habitats almost disappear (Tsuyama et al., 2008).

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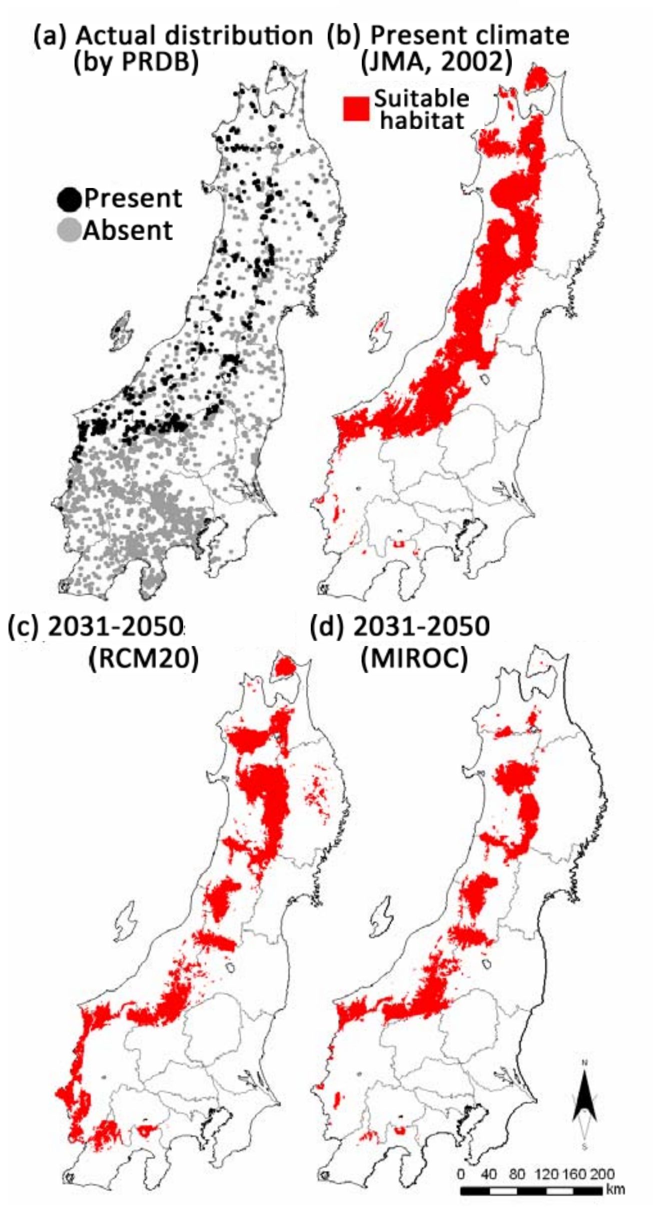

Fig. I-II-7 (a) Actual distribution of *S. kurilensis* in eastern Honshu, and projection of suitable habitats under (b) present climate and (c, d) after global warming

(4) Mountain bogs

With the trend toward mild winters and decreases in snow, mountain bogs have been shrinking.

Large and small bogs are distributed around the summit area of Mt. Hiragatake (summit altitude 2,140 m) situated on the border between Gunma and Niigata prefectures. These bogs have become established here because there is a large volume of snow in a poorly drained topography. Bog plants such as *Sphagnum* spp., *Carex blepharicarpa, Moliniopsis japonica,* etc., and snowbed plants such as *Nephrophyllidium crista-galli* subsp. *japonica, Rhodococcum vitis-idaea,* etc., grow in these bogs. *S. kurilensis* thickets, *P. pumila* bushes, *Abies mariesii* forests, etc. are distributed in areas surrounding bogs.

Analysis on aerial photographs of a bog on Mt. Hiragatake (**Fig. I-II-9**) revealed that during the 30 years from 1971 to 2000, the area of the bog shrank by approximately 10% (Yasuda et al., 2007). A field survey revealed that the boundary area had changed to colonies of *S. kurilensis* accompanied with conifers such as *P. pumila* (**Fig. I-II-8**).

Following the trend of mild winters in recent years, a decrease in snow cover has been observed in this area (Yasuda and Okitsu, 2006). When snow depth decreases, photosynthesis of plants becomes possible for a longer period and the peat layer underlying a bog becomes drier, facilitating the plant species other than bog plants to grow in a bog. The shrinkage of bogs due to the invasion of *S. kurilensis* and *P. pumila* is considered to be an impact of mild winters and less snow. There is a concern that further shrinkage of bogs will continue with future increases in temperature and reductions in snow.

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Fig. I-II-8 *S. kurilensis* and *P. pumila* invading bogs

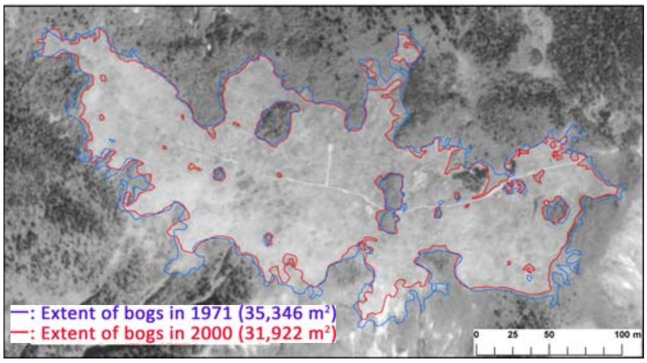

Fig. I-II-9 Comparison of extent of bogs in 1971 and 2000 based on aerial photographs

(5) *P. pumila*

P. pumila in the Tohoku region is vulnerable to global warming.

To assess the impacts of global warming on *P. pumila*, which is a typical alpine zone species, a model to project its distribution from climate conditions was prepared and the distribution of suitable habitats was projected. The present distribution of *P. pumila* is limited to the upper elevations of mountainous areas and divided into parts by tracts of land intervening between these mountainous areas. Therefore, on the assumption that migration to other mountainous areas will not occur after global warming, the projection of suitable habitats was carried out in the actual areas of distribution of *P. pumila* (**Fig. I-II-10).**

The size of the suitable habitats under the present climate in the actual area of distribution of *P. pumila* is 7,867 km^2. In 2031-2050, after the occurrence of climate change, the area of suitable habitats is reduced to 3,855 km^2 (49%) in the case of RCM20 and to 4,392 km^2 (56%) in the case of MIROC. In 2081-2100, the area is reduced to 2,456 km^2 (31%) and 1,061 km^2 (14%) by RCM20 and MIROC, respectively. In either case, the area of suitable habitats was projected to shrink or disappear in all of the mountainous locations in which this species is distributed. The Tohoku region is considered to be particularly vulnerable, with the suitable areas projected to be reduced to 14% and 9% in 2031-2050 and 2081-2100, respectively, by RCM20 and 6% and 0% by MIROC. With the disappearance of suitable habitats in the Tohoku region, the suitable areas will be roughly divided into two regions: the mountainous areas of Chubu and Hokkaido.

Masahiro HORIKAWA and Nobuyuki TANAKA
(Forestry and Forest Products Research Institute)

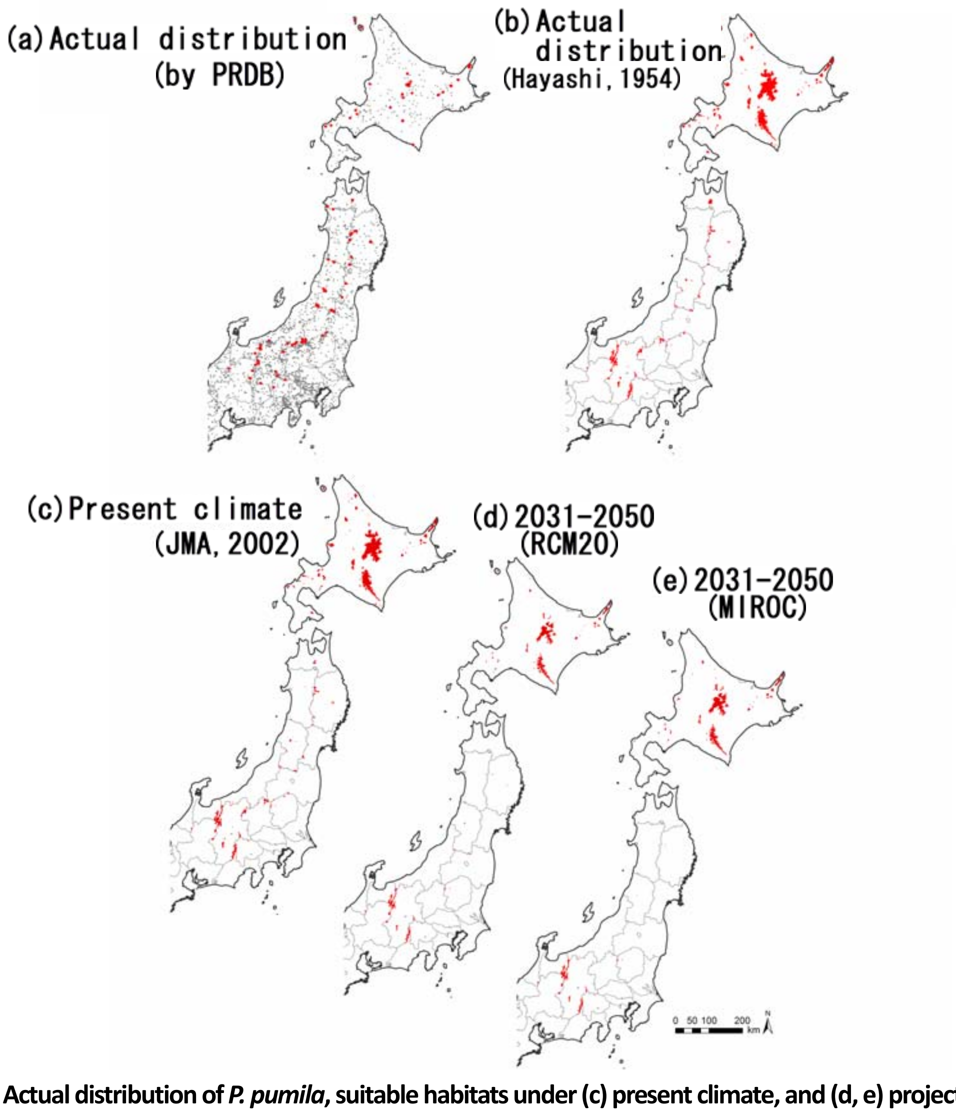

Fig. I-II-10 (a, b) Actual distribution of *P. pumila*, suitable habitats under (c) present climate, and (d, e) projected suitable habitats after global warming

(6) *A. veitchii*

***A. veitchii* var. *reflexa* (shikoku shirabe) is concerned to become extinct due to global warming.**

A. veitchii is a dominant species in the subalpine zone from Fukushima Prefecture in Honshu to Shikoku. In Shikoku, a variety of this tree species, *Abies veitchii* var. *reflexa*, is distributed only around the summits of high mountains. To assess impacts of global warming on *A. veitchii*, a model to project its distribution from climate conditions was prepared and by incorporating the RCM20 and MIROC climate change scenarios, the distribution of suitable habitats after global warming was projected (**Fig. I-II-11**).

The area of suitable habitats for *A. veitchii* under the present climate in Honshu from Fukushima Prefecture southward and in Shikoku is 3,859 km^2. In 2031-2050, after the occurrence of climate change, the area is reduced to 991 km^2 (26%) in the case of RCM20 and to 1,864 km^2 (48%) in the case of MIROC. In 2081-2100, the area is reduced to 879 km^2 (23%) and 509 km^2 (13%) by RCM20 and MIROC, respectively. In either case, the area of suitable habitats is expected to shrink or disappear in all of the mountainous areas in which this species is distributed. In particular, suitable habitats are projected to disappear in Shikoku under either scenario, and it is therefore concerned that *A. veitchii* var. *reflexa* will become extinct.

Nobuyuki TANAKA and Etsuko NAKAZONO
(Forestry and Forest Products Research Institute)

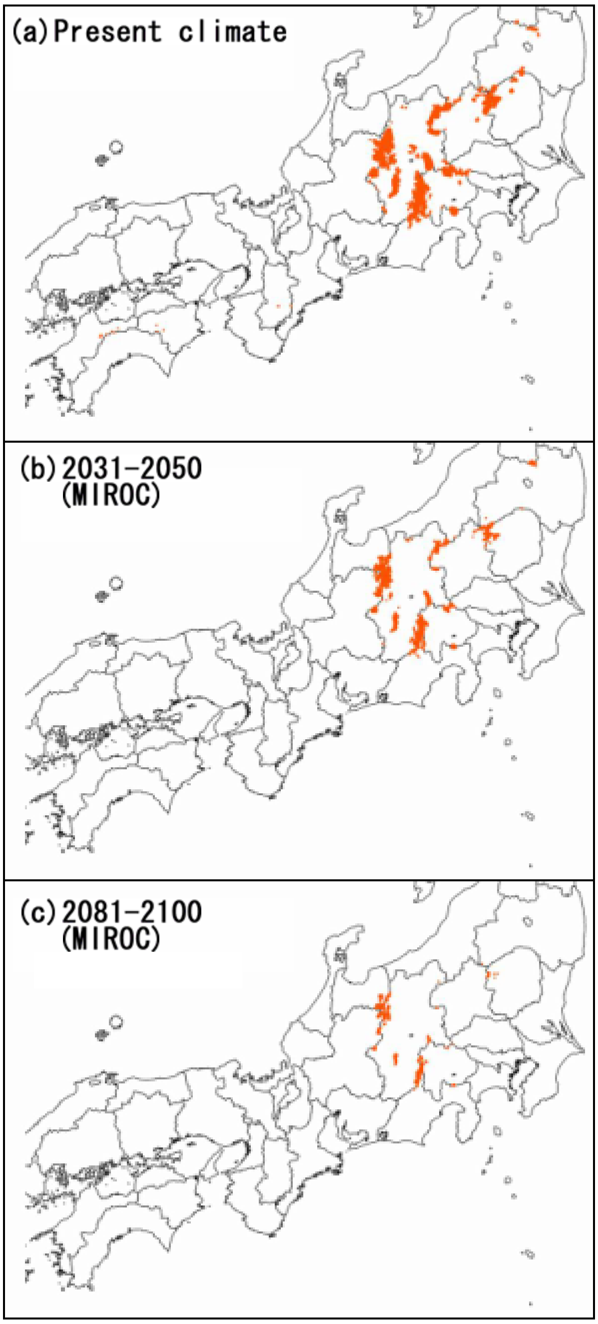

Fig. I-II-11 Changes in suitable habitats for *A. veitchii* (vermilion color), under present climate and projections in 2031-2050 and 2081-2100 under MIROC climate change scenario

Topic Impacts of global warming on sika deer (*Cervus nippon*)

It has been reported that the habitats of sika deer (Japanese name: *shika*) have been expanding in various locations in recent years. This has mainly been attributed to the compound effect of a growing population of these deer and decreasing snow depth in mountainous areas. The activities and food intake of sika deer are hindered when the depth of snow exceeds 50 cm, and the number of dead individuals increases when such a snow condition continues for a prolonged period. Damages caused by sika deer and observation in recent years have been reported from areas where their distribution was previously restricted by snow, and the impact of the decrease in snow depth since the 1980s has been pointed out as one of the causes of this together with the growth in the deer population. In order to assess the impacts of global warming in greater detail in the future, it will be necessary to accurately monitor both the snow depth in mountainous areas and the distribution of sika deer.

Hiromu DAIMARU
(Forestry and Forest Products Research Institute)
(Reference: Li et al., 1996)

3. Impacts on Agriculture

3.1 Outline

The production of major cereals in the world (rice, wheat, maize, and soybeans) posted a higher rate of growth than the population growth in the past due to the progress made in breed improvement, cultivation techniques, etc. From the 1980s, however, the growth in production began to slow and an increasingly fluctuating trend appeared. The following are sources of concern as factors leading to further destabilization of the food supply: firstly, climate change and accompanying extreme weather events such as droughts, flood, high temperatures, etc.; secondly, increasing demand for food and declining self-sufficiency due to economic growth and population increases in Asian countries; and thirdly, extremely uneven distribution of cereals by the world's major exporting countries in the continents of North America, South America, and Australia due to dependence on foreign trade and international division of labor. Moreover, competition with biomass fuels is now an additional source of concern.

With regard to the impacts of climate change on the food supply in Japan, this report presents the results of estimations carried out from two perspectives: direct impacts on production in Japan, and indirect impacts through changes in global food supply and demand relationships. In the case of the former, impacts on the production of rice, the staple food of Japan, are targeted.

3.2 Targets and Methods of Impact Assessment

(1) Rice production in Japan

In order to assess the risk of changes in rice yield (production per unit area) in Japan accompanying climate change, a mechanistic model that describes the whole of Japan by prefecture (**Fig. I-III-1**) was constructed to elucidate the relationship between the weather environment such as temperature, insolation, atmospheric CO_2 concentration, etc. on the one hand, and the growth of rice plants and the yield of rice on the other. This model quantitatively reproduces the average heading date of rice by prefecture as well as inter-annual variation in average rice yield from the conditions of the past weather environment, and estimates the impacts of future climate change on the growth of rice plants and the yield of rice.

The procedure for preparation of the model to assess rice yields over a wide area is as follows (Yokozawa et al., 2006):

1) The paddy field mesh for each prefecture is extracted using land use distribution data (digital national land information).
2) The average weather conditions (maximum and minimum temperatures and insolation, by day) are calculated for the paddy field mesh of each prefecture extracted in step 1), using weather mesh data (prefectural average paddy field weather data).
3) Targeting the 25 years from 1979 to 2003, the prefectural average paddy field weather data prepared in step 2) are input using a nonlinear optimization technique while making comparisons with the average transplanting date, average heading date, average harvesting date, and yield data using crop statistics by prefecture to determine the parameters of the model. Note that determination of the parameters is carried out for odd-numbered years within the target period, while verification of the model is carried out for all years including even-numbered years. This process is implemented for all prefectures.

This model is similar in structure to the Simulation Model for Rice-Weather Relations (SIMRIW), which is Japan's representative prediction model for paddy rice growth and yield. However, prediction models for paddy rice growth and yield up to now have targeted phenomena on the cultivated field scale and have required detailed information such as varieties, cultivation management, etc., making them unsuitable for assessing the whole of Japan on a broad scale. Compared with these previous models, a distinctive feature of the model used in the present study is that although in terms of prefectural averages it statistically reflects past actual growth conditions and changes in yield, and also incorporates the mechanism of the environmental responses of crops, thus allowing the impacts of future climate change to be quantitatively estimated. Moreover, Bayesian inference is utilized as well to quantitatively reproduce inter-annual variation in past yields and take uncertainty of the model's parameters into account. This makes it possible to probabilistically reproduce inter-annual variation in yields, which is an unprecedented feature of such a model (**Fig. I-III-2**; Iizumi et al., 2008).

Since this model targets changes in prefectural average growth and yield of rice crop, it does not show impacts on specific varieties but reflects the average characteristics of the varieties that have been used in the target prefectures up to now. Moreover, this model does not have precipitation as an input. This is because the infrastructure for farmland has been developed in Japan in such a way that there have been almost no reports of damage caused by lack of precipitation over the past 25 years, with the result that precipitation could not be used for construction of the model. In the future climate scenario as well, there is no projection of insufficient precipitation in terms of the total amount required for rice production in Japan. However, as pointed out in the section dealing with impacts on water resources, for example, there is a possibility that decreased snowfall will cause water shortages during the time of plowing and irrigation of fields and during rice planting. Moreover, the results of estimations with regard to insect pests show increasing frequency and severity of appearance accompanying the progress of global warming. Hence, comprehensive assessment of the impacts on paddy ecosystems, including changes in water resources as well as crop damage caused by diseases and insect pests, and crop interaction with weeds, etc., is a future task.

Only yields are focused on in this impact assessment. However, as described later, assessment of the impacts on the food supply also needs to be carried out based on production, calculated by multiplying the area under cultivation by the yield. The likelihood of shifts in the areas in which planting is currently possible will increase due to climate change, although areas under cultivation are determined not only by the natural environment but also by the relationships with economic conditions in Japan and other countries, population, policies, etc. No study has yet been conducted to estimate production in Japan on a detailed scale incorporating not only factors related to the natural environment but also those related to social science; this remains a future task. In the present assessment, the impacts of climate change on rice yields are analyzed assuming the current areas of cultivation, technological levels, rice varieties, and management. With regard to food supply and demand taking socioeconomic factors into account, the analysis was carried out at the country level.

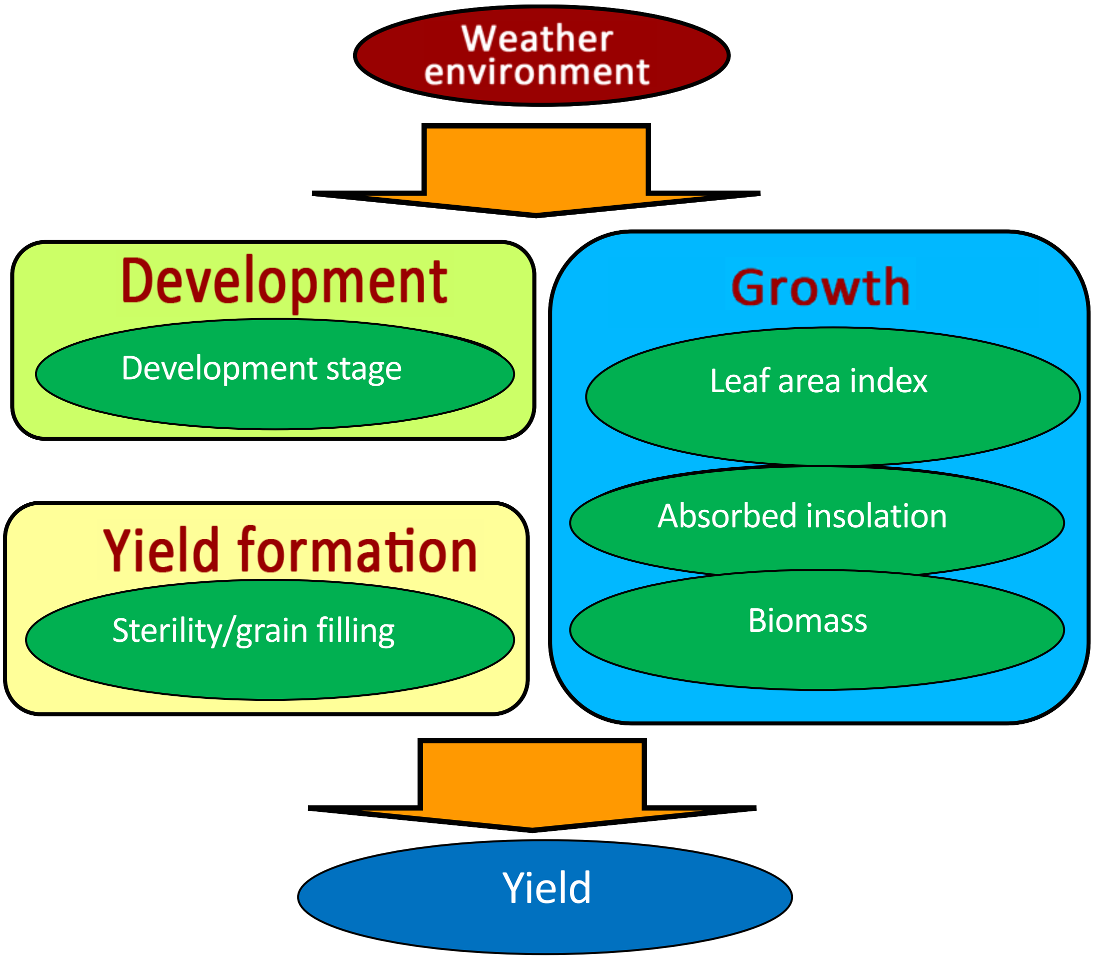

Fig. I-III-1 Structure of model for estimating rice yield by prefecture

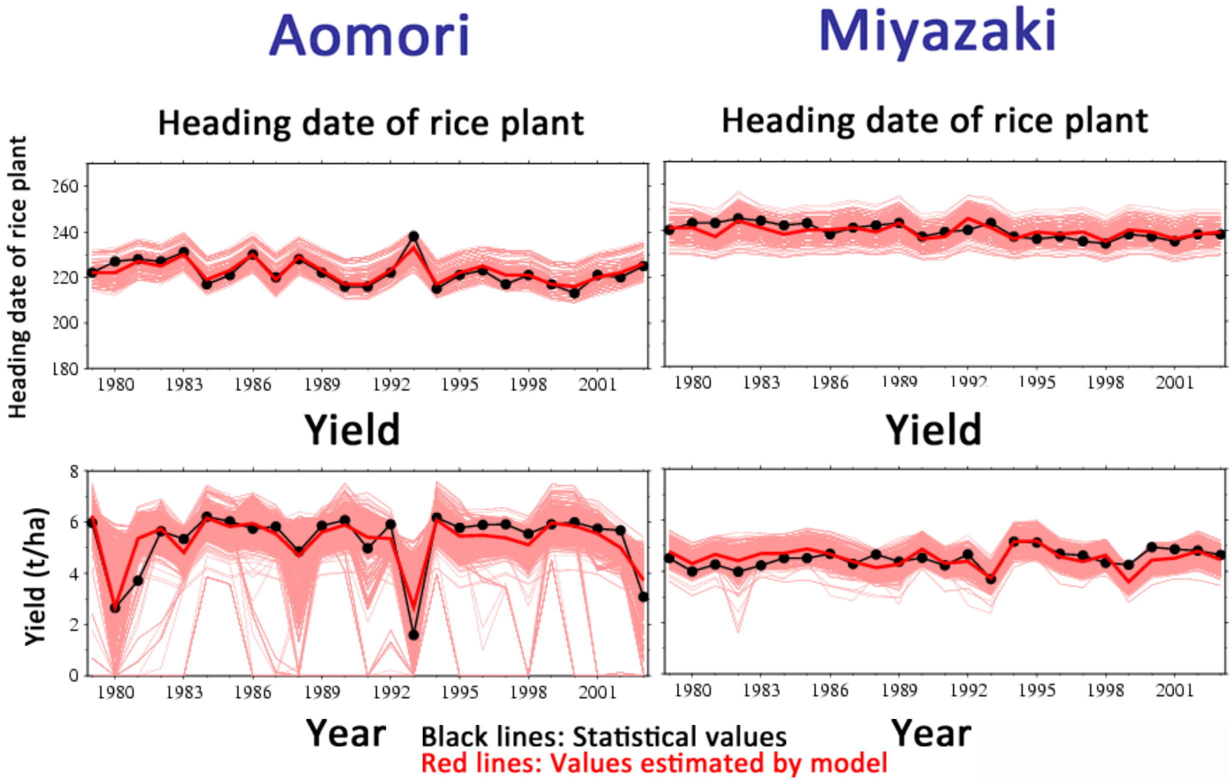

Fig. I-III-2 Example of comparison between values estimated by model for estimating rice yield by prefecture and statistical values

(2) Outlook of impacts of global warming by world food model

When considering the impacts of climate change on food supply and demand, it is necessary to assess such impacts in terms of production (= Yield x Area) taking not only changes in crop yield but also impacts on the area under cultivation into account. Producers change the area under cultivation according to price changes in the market; for example, farmers increase the area under cultivation when they expect the prices of their farm produce to rise in the following year. Market prices are determined by changes in cereal crop stocks, international trade, and other factors. Here, in order to assess impacts on the food supply and demand relationship by country accompanying climate change as well as changes in such economic activities, analysis was carried out using the already developed world food model.

The climate change scenario adopted in this study followed the IPCC Special Report on Emission Scenarios (SRES) A2 scenario, using data (temperature and precipitation) aggregating the results estimated by the HadCM3 (Hadley Centre Coupled Model, version 3) GCM of the Met Office Hadley Centre in the United Kingdom by country. By inputting the projected values of weather variables into the world food model, the impacts of temperature rise on the production and supply of farm produce in the world were estimated.

The world food model (International Food and Agricultural Policy Simulation Model: IFPSIM), which was used as the basis for this assessment, consists of individual functions related to yields, areas under cultivation, exports, imports, stocks, and prices, targeting 14 items and 32 countries and regions (Oga and Yanagishima, 1996). The targeted crops are wheat, maize, other coarse grains, rice, and soybeans; other coarse grains include barley, rye, oats, millets, and sorghum. Furuya and Koyama (2005) prepared yield functions containing temperature and precipitation as variables, and replaced them with the yield functions of IFPSIM. The equation is as follows:

$$\ln YH_t = a + b_1 T + b_2 \ln TMP_t + b_3 \ln PRC_t \qquad (1)$$

where YH is the yield (production per unit area), T is the time trend, and TMP and PRC are the temperature and precipitation, respectively, at the time of flowering. Moreover, when a spurious correlation is detected, the following difference function is used:

$$\mathrm{dln} YH_t = a + b_2 \mathrm{dln} TMP_t + b_3 \mathrm{dln} PRC_t \qquad (2)$$

where $\mathrm{dln}YH_t = \ln YH_t - \ln YH_{t-1}$, $\mathrm{dln}TMP_t = \ln TMP_t - \ln TMP_{t-1}$, and $\mathrm{dln}PRC_t = \ln PRC_t - \ln PRC_{t-1}$. For the temperature and precipitation parameters b_2 and b_3, values significant at the level of 10% or more were used and others were set to 0.

However, for wheat, maize, other coarse grains, and rice in the U.S. and the EU, and soybeans in all countries and regions, the following yield function responding to prices was used:

$$\ln YH_t = a + 0.1\ln(PI_{t-1}/PI_{t-2}) + b_1 T + b_2 \ln TMP + b_3 \ln PRC \quad (3)$$

where a is the calibrated intercept, PI is the subsidized producer price, and b_1, b_2, and b_3 are the parameters of the time trend, temperature, and precipitation, respectively. Other functions of the yield per unit area are the same as in Eq. (1).

Figure I-III-3 is a flowchart related to leader countries in the crops section of the world food model. As shown in the figure, yield, area, production, imports, exports, stock, and demand are internal variables, that is, variables determined in the model, while population, gross domestic product (GDP), temperature, and precipitation are external variables, that is, variables given from outside the model. For the parameters related to temperature and precipitation in the yield functions, those determined by Furuya and Koyama (2005) are used. Other parameters such as the price elasticity of demand are the same as in IFPSIM. The base year of the simulation is 1998, and the period of the projection was set at up to 2030.

The assumptions used for the simulation of climate change impacts are as follows:

1) The cropping calendar is fixed.
2) The cropping area is fixed.
3) Yield is directly affected by weather changes.
4) Temperature and precipitation change according to the climate change scenario of HadCM3 (SRES-A2).

All of the parameters are fixed.

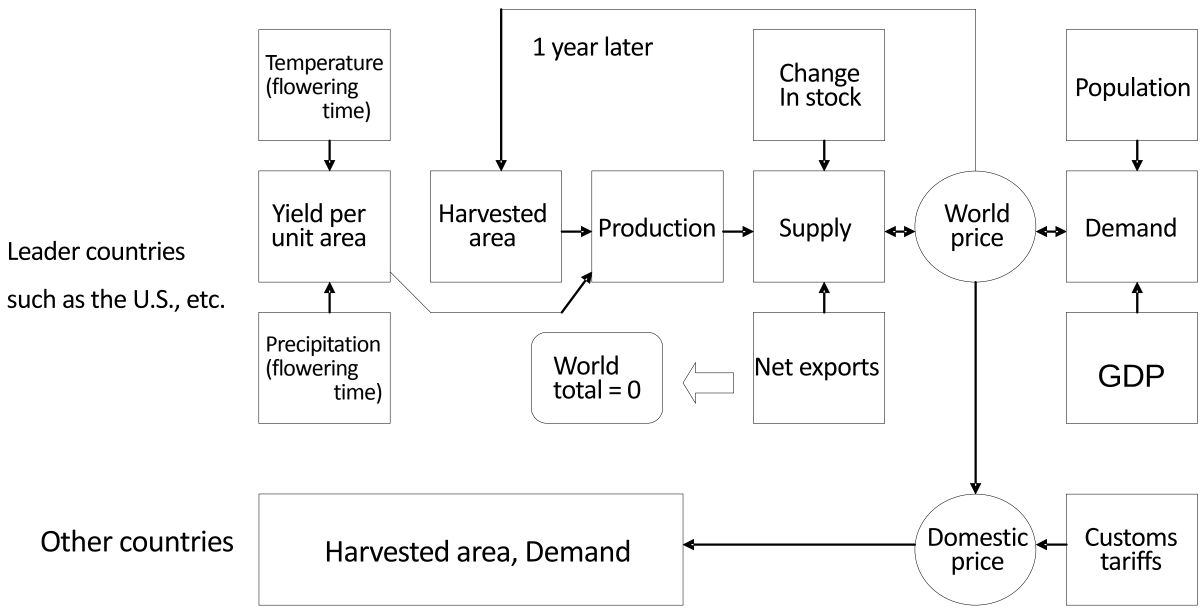

Fig. I-III-3 Flowchart related to leader countries in the crops section of the world food model

3.3 Future Projection of Agricultural Impacts
(1) Rice yield in Japan

Rice yields will increase in northern Japan, while yields in western Japan will be roughly the same as at present or will show a trend of slight reduction.

Rice yield is determined by temperature and insolation in the vegetative growth stage from transplanting (rice planting) to heading, and in the grain-filling stage from heading to harvesting. Temperature rise promotes growth, and affects biomass accumulation and grain formation after heading. Based on the relationship between the growth process of paddy rice and the weather environment, a model for estimating rice yield by prefecture that reproduces past data was prepared and by inputting the climate scenario (MIROC, A1B), the changes in rice yield were estimated.

As a result, assuming the same transplanting dates as at present, it was estimated that the average yields from 2046 to 2065 will increase by 26%, and 13% in the Hokkaido and Tohoku regions, respectively, compared with the present yields (1979-2003 annual mean) (**Fig. I-III-4a**). On the other hand, the yield in both the Kinki and Shikoku regions was estimated to decrease by 5% compared with the present values. This trend becomes more pronounced in 2081-2100, with the estimates showing decreased yields expanding to the Chugoku and Kyushu regions (**Fig. I-III-4b**). The results of these estimations agree with the existing research results with regard to the trend that rice yields will increase in northern Japan, while yields in western Japan will be roughly the same as at present or will show a trend of slight reduction; however, the regional distribution of average yields is different from that obtained in the past. In the scenario used this time, due to the impact of the Pacific high-pressure system ("Pacific high"), a decrease in yields due to high temperature appears, concentrated around central Japan.

As mentioned in 3.2 above, the present assessment takes into consideration impacts in relation to only three weather environment changes; namely, temperature, insolation, and atmospheric CO_2 concentration. Although comprehensive assessments incorporating interactions with other factors remain a future task, the example of assessment incorporating snowmelt water resources and impacts of insect pests in a simplified manner, described in the Topic, "Vulnerability of paddy ecosystems," can be considered to serve as a reference for such assessments. Since the present study and the research described in the Topic use different climate change scenarios and structurally dissimilar rice yield estimation models, a quantitative comparison cannot be made. However, the regional trends in yield changes (e.g. increased yield in northern Japan and decreased yield in western Japan) are similar. As seen in **Fig. I-III-5**, in regions in which rice yield is estimated to increase by this impact assessment, particularly in the area on the Sea of Japan side extending from Tohoku to Hokuriku (the regions colored red and yellow in the map), the possibility of yields changing to a decreasing trend due to the effects of changes in water resources during the snowmelt period is suggested.

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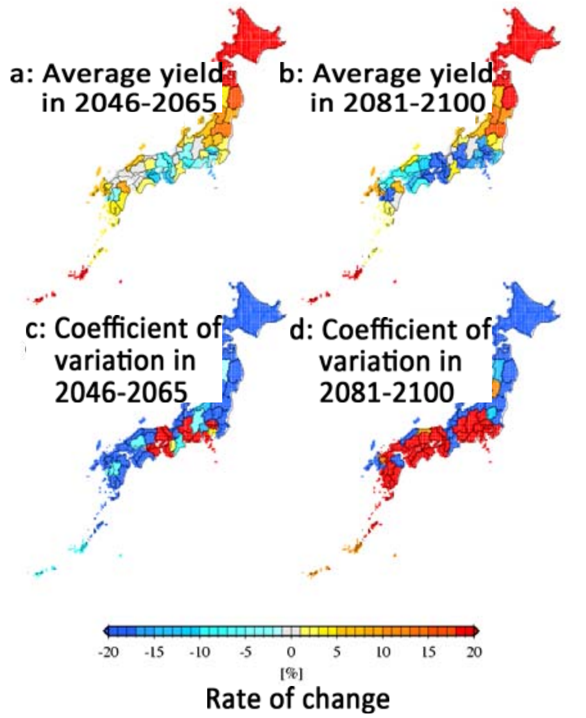

Fig. I-III-4 Results of estimation of changes in rice yield by climate scenario (MIROC, A1B)
Maps *a* and *b* show average yields, while *c* and *d* show the rate of change of the coefficient of variation (the ratio of the standard deviation and average) of the yield for 20 years. The rate of change was defined as the ratio of the difference between the values in the target period (2046-2065 or 2081-2100) and the present values (1979-2003).

Topic Vulnerability of paddy ecosystems

To assess the impacts of climate change on agricultural ecosystems in Japan, there are demands for comprehensive assessments taking not only weather-related factors but also other growth-inhibiting factors such as shortages of agricultural water resources and the occurrence of diseases and insect pests into consideration. Here, an example of such research is introduced (Nishimori et al., 2008). By estimating rice yields and the changes in snowfall and frequency of generations of insect pests in the unit of a 10 km mesh covering the whole of Japan while assuming an increase in mean temperature of approximately 2°C (representing an assumed time period of roughly the 2060s), and by combining these impacts to assess the intensity of negative impacts of global warming on paddy ecosystems, an attempt was made to identify vulnerable regions.

Firstly, using a regression estimation equation with the temperature at ripening period as a variable, the ideal temperature at which the maximum rice yield can be expected was estimated. Hokuriku, southern Kanto, and northern Kyushu are susceptible to high-temperature injury due to global warming because cultivation will take place under conditions of higher temperature than the ideal temperature of the present climate conditions (Nishimori et al., 2002). Secondly, by estimating changes in snowfall from the temperature changes resulting from global warming, it has been found that snowfall will decrease by about 15% and the time of snow melting will also become earlier in the area on the Sea of Japan side extending from Tohoku to Hokuriku (Inoue et al., 2001). Consequently, the volume of river water will decrease in these areas during the time of plowing and irrigation of fields and planting of paddy rice, and the possibility of shortages in agricultural water is considered to be high. Moreover, the results of estimating the rate of growth of the small brown planthopper (*Laodelphax striatellus* (Fallen)) using the theory of effective accumulated temperature have shown that under the conditions of global warming, the rate of growth will accelerate and the number of generations will increase, with the regions at risk of frequent occurrences of rice stripe disease projected to expand to the area from Tohoku to Hokuriku as well as southern Kanto (Yamamura et al., 2006).

When the above results are combined, it is found that under the conditions of global warming, simultaneous changes in the three growth-inhibiting factors of climate, water resources, and insect pests have a particularly negative impact on paddy rice production in the Hokuriku region, so that this region is estimated to be the most vulnerable (red area in **Fig. I-III-5**). The next most vulnerable areas are estimated to be the area of Tohoku on the Sea of Japan side (vulnerable to changes in water resources and insect pests: yellow area in the figure) and the southern Kanto area (vulnerable to changes in climate and insect pests: light-blue area in the figure).

Incidentally, interrelationships among the factors, differences in varieties and soils, and adaptation measures such as changes in the cropping system, etc., were not taken into consideration in this research, and remain to be a future task.

Motoki NISHIMORI (National Institute for Agro-Environmental Sciences)

References：Nishimori et al.(2008), Nishimori et al. (2002), Inoue et al. (2001), Yamamura et al. (2006)

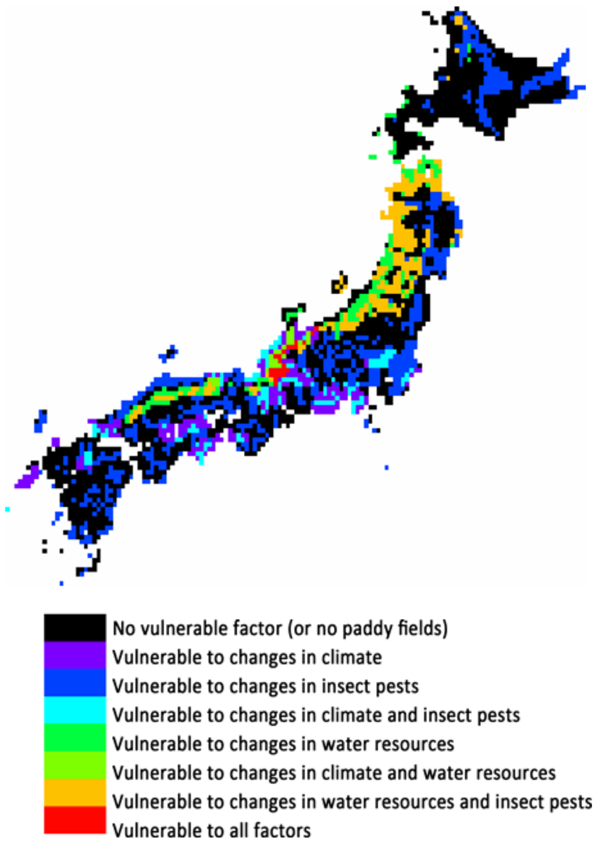

Fig. I-III-5 Distribution of vulnerability of rice production in Japan examined by the three factors of climate (high-temperature stress), insect pests (frequency of generations of planthoppers), and water resources (decrease in snowfall) using a 10 km mesh.

In the area centering around western Japan, average paddy rice yields will decrease and a trend toward greater inter-annual variation in yields will also be evident in the same area.

In 1993, as a result of a major failure of the rice crop, Japan urgently conducted large-scale imports of rice totaling 2.5 million tons (approximately 20% of the world trade in rice), causing great confusion in the global rice market. The Republic of Korea also urgently imported rice on a scale of 2 million tons in the early 1980s. Moreover, China, which had been exporting about 1 million tons of rice annually up to 1988, conversely imported as much as 1.2 million tons in 1989 because of a poor crop and the expansion of demand. Subsequently, after supplying 1 million tons to Japan at the time of its crop failure in 1993, China imported close to 2 million tons in 1995. These are among the past examples of unstable rice production conditions. The model for estimating rice yield by prefecture used here can reproduce year-by-year changes in past yields. Assuming that this model continues to remain appropriate under the future environment, inter-annual variation in future yields were estimated by inputting a climate change scenario containing inter-annual variation output by MIROC.

Maps ***c*** and ***d*** in **Fig. I-III-4** show the changes in the coefficient of variation of yields in 2046-2065 and 2081-2100, respectively. The coefficient of variation is defined as the standard deviation of values of the period divided by the average value. Accordingly, when the standard deviation increases or the average value decreases, the coefficient of variation becomes larger. The coefficient of variation is estimated to become larger in almost the same regions (Kinki, Shikoku, Chugoku, and Kyushu) as those in which the average yield will decrease. This result suggests inter-annual variation in yields, and in particular, the frequent occurrence of lean crop years. Such a situation can be expected to lead to instability of the food supply and to cause more serious problems than average changes.

Figure I-III-6 shows a time series indicating inter-annual variation in the average yield nationwide. A projected trend of increasing yields from 2040 to 2060 can be seen, after which the average yield decreases and inter-annual variation become larger. Hence, there is a possibility of increases in yield centering around northern Japan as an average trend due to global warming, but the increase in inter-annual variation means that there is a risk of cold weather damage even in an environment with a high mean temperature (refer to the Topic, “Possibility of damage to paddy rice by cold weather”). However, the reliability of the climate model and impact assessment model is still low, and it is therefore necessary to use multiple climate scenarios and models and to improve the methods of assessment, etc.

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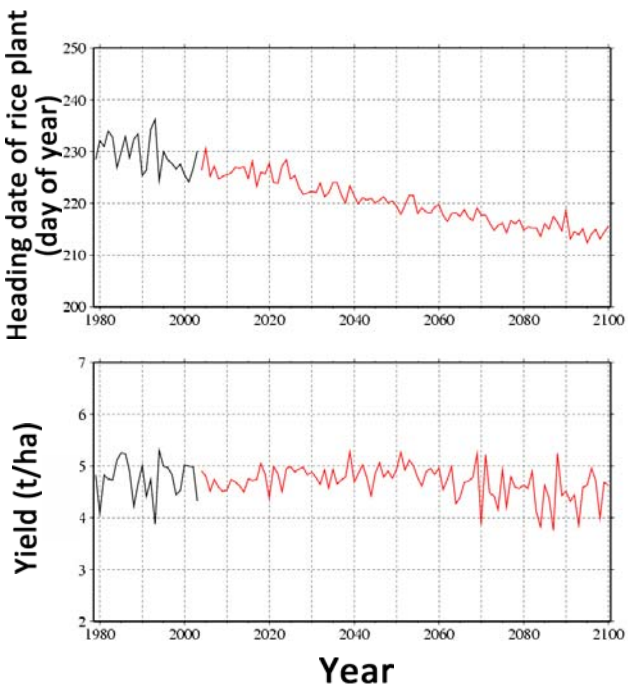

Fig. 1-III-6 Projected inter-annual variation in average rice yield nationwide (MIROC, A1B scenario)

Topic

Possibility of damage to paddy rice by cold weather

According to IPCC (2007), the global surface temperature has increased by 0.74°C over the past 100 years. The increasing trend over the past 30 years is particularly significant, with a further increase of 1.1-6.4°C projected to occur during the coming 100 years. Although global warming is visualized in terms of increasing mean temperature, this does not mean that the daily mean temperature gradually rises. Rather, its salient feature is generally considered to be the frequency of appearance of weather systems that bring high temperatures to certain areas.

Year-by-year weather conditions are important for agriculture, particularly paddy rice cultivation, and the limited accuracy of seasonal forecasts means that risks exist in this sector every year. **Figure I-III-7** shows the changes in paddy rice yield and annual mean temperature in Japan from 1883 to 2004 (Hayashi, 2005). Both values exhibit a rising trend, giving the appearance that the temperature increase is a factor in the increased yield. This is merely a spurious correlation, however. In actuality, there was no large difference between the temperatures from the 1970s to the 1980s and those from the latter half of the 1940s to the 1950s, but a comparison of the yields in those periods shows that the yield in the former period was larger than that in the latter period by about 100 kg/10 a. The development of cultivation techniques and breed improvements in recent years are the main factors contributing to this change in yield. Hence, when extracting latent signs of global warming from changes in yield, it is necessary to subtract anthropogenic effects such as these.

Meanwhile, will cold weather damage disappear with the progress of global warming? The solid circles in the figure (on the x-axis) indicate years in which cold weather damage occurred. These years correspond to those in which both the yield and temperature were relatively lower. When examined over the entire 122-year period, it is evident that cold weather damage has frequently occurred, even recently, and it cannot be said that the lower the mean temperature in past periods, the more frequent the years with cold weather damage. Rather, when the cultivation of heat-tolerant varieties expands as a measure to mitigate the impact of global warming, a risk of major damage can be foreseen in the case of cold summers. The amplitude of the year-by-year mean temperature exceeds the range of temperature rise due to global warming, so cold weather damage is expected to occur in the future as well.

Incidentally, large-scale cold weather damage has appeared up to now in the Tohoku region, and the primary factor is known to be the so-called Yamase, a cold northeasterly wind that produces cool weather in summer over northeastern Japan. According to Hayashi et al. (1999), under the distribution of atmospheric pressure in which the Yamase occurs, a similar cold northeasterly air current strikes the Sea of Japan side of the Korean Peninsula, with the result that cold weather damage to paddy rice occurs simultaneously in both areas. Any change in the appearance of such weather systems that may occur in the process of global warming is therefore an important issue for paddy rice cultivation in Northeast Asia.

Yosei HAYASHI (University of Tsukuba)

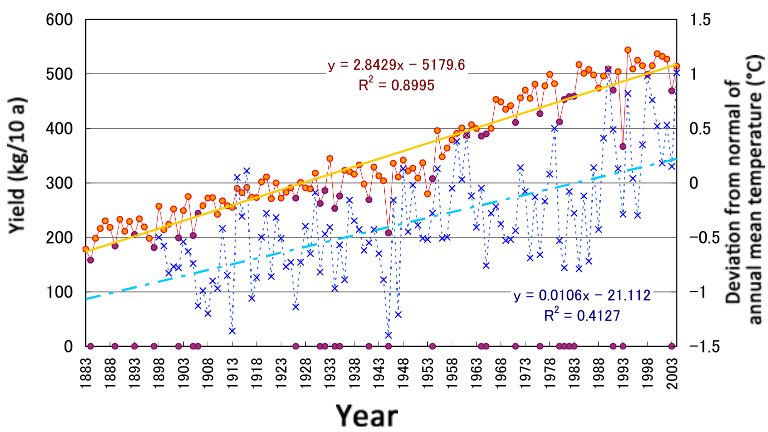

Fig. I-III-7 Changes in paddy rice yield and annual mean temperature

The yield (left-hand y-axis) is shown by the red solid line, with the orange solid line indicating the regression line; the mean temperature (right-hand y-axis) is shown by the blue broken line, with the light-blue dash-dotted line indicating the regression line.

Topic Compound impacts of high temperature and insufficient sunshine on paddy rice yield

The paddy rice crop index by region over the past 20 years is shown in **Fig. I-III-8**. In Kyushu, a decline in the crop index is seen in 1991 due to the effects of typhoon damage, in 1993 due to cold weather damage, and also in 1999 and from 2004 onward. This phenomenon can be considered to be the negative impact of high temperatures during the ripening period, and is important as a concrete case of the impact of global warming on paddy rice cultivation that illustrates the need for measures to be taken (Ministry of Agriculture, Forestry and Fisheries, 2006). In response, progress has been made in the development of the “Nikomaru” variety, which possesses excellent heat tolerance as well as good taste, as a replacement for the conventional varieties, and cultivation of this variety commenced in Fukuoka and Saga prefectures in 2007.

Studies on the ripening grades of paddy rice have shown that the ripening grade depends not only on the conditions of temperature but also light. Masuya (2008) investigated the mean temperature (maximum and minimum temperatures) and the trend of sunshine duration for 20 days after the heading of rice targeting cropping zones in Kyushu in 1999 and 2004. The results are shown in **Fig. I-III-9**. The years 1999 and 2004 are indicated in red and yellow, respectively, with maximum temperatures shown by circles and minimum temperatures by triangles. Years other than the targeted two years are indicated in gray. When the daily maximum temperatures are examined, they are distributed at the upper left of the dispersed group for both of the targeted years. A similar trend is seen for the daily minimum temperatures. From this, the lowering of the rice crop index in 1999 and 2004 can be considered to have occurred due to the weather conditions compounded by relatively high temperatures and shorter durations of sunshine.

Additional studies are necessary to elucidate the mechanism by which the rice crop index is further lowered by the compound effects of high temperature and insufficient sunshine. The modeling of such phenomena and utilization of such a model for future projections is desired.

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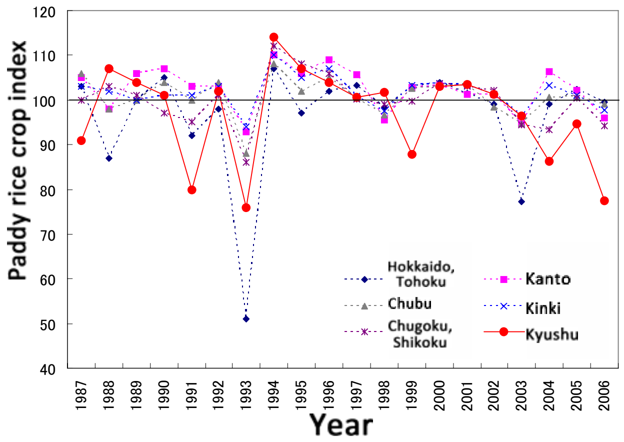

Fig. I-III-8 Annual trend in paddy rice crop index by region.

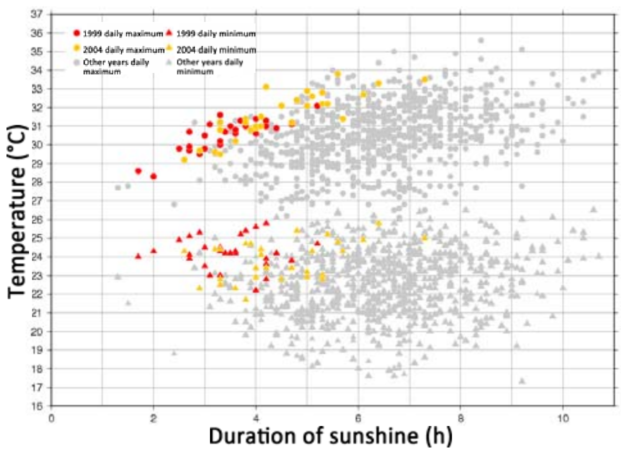

Fig. I-III-9 Relationship between daily maximum and daily minimum temperatures and duration of sunshine for 20 days after heading of rice in 1999 and 2004.

(2) Outlook of impact of climate change by world food model

The rate of growth in output of major cereals by the U.S. will decrease up to the 2030s due to climate change. Although the impact on the supply of food to Japan will be small during this period, the rate of growth in the supply of maize will decrease.

To assess the impacts of climate change on world food supply and demand, and in turn on the food supply to Japan, using the world food model, the changes in production of major cereals accompanying changes in temperature and precipitation were estimated. The climate scenario used here was estimated by the HadCM3 GCM of the Met Office Hadley Centre in the United Kingdom in accordance with the SRES-A2 greenhouse gas emissions scenario. In order to examine the impacts due solely to climate change, the socioeconomic scenario was fixed and a comparison was made of the results of estimations for the case of the weather conditions of an average year without the occurrence of climate change (baseline) and the case of climate change taking place in line with the scenario.

First, the production trend of the U.S., which is the leader of world market prices of major cereals, is examined. **Figure I-III-10** shows the rate of increase in annual mean production of each cereal crop from 2005 to 2030. On the baseline, the annual rates of increase in the production of maize and soybeans are 0.67% and 1.97% respectively, while in the case of climate change occurring, the annual rates of increase are lowered to 0.55% and 1.81% respectively. With regard to the production of other coarse grains such as barley, rye, etc., and the production of rice, there is almost no increase in the case of the baseline but when climate change occurs, the trend turns to annual decreases of 0.10% and 0.26% respectively. Wheat production shows an annual decrease of 0.21% in the case of the baseline because production by other countries such as Canada, Australia, etc. will increase; however, in the case that climate change occurs, the annual rate of decrease is estimated to further expand to 0.27%.

With regard to the impacts of climate change on the production of livestock products in the U.S., **Fig. I-III-11** shows the rate of increase in annual mean production of each type of livestock from 2005 to 2030. When temperature rises, heat is accumulated in the bodies of livestock, weight gain and milk yield decrease, and the quality of both the meat and milk also becomes lower; however, here only the impacts of changes in the production of feed such as maize, etc. are taken into consideration. In the case of the baseline climate, the production of beef, chicken, eggs, and milk will increase annually by 0.79%, 1.61%, 1.78%, and 1.04%, respectively, while in the case of climate change occurring, the rate of increase in annual production of beef will be lowered to 0.76%. Pork production is estimated to post a decrease of 0.12% annually in the baseline case, and 0.18% in the case of climate change. Hence, when the impacts of climate change on the production of livestock products are examined only through changes in feed production, it can be inferred that the impacts on beef and pork production are large.

Next let us examine changes in the supply of food to Japan. Here, the supply consists of imports together with the starting stock (the stock remaining from the previous year) added to the amount of production, minus exports and the term-end stock (the current year's remaining stock); this is equal to the total demand of the country. It also includes the demand for animal feed. **Figure I-III-12** shows the rate of increase in annual supply of cereal crops in Japan. On the baseline, the supply of maize, other coarse grains, and soybeans will show an annual increase of 0.78%, 1.50%, and 0.48%, respectively, while the supply of wheat and rice will show an annual decrease of 0.16% and 0.71%, respectively. In the case of climate change occurring, the supply of maize is estimated to decrease by only 0.048%, with no changes seen in the supply of other cereal crops.

With regard to the impacts of climate change on a global scale, **Fig. I-III-13** shows the rate of increase in annual production of each cereal crop in the world. The baseline shows annual rates of increase in production of 1.56% for wheat, 1.67% for maize, 1.91% for other coarse grains, 1.72% for rice, and 1.85% for soybeans, while in the case of climate change, the percentages decrease by only 0.021, 0.010, 0.012, 0.032, and 0.025, respectively. In particular, rice is relatively susceptible to the impacts of global warming, and its rate of increase is projected to show a comparatively large decline.

Summarizing the above information, although there are areas that will be greatly affected by the impacts of global warming, it can be said that the impacts are not so large when examined in terms of the global total. This is because as well as the offset of positive and negative impacts by simple aggregation, transfers of farm produce between areas through trade will ease the impacts on the world as a whole. Moreover, if production in a certain area decreases due to global warming, the price of the farm produce concerned will rise and the producers will therefore take measures to increase production. In this case, although some time may elapse from when the relevant decision is made for the development of arable land, etc. until produce is obtained, worldwide production can be expected to recover in the long term.

These are the results of an estimation until around the 2030s, however, and the rise in global mean temperature in the climate change scenario used for this estimation is on the scale of about 1°C at most. Therefore, particularly in the mid-latitude regions, where major production areas are distributed, impacts of global warming do not conspicuously appear. According to the Fourth Assessment Report of the IPCC, when the global mean temperature rises by 3-4°C or higher than at present, productivity in some agricultural areas at the mid to high latitudes will be lowered.

Estimations of the long-term future reflecting socioeconomic conditions, like the present assessment, are extremely difficult. This is because as well as the necessity to take interactions with other industrial sectors into consideration, in the case of agriculture in particular the estimation is subject to significant changes due to the external factors such as policies, etc. Moreover, the estimation results described here are the average movements in production; that is, the projection of changes in trends. Recently, however, demand for cereals for use as biomass fuel has also appeared, further exacerbating the difficulty of projection.

Jun FURUYA (Japan International Research Center for Agricultural Sciences)

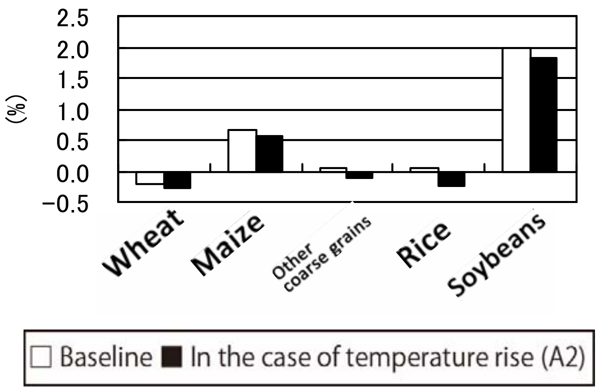

Fig. I-III-10 Rate of increase in annual production of cereal crops in the U.S.

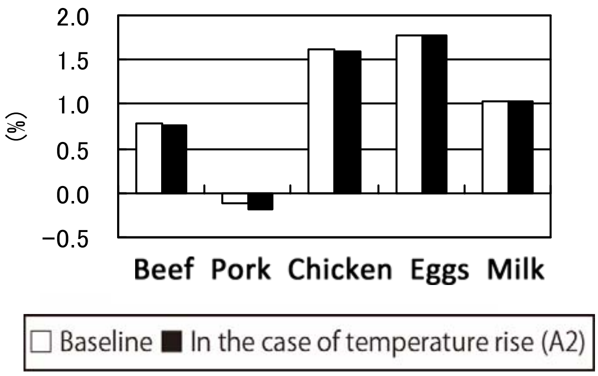

Fig. I-III-11 Rate of increase in annual production of livestock in the U.S.

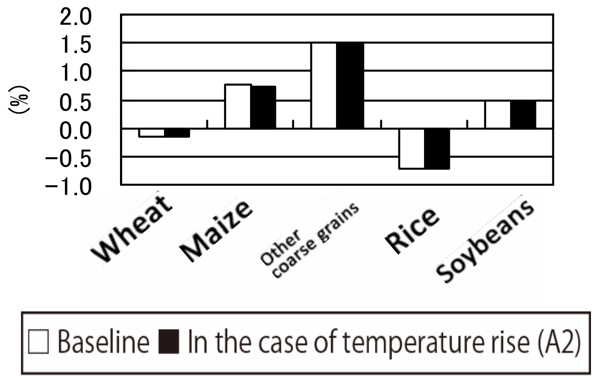

Fig. I-III-12 Rate of increase in annual supply of cereal crops in Japan

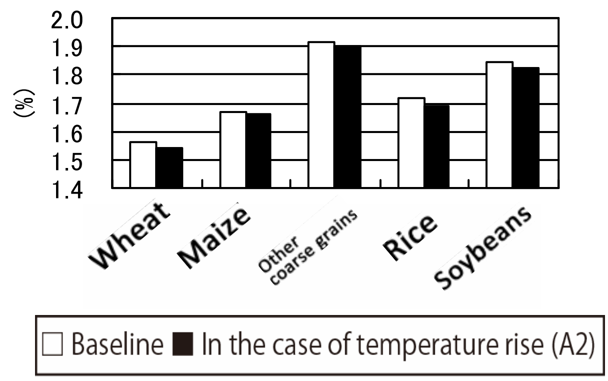

Fig. I-III-13 Rate of increase in annual production of cereal crops in the world

Topic Increasing instability of Mekong Delta rice production

It is no exaggeration to say that monsoon Asia's dense population has been supported by rice up to now, and this relationship of dependence will remain unchanged in the future as well. Most rice cultivation in this region is greatly affected by severe conditions of the natural environment, and can be expected to be even more vulnerable compared with rice production in Japan and other countries having a highly developed production infrastructure that will also help to protect against climate change. Monsoon Asia has a diverse range of natural environments according to the area, and the key factors causing changes in rice production are therefore also diverse.

Here, the problem of the intrusion of seawater in Vietnam's Mekong Delta, which is one of the world's major rice production areas, is introduced as an example. The phenomenon of seawater intrusion occurs when the tide level of the sea becomes higher than the water level of a river, resulting in the inland intrusion of seawater as it travels upstream. In particular, the Mekong Delta is characterized by low-lying flat land, so the extent of seawater intrusion is wide and its degree varies significantly by the day, season, and year accompanying the changes in tide levels and river flow. There are concerns that the scale of this problem will further expand in the future due to rises in sea level and decreased river flow. Needless to say, salinity is not desirable for the growth of rice plants. In the present circumstances, the cropping calendar has been adapted to the seasonal periodicity of seawater intrusion; that is, by concentrating cultivation in periods of low salinity, impacts on the growth of rice have mostly been avoided and high yields have been maintained. One aspect of this adaptation measure, however, is that it may not be able to withstand further expansion of the scale of seawater intrusion.

Expansion of the scale of seawater intrusion will shorten the periods of low salinity suitable for cultivation. Accordingly, with the cultivation system having followed the seasonal periodicity of seawater intrusion up to now, a situation can be projected to occur in which a decrease in the number of plantings per year will become unavoidable when the intrusion of seawater exceeds a certain limit; for example, farmland on which two harvests per year have been possible up to now will only support one harvest per year. This means that areas in which rice can be cultivated in the Mekong Delta will be lost and production capacity will definitely be lowered. Moreover, our recent research has revealed that there are significant areas of farmland vulnerable to highly catastrophic circumstances, which will suddenly become uncultivable with even a small expansion of seawater intrusion (**Fig. I-III-14**; areas colored in red).

Not only in areas with such problems of seawater intrusion, but also in other areas of the monsoon zone, rice cultivation systems following a natural periodicity such as the monsoon season, seasonal floods, etc. are often seen. The present rhythm of cultivation in these areas will therefore become unstable with even small environmental changes, as seen in the Mekong Delta, greatly affecting rice production. Such a risk can be considered a problem that could occur in any area.

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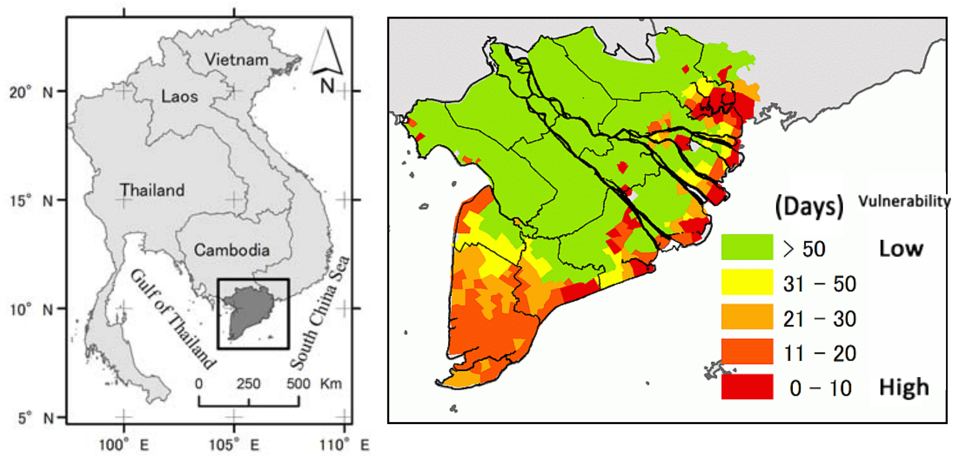


Fig. I-III-14 Spatial distribution of rice cultivation vulnerability to seawater intrusion in Mekong Delta, Vietnam, in 1998 from the perspectives of seasonal changes and rainfall patterns

SMC (Safe margin for cropping) = [Number of days on which cultivation is possible] – [Number of days required for crop cultivation]

SMC represents the limit of the decrease in the number of days on which crop cultivation is possible at which the present number of crop plantings can be maintained. The shorter the SMC, the higher the vulnerability of rice production to expansion of seawater intrusion and decrease in precipitation.

Topic Japanese-style rice cultivation in China

The projection of changes in the production of major cereals in China is an essential factor in the country's food security. In particular, the area of cultivation of good-tasting japonica-type rice is rapidly expanding in the northeastern plains of China in line with the recent increase in domestic demand. The main varieties that have been grown up to now in China are the indica and hybrid types, with their cultivation concentrated around the central and southern regions.

According to Jiang and Xu (2004), the area of paddy rice cultivation in China has shown a decreasing trend since the 1980s, when reforms of the production system in rural areas were initiated, shrinking by approximately 16.5% during the 25 years from 1979 to 2003. When examined by region, a conspicuous decrease was seen in southern China (-23.4%). On the other hand, the northeastern plains as a whole have shown a significant increase (+92.5%) (**Fig. I-III-15**). This trend in the northeastern plains is particularly evident in Heilongjiang Province, where the area of paddy rice cultivation has expanded by almost 7.5 times during this 25-year period. When the planted areas in 2000 are compared by province, Heilongjiang ranks ninth (1,606,000 hm^2), representing about 41% of the area of first-ranked Hunan Province (3,896,000 hm^2).

According to a field survey conducted in the summer of 2007, in Heihe City (**Fig. I-III-16**) located at 50° north latitude in Heilongjiang Province, which is said to be the northern limit of paddy rice cultivation, approximately 30% of the farmland is rice paddies and the area of cultivation is continuously increasing. This trend of a northward movement of the rice production zone that has been concentrated around central China up to now can be expected to continue. Elucidation of the relationship between global warming and rice production in the northeastern plains of China is therefore an important research task (Jiang et al., 2007).

Yosei HAYASHI (University of Tsukuba)

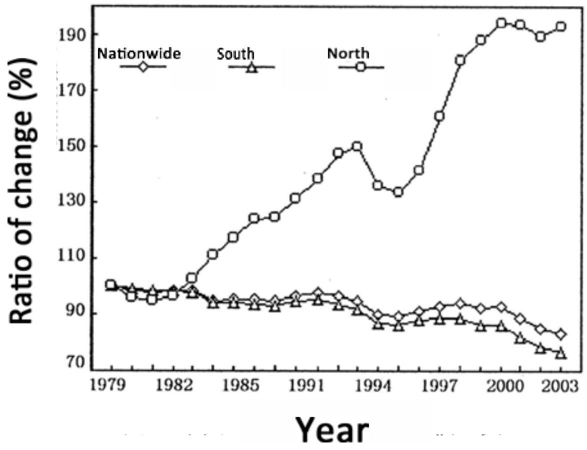


Fig. I-III-15 Changes in area of paddy rice cultivation in China with 1979 as the base year Nationwide: whole of China; South: area centering around the southern China region; North: area centering around the northeastern plains (Jiang and Xu, 2004)

Fig. I-III-16 Paddy rice cultivation in Heihe (lat. 50° north), in Heilongjiang Province of China (Photograph by Y. Hayashi; August 28, 2007)

4. Impacts on Coastal Zones

4.1 Outline

Coastal zones and riversides are considered the residential areas that are most influenced by global warming. Especially, seashores will be influenced most if global warming induces increased frequency or intensity of typhoons. Climate factors might cause more serious disasters if smaller disasters were to occur simultaneously. A disaster produced by overlapping factors, which is deemed important, is designated as a complex disaster in this manuscript. **Figure I-IV-1** depicts such a complex disaster schematically. This figure illustrates that complex disasters are classifiable roughly into disasters related to water (water disasters) and disasters related to soil or ground conditions or behaviors (geological hazards).

Figure I-IV-2 portrays that such complex disasters are also divisible into disasters that take place by overlapping of global warming factors, and those by overlapping of factors related to and independent of global warming. Complex disasters accordingly might include the following cases.

1) Disasters caused by overlapping of multiple phenomena caused by global warming, e.g., a storm surge flood that is intensified because of a big typhoon attacking a coastal zone that has undergone a period of sea level rise.
2) Disasters caused by overlapping of sea level rise and local heavy rains brought about by global warming and a phenomenon unrelated to global warming, such as an earthquake.

Especially, large cities in Japan are vulnerable to natural threats because they are located in low-lying coastal areas. It is therefore important to predict these natural threats and to think of appropriate countermeasures. Previous studies have revealed the following:

1) The risk of flooding by storm surge is enhanced in reclaimed lands developed long ago and their perimeter in the inner parts of Japan's Three Big Bays (Tokyo Bay, Isewan, Osaka Bay) when global warming progresses.
2) Sea level rise caused by climate change and change in frequency and intensity of rains magnify high risks in areas prone to liquefaction in coastal zones.
3) Great economic merits of sands and tidal flats will disappear according to a sea level rise.
4) River levees might be degraded and damaged if seawater rises to rivers because of sea level rise. The mechanism was clarified, and the vulnerability of river levees over rainfall resulting from global warming has been clarified on a Japanese national level.
5) Disaster risk will be exaggerated on slopes adjacent to coastal zones by heavy rain because of global warming. Therefore, it is necessary to study a slope recovery plan using an index representing risks.

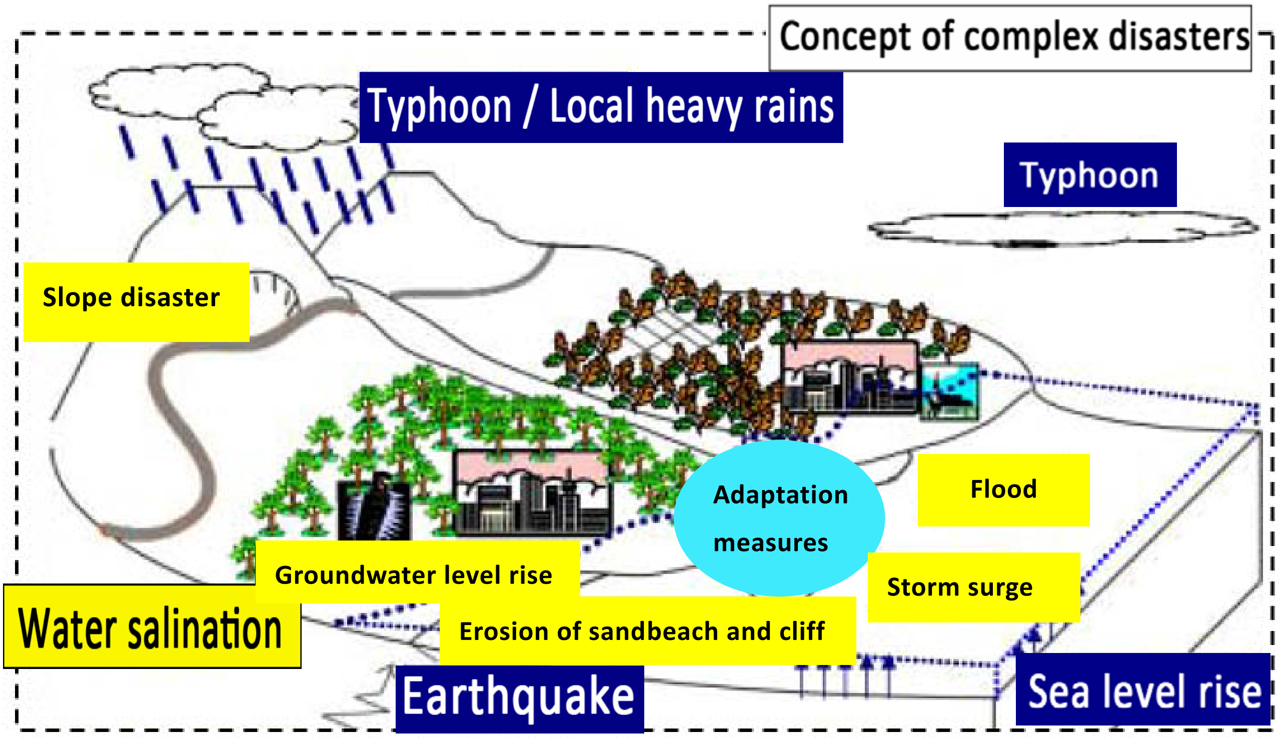


Fig. I-IV-1 Conceptual diagram of complex disasters caused by global warming.

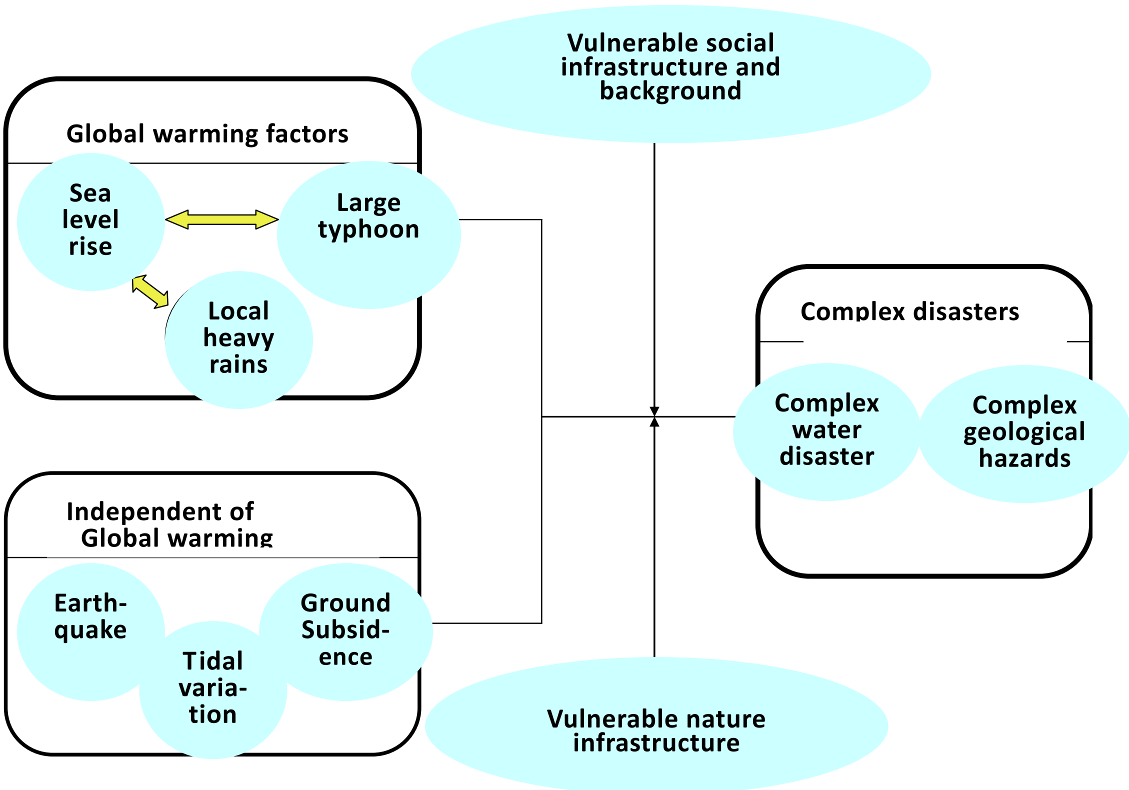


Fig. I-IV-2 Summary diagram of complex disasters caused by global warming.

4.2 Object and Method of Impact Evaluation

(1) Storm surge flooding

In Japan, 46% of the population, 47% of industrial production, and 77% of commercial sales are concentrated in cities, towns, and villages facing oceans. Coastal zones are therefore vital for socioeconomic activities. When global warming advances, it is expected that sea levels will rise because of melting of land snow ice and volumetric expansion of seawater, and that a typhoon is intensified by a seawater temperature rise. Such a change will enhance the risk of flooding by storm surges on a coastal zone. The area of flooding by storm surges and populations that reside there were predicted as indices for evaluating the risk.

Estimates of flooding areas and population were performed as follows: spatial data with information related to ground surface height and protective facilities are constructed on a computer; sea level variation assuming the buildup of sea level rise and storm surge is used to adjust the sea boundary. Then the inflow of seawater and corresponding onshore flooding were computed. Wave overtopping by tidal waves is also involved in the calculation of seawater inflow for the Three Big Bays. The calculation region includes the inner part of the Three Big Bays, where a buildup of population or property is large, and the western part of Japan (the Chugoku, Shikoku, and Kyushu districts) with wide expanses of low-lying areas and high invasion frequency of typhoons.

(2) River levee

It is expected that a sea level rise attributable to global warming will cause seawater to move up a river. As a result, a brackish water region in a river downstream area might be extended upstream. Such an event might affect a river levee, a necessary disaster prevention facility. Quantitative assessment of the vulnerability of infrastructure facilities by global warming is a pressing issue. Therefore, in addition to the investigation directed to a river levee described above, selection of suitable adaptation measures for improving vulnerability is also demanded.

For an evaluation of the impact to river levees by global warming, soils constituting river levees were collected from all over the country: experiments were carried out to investigate the consistency (deformability according to water content) and compressibility (ability of volume change by force) of those soils. The mechanisms of a river levee being degraded and damaged were clarified when seawater moves up a river because of the sea level rise, based on these experiments.

Moreover, a test was conducted to investigate the water holding capacity of soil, to evaluate the vulnerability of the river levee over rainfall. The water holding property database of earth materials assumed to constitute the river levee of every region was created. Vulnerability of a river levee to rainfall was displayed, although roughly, on a Japanese national level based on the result.

(3) Economic value of sands

Hanyu (2000) reported that Japan’s coastline extends to 35,236 km; about 20% (7,060 km) of it is sand. The coast has been a basis of marine traffic and a field used for fisheries or aquaculture for many years. It has supported many people’s lives. Today, sands act as a field of recreation for wading and swimming, camping, bird watching, and walking, so that such areas’ aesthetic and cultural value are also recognized: not only their market value but non-market value can be recognized widely in the sands.

However, in recent years, sands with such value are confronting a crisis of extinction by sea level rise attributable to global warming. Mimura et al. (1993: 1994) predicted that sands of 108 km^2 (56.6%), 156 km^2 (81.7%), or 173 km^2 (90.3%) in Japan (gross area of 191 km^2), respectively, will disappear by sea level rises of 30 cm, 65 cm, or 100 cm.

The value of sands and those disappearing by sea level rise in each prefecture were evaluated. The assessment specifically addressed the utility value as an area for bathing among the non-market values of sands. Travel Cost Method (TCM), a road assessment method based on revealed preference data, was used as the evaluation method.

(4) Economic value of tidal flats

The fourth National Survey of the Natural Environment by Environment Agency of Japan (now the Ministry of the Environment) confirmed 145 tidal flats on Japanese seashores, which have area of about 514 km^2. Tidal flats host abundant bioresources with their unique environments, and serve an essential role for maintenance of biodiversity. Creatures of tidal flats, such as mussel worms and short-necked clams, purify the sea area, so that the tidal flats can support industries such as fisheries and shipping, and people’s lives. Furthermore, through seashell digging, bird watching, etc., in tidal flats, the mental and cultural value of the tidal flats as "a field of recreation and relaxation" and "a field of healing" are widely acknowledged.

The economic value of tidal flats for each prefecture was evaluated. The assessment was limited to the value of the biodiversity maintenance function of tidal flats throughout Japan. Contingent Valuation Method (CVM), a virtual market assessment method based on stated preference data, was adopted as an assessment method.

(5) Variation of liquefaction risk

The following issues are pointed out for soil of coastal land areas that undergo a sea level rise attributable to global warming: increased liquefaction risk of soil by an earthquake; deterioration of the stability of coast structures, such as levees, shore protection, and breakwaters; issues resulting from rising of groundwater level, such as diffusion by the submersion of soil pollutants that had existed above the groundwater level; and groundwater salination, i.e., groundwater of high salinity extending inland. For that reason, the fluctuation of groundwater levels in coastal zones because of sea level rise or climate change should be predicted, and a diagnostic technique of local disaster prevention capability must be established considering fluctuation of groundwater levels. Such an impact evaluation of climate change to liquefaction risks in case an earthquake occurs, has been done for the object region of the Tokyo Bay coastal zone.

Impact evaluation was performed as follows: the ground structure was modeled using the soil information database in the object region; then, the rise of the groundwater level in coastal zone soil caused by sea level rise or climate change was predicted using the 2-D unconfined groundwater flow analysis method (Murakami et al. 2005) with finite element method (FEM). Vulnerability assessment was performed in the event of an earthquake at a coastal zone ground because of the sea level rise with this method, by computing the variation of liquefaction risk before and after sea level rise and climate change. A climate unification scenario by the Meteorological Agency, RCM20, was used for the assumed rainfall.

(6) Risk of slope disaster

Abnormal weather resulting from global warming might include increased intensity of typhoons and frequent heavy rains. Typhoons and heavy rains bring serious damage to human and social property (direct economy loss). Heavy rains also cause landslides and economic loss through slope disasters (indirect economy loss). It is important to predict these economic losses and to propose measures to investigate the effects of global warming. Correlation between the magnitude (intensity) of a typhoon and the economic loss ratio (loss/assets) were analyzed, and an inference model of economic loss with respect to the magnitude of a typhoon was established using past data to evaluate the risk of increased economic loss through intensification of typhoons as a result of global warming. Moreover, the preparation method of the risk curve of a typhoon through Monte Carlo simulation was established using statistical characteristics of the typhoon magnitude. The risk curve of a future typhoon was presumed assuming typhoon intensification because of global warming, which was then compared with the present risk curve. The increase in the risk of economic loss was evaluated.

An assessment method of the risk of slope disaster by heavy rains because of global warming was developed. The proposed assessment method of the risk of slope disaster includes a local range method and a wide range method according to the range of the assessment object. The local range method determines the risk of slope disaster considering the compound effect of heavy rains and earthquakes on the object slope.

On the other hand, for assessment of the risk of landslide disaster nationwide, the risk of landslide disaster in a wide area was estimated using a geographic information system (GIS) according to the following procedures (wide range method).

1) A hazard map was created to illustrate the landslide probability using an estimation method of landslide probability by rainfall in the fourth mesh of Digital national land information.
2) Economic loss by landslide was evaluated based on property using the estimation method of the assets distribution in the fourth mesh.
3) The risk of slope disaster was computed as the product of the landslide probability and economic loss attributable to the landslide.
4) Slope disaster risk maps were created in the present climatic condition and in the assumed climatic conditions by global warming in 2050, 2100, and later. The effect of global warming on slope disaster was inferred from a comparison of risk maps before and after global warming. The risk of slope disaster and its increase by global warming in Fukuoka in 2050 was presumed based on this method.

4.3 Estimation of Future Effects on Coastal Zone

(1) Estimation of future storm surge flooding damage

Sea level rise and buildup of storm surge by global warming expands the flooding area and population because of storm surge. The area and population increases gradually with the progress of global warming.

The buildup of storm surge deflection because of sea level rise and intensification of typhoons by global warming enhances damage because of storm surge.

To anticipate such effects, spatial data with ground surface height and information related to protective facilities like a levee was constructed on a computer. The sea level rise and storm surge (also the tidal wave for the Three Big Bays) were provided thereto, and calculation was performed for area flooded in seawater that flowed onshore, and for the population that resides there (Suzuki, 2007a: 2007b). Sea level rises were varied from 0 cm to 100 cm at a 10 cm pitch, and the rate of storm surge increase was varied from 1 up to 1.6 at a 0.1 pitch based on the magnitude of storm surge deflection in 2000 in the calculation. Then it was assumed that the sea level rise of the climate scenario MIROC would take place, and that storm surge deflection would increase from 2000 at a fixed rate up to 1.3 times in 2100. The flooding area and population in 2030 and 2100 were predicted based on these computation results.

Areas with a risk of being flooded by storm surges were 20,000 ha, within which a population of 290,000 resided in 2000, in the inner part of the Three Big Bays and in the western part of Japan (Chugoku, Shikoku, and Kyushu districts). The prediction result tells that the flooding area will be 29,000 ha and that the flooded population will be 520,000 in 2030, and 58,000 ha and 1,370,000 in 2100. Buildup of storm surge deflection attributable to sea level rise and intensification of a typhoon by global warming increases areas vulnerable to storm surges by 38,000 ha, and the population residing there by 1,080,000 during 2000–2100.

Flooded areas and populations by storm surges do not increase abruptly at a certain sea level rise and certain typhoon intensity. Rather they increase linearly overall. Therefore, it is inappropriate to take measures of storm surges when a certain level is approached. It is necessary to take suitable measures continually according to the situation at any level.

Takeshi Suzuki (National Institute for Land and Infrastructure Management)

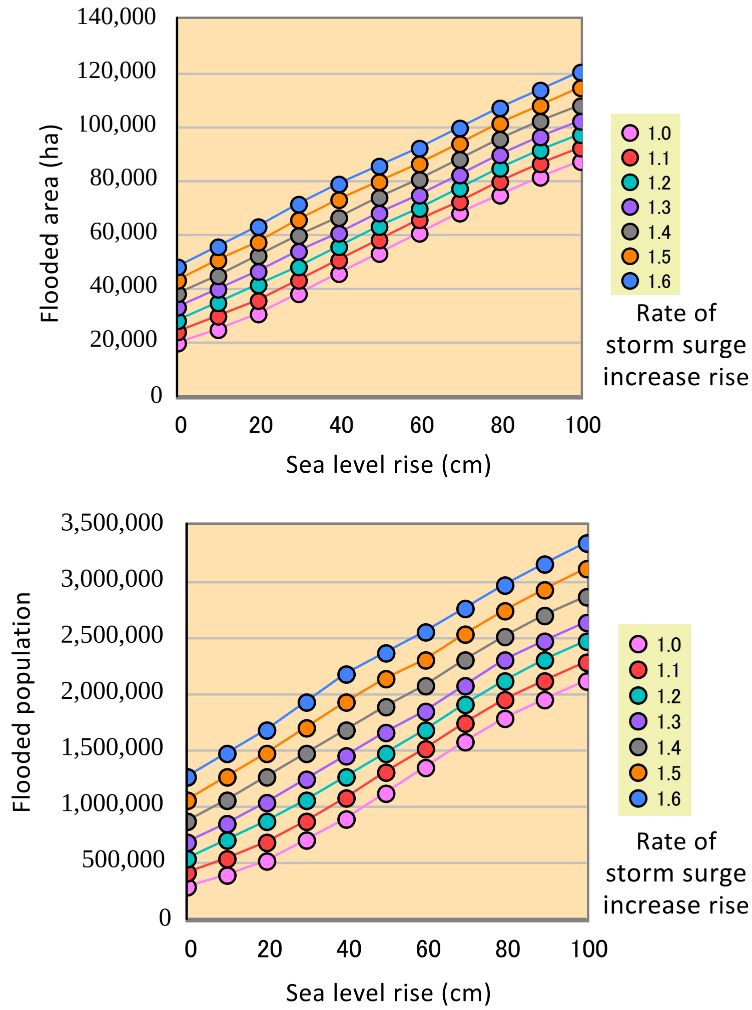


Fig. I-IV-3 Increase of the flooding area and population with sea level rise and buildup of storm surge.

X axis represents the sea level rise in cm, and y axis represents the flooding population. Circles indicate the number of storm surge growth rate.

In western Japan, areas and population flooded by storm surges because of global warming are large in closed sea areas like the Seto Inland Sea and inlets.

In the western part of Japan (Chugoku, Shikoku, and Kyushu districts), which frequently experience typhoons, areas of high risk of being flooded because of storm surges when global warming advances include the Setouchi coast, the Ariake sea coast, the Yatsushiro sea coast, and inner bays and inlets of northwestern Kyushu.

In fact, 15,000 ha of land are at risk of being inundated because of storm surge. That area supported residences of 260,000 people in 2000. The flooded area will be 22,000 ha and the flood-affected population will be 400,000 in 2030; they are expected to be 44,000 ha and 900,000 people in 2100. Buildup of storm surge deflection because of the sea level rise and intensification of a typhoon by global warming is expected to increase vulnerable areas to the storm surge by 29,000 ha, and population residing there by 640,000 during 2000–2100.

It is presumed that closed sea areas and inlets have a high risk of flooding because of storm surges, where the seashore protection level is low, and lowlands spread out in many cases because there is little risk of a surge or tsunami. Because such sites were developed long ago, protection levels, such as shore protection and a levee, are low. Traffic areas of land and sea, such as harbors or fishing ports require low protection levels.

Takeshi Suzuki (National Institute for Land and Infrastructure Management)

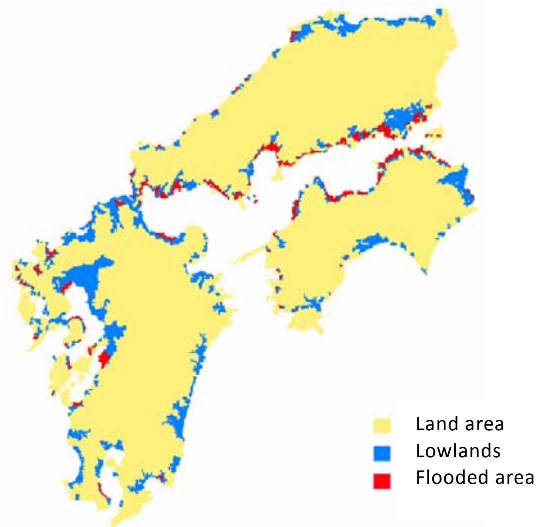


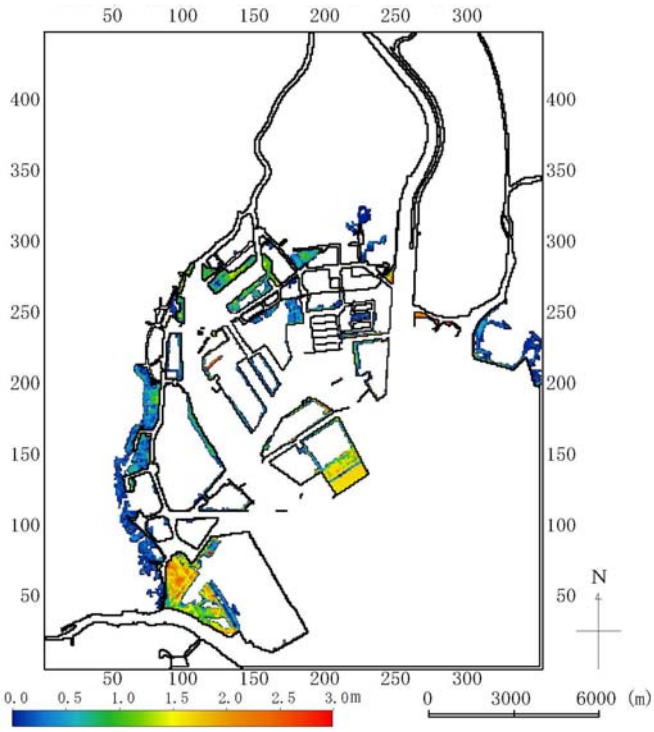
Fig. I-IV-4 Storm surge flooding in western Japan with the climate of 2100.

When global warming progresses, reclaimed lands developed long ago and their surrounding areas will face high risk of flooding by storm surges in the inner parts of the Three Big Bays.

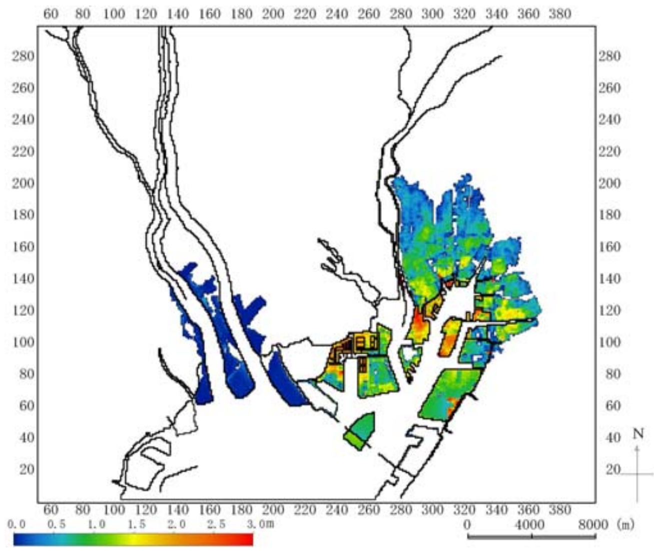
The Three Big Bays are adjacent to large low-lying areas including areas at sea level in their inner parts, where urban areas and seaside industrial zone of a metropolitan region spread, and where flooding will cause serious damage. Flooding estimates revealed areas of high risk of storm surge flooding in 2000 as 4,900 ha (740 ha in Tokyo Bay, 3,400 ha in Isewan, and 710 ha in Osaka Bay). The population residing there is 31,000 (4,000 around Tokyo Bay, 20,000 around Isewan, and 7,000 around Osaka Bay). Flooded areas will be 7,200 ha (970 ha in Tokyo Bay, 5,000 ha in Isewan, and 1,200 ha in Osaka Bay) and the flood-affected population will be 125,000 (5,000 people around Tokyo Bay, 91,000 around Isewan, and 29,000 around Osaka Bay) in 2030. Then flooded areas will be 14,000 ha (1,700 ha in Tokyo Bay, 9,600 ha in Isewan, and 2,600 ha in Osaka Bay) and the flood-affected population will be 470,000 (40,000 people around Tokyo Bay, 320,000 around Isewan, and 11,000 around Osaka Bay) in 2100. Buildup of storm surge deflection caused by the sea level rise and intensification of typhoons by global warming increases areas vulnerable to storm surge by 9,100 ha, and population residing there by 440,000 during 2000–2100.

Areas vulnerable to storm surge are often reclaimed lands that were developed widely many years ago, in addition to their peripheral areas such as the southern Tokyo coast, Nagoya port, and the coast in mid-southern Osaka.

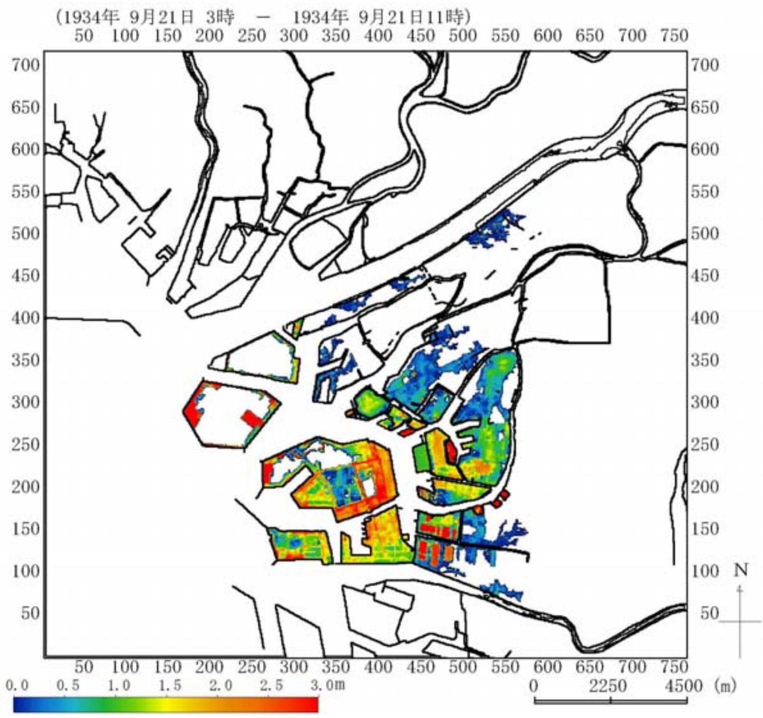
Takeshi Suzuki (National Institute for Land and Infrastructure Management)



(a) Tokyo Bay



(b) Ise Bay



(c) Osaka Bay

Fig. I-IV-5 Storm surge flooding depth in the inner part of the Three Big Bays at the climate in 2100.

(2) Future estimate of vulnerability of river levee

Sea level rise by global warming expands river brackish water regions, thereby deteriorating levee strength.

There is apprehension that sea level rise and frequent heavy rain by global warming will exaggerate the vulnerability of river levees. It is expected that sea level rises will expand brackish water areas within river regions, as portrayed in **Fig. I-IV-6**.

Moreover, it is expected that frequent heavy rains and the increases in a river levels will encourage soaking into river levees. Experiments were conducted from such a viewpoint assuming the trespass of a seawater component to a river levee or increased flood volume; the vulnerability of a river levee was evaluated (Komine 2007a: 2007b).

Nine earth materials assumed to be used for river levees were collected from various places in Japan; several experiments were conducted as shown in **Fig. I-IV-7.**

Effects on levee embankment materials of the extension of river brackish water regions because of sea level rise are estimated as follows. The future could not be designated as a definite period in this estimate.

1) <u>Hokkaido</u>: strength reduction, increased compression, and enhanced permeability of levee embankment materials are anticipated. A dyke break pattern is expected to be seepage and overtopping failures.
2) <u>Kanto and Shin-etsu districts</u>: deterioration of water permeability of embankment materials is expected. A dyke break pattern is expected to be levee body breakage from residual water pressure.
3) <u>Chugoku district</u>: strength reduction, increased compression, and enhanced permeability of levee embankment materials are expected. An expected dyke break pattern is seepage and overtopping failure.
4) <u>Kyushu district</u>: permeability rise and decline and compression increase and decrease might be observed depending on embankment materials. Major dyke break patterns expected include seepage and overtopping failures and levee body breakage by residual water pressure.

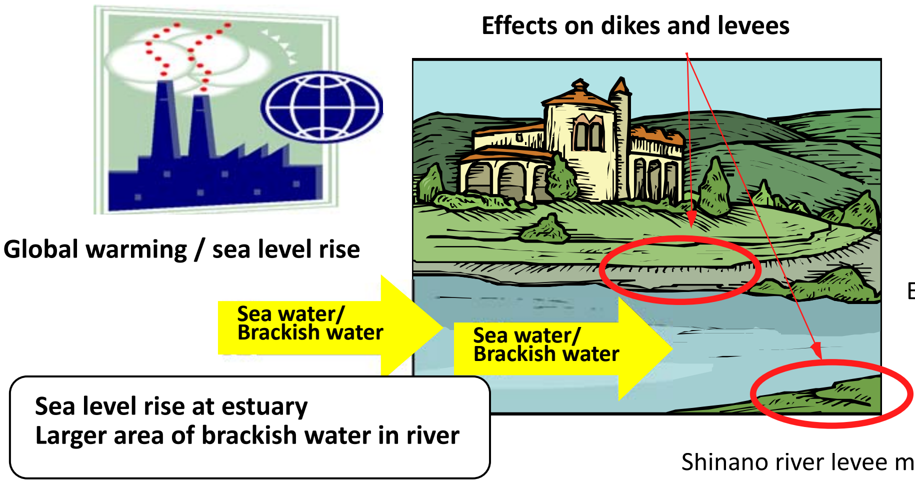


Fig. I-IV-6 Schematic drawing of expanded brackish water region in rivers by global warming/sea level rise

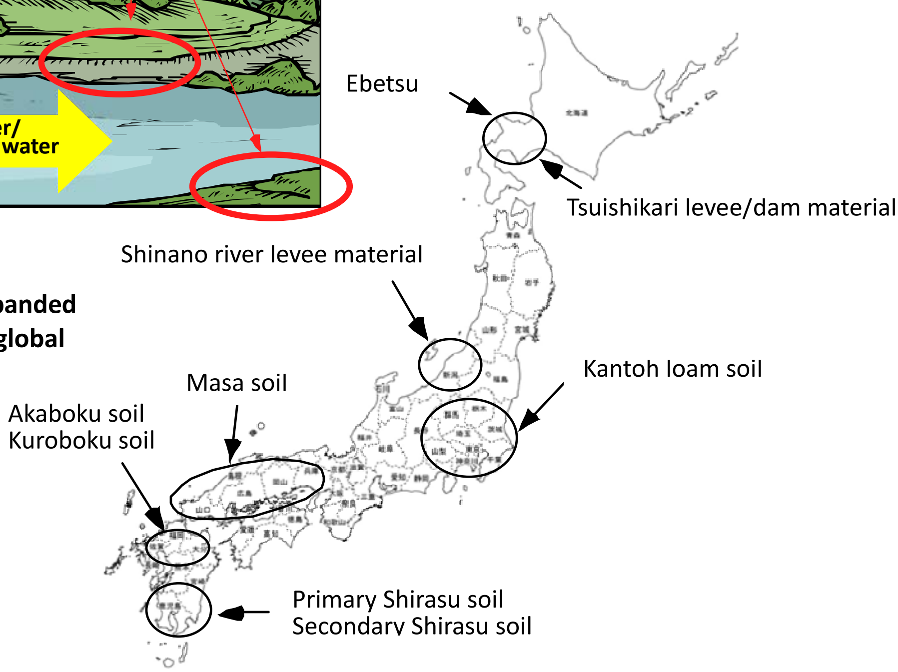


Fig. I-IV-7 Map of effects of expansion of river brackish water region on levee embankment materials.

Figure I-IV-8 portrays maps of the vulnerability assessment described above.

Estimate of and measures for expected vulnerability of river levee embankment materials to rainfall are as follows (Uchida et al. 2007). Also in relation to these estimates, the future hereof cannot be designated as a definite period.

1) Hokkaido: when water that has penetrated into a levee body by rainfall is drained, the strength of levee embankment materials drops abruptly, which might cause sudden slope failure. Devices in the drained areas can be thought of as measures.
2) Kanto and Shin-etsu districts: when water that has penetrated into the levee body by rainfall is drained, the volume shrinkage of river levee embankment materials is considerable, which might decrease the freeboard. Extrabanking is among candidate measures.
3) Chugoku district: the water holding capacity of levee embankment materials is low. This low holding capacity renders levees vulnerable to rainfall, thereby engendering their sudden collapse and volumetric shrinkage of slope faces. Possible measures include sealing.
4) Kyushu district: the water holding capacity of levee embankment materials is low. This low holding capacity renders levees vulnerable to rainfall, thereby engendering their sudden collapse and volumetric shrinkage of slope faces. Possible measures include sealing. Deterioration of water holding capacity and strength are especially rapid in the Kagoshima area, where a remarkable volumetric shrinkage might arise; it is expected that synthetic measures are required there especially.

Figure I-IV-9 displays the above-described vulnerability assessment and each measure as a map.

Hideo Komine (Ibaraki University)

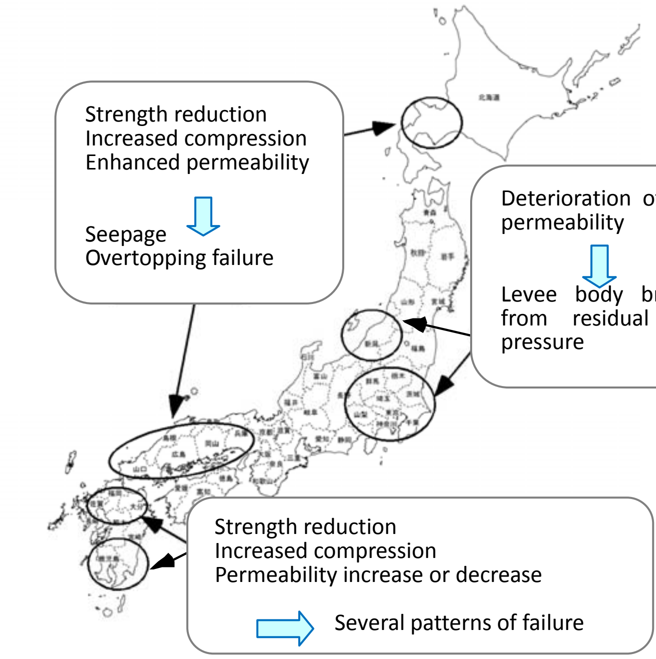


Fig. I-IV-8 Vulnerability assessment and measures map of river levee embankment materials to rainfall.

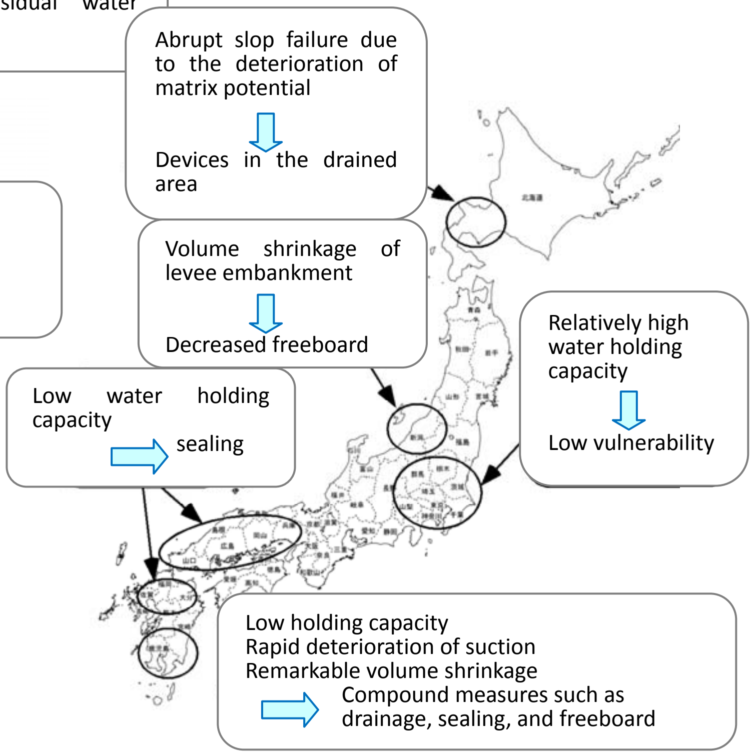


Fig. I-IV-9 Vulnerability assessment and measures map of river levee embankment materials to rainfall.

(3) Economic value of sand beaches

The economic value of sand beaches is about 12,000 yen/m^2. The value of sand beaches lost by a 30 cm sea-level rise will reach about 1.3 trillion yen.

Figure I-IV-10(a) shows the area of sand beaches by prefecture. It can be seen that the prefectures having the largest areas of sand beaches are Hokkaido with 43.9 km^2, Shizuoka with 14.0 km^2, and Aomori with 12.5 km^2, in descending order, while the area in the eight prefectures that do not border the ocean (Tochigi, Gunma, Saitama, Yamanashi, Nagano, Gifu, Shiga, and Nara) is zero. **Figure I-IV-10(b)** shows the number of annual users of sand beaches (for sea bathing) by prefecture. The prefectures with the largest number of users, also in descending order, are Kanagawa with 5.05 million people/year, Niigata with 3.99 million people/year, and Okinawa with 3.61 million people/year.

An estimation using the travel cost method (TCM) found that the recreational value of sand beaches per one time of use is 2,179 yen/time. By multiplying the number of annual users of sand beaches (for sea bathing) by prefecture by this basic unit, the annual recreational value of sand beaches can be obtained. When these numerical values are totaled, the annual recreational value of sand beaches in the whole of Japan becomes 92.2 billion yen. Moreover, when this value is converted to present value using a social discount rate of 4% per year, the recreational value of sand beaches in the whole of Japan becomes 2,304.6 billion yen[1].

Here, the recreational value of sand beaches by prefecture is as shown in **Fig. I-IV-10(c)**. It can be seen that the prefectures with the largest recreational value of sand beaches are, in descending order, Kanagawa with 9.6 billion yen/year (present value: 275.1 billion yen), Niigata with 8.7 billion yen/year (217.4 billion yen), and Okinawa with 7.87 billion yen/year (196.7 billion yen), in direct proportion to the number of annual users of sand beaches.

Since the total area of sand beaches in Japan is 191 km^2, the asset value of sand beaches (recreational value per unit area) is 12,058 yen/m^2. This numerical value serves as the basic unit of monetary assessment. Hence, from the area of sand beaches (**Fig. I-IV-10(a)**) and recreational value of sand beaches (**Fig. I-IV-10(c)**), the asset value per unit area of sand beaches by prefecture is as shown in **Fig. I-IV-10(d).** It can be seen that the prefectures with the largest asset value of sand beaches are Osaka with 114,951 yen/m^2, Kanagawa with 82,354 yen/m^2, and Hyogo with 64,823 yen/m^2, in descending order. Here, the main factor affecting the change in the relative order of the prefectures in **Fig. I-IV-10(d)** is the smallness of the area of sand beaches.

On the other hand, the results of projections of sea-level rises of 30 cm, 65 cm, and 100 cm found that 56.6%, 81.7%, and 90.3%, respectively, of the area of sand beaches in Japan will be encroached upon. Therefore, the recreational value of sand beaches that will disappear with sea-level rises of 30 cm, 65 cm, and 100 cm is 52.2 billion yen/year (present value: 1,304.4 billion yen), 75.3 billion yen/year (1,882.9 billion yen), and 83.2 billion yen/year (2,081.1 billion yen), respectively.

The situation of disappearance by prefecture is shown in **Fig. I-IV-10(e)**. In the legend of this figure, “Sea-level rise 0-30 cm,” “Sea-level rise 30-65 cm,” and “Sea-level rise 65-100 cm” refer to the value of sand beaches that will disappear as a result of the respective sea-level rises, with the length of the bar of the first color indicating the value of sand beaches that will disappear with a sea-level rise of 30 cm, the length of the bar totaling the first and second colors indicating the value that will disappear with a sea-level rise of 65 cm, and the length of the bar totaling all three colors indicating the value that will disappear with a sea-level rise of 100 cm.

From **Fig. I-IV-10(e)**, it can be seen that in the case of a sea-level rise of 30 cm, the prefectures with the largest value of sand beaches that will disappear as a result are Okinawa with 7.63 billion yen/year (present value: 190.8 billion yen), Niigata with 6.27 billion yen/year (156.8 billion yen), and Kanagawa with 4.71 billion yen/year (117.7 billion yen), in descending order. In the case of a sea-level rise of 65 cm, however, the order changes to Kanagawa with 8.35 billion yen/year (present value: 208.8 billion yen), Niigata with 8.23 billion yen/year (205.7 billion yen), and Okinawa with 7.83 billion yen/year (195.7 billion yen). Similarly, when the sea-level rise is 100 cm, the order is Kanagawa with 9.65 billion yen/year (present value: 241.2 billion yen), Niigata with 8.61 billion yen/year (215.3 billion yen), and Okinawa with 7.85 billion yen/year (196.3 billion yen). The

[1] With regard to the social discount rate, since a social discount rate of 4% per year is currently used for the assessment of public works in Japan, the same rate was adopted in the present study. Moreover, with regard to the method of conversion from annual value to present value, based on the assumption that the annual value will continue in perpetuity, the present value was obtained by dividing the annual value by the social discount rate of 4% per year.

changes in the order here are due to differences in the configuration of each marine area. Incidentally, when the rate of disappearance of value is examined, a sea-level rise of 30 cm results in a rate of disappearance of 97.0% for Okinawa, 88.4% for Okayama, and 80.7% for Tokyo Metropolis, in descending order. Moreover, eight prefectures will experience a rate of disappearance of value of more than 98% with a sea-level rise of 65 cm (Akita, Yamagata, Tokyo, Kyoto, Wakayama, Shimane, Okayama, and Okinawa), and with a sea-level rise of 100 cm, eight more prefectures (Niigata, Ishikawa, Fukui, Osaka, Hyogo, Hiroshima, Yamaguchi, and Kochi) will be added to this list.

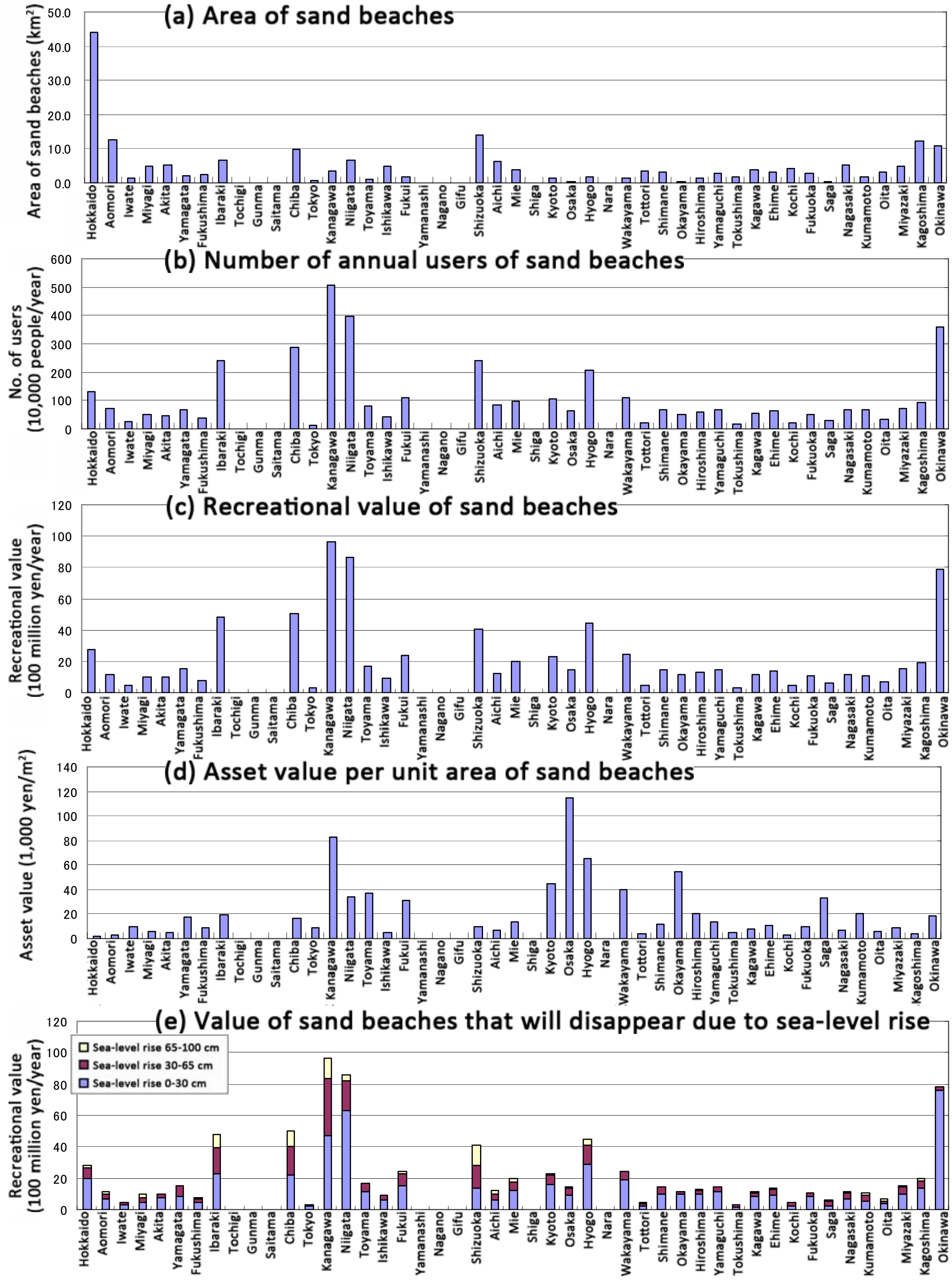


Fig. I-IV-10 (a) Area of sand beaches, (b) number of annual users of sand beaches, (c) recreational value of sand beaches, (d) asset value per unit area of sand beaches, and (e) value of sand beaches that will disappear due to sea-level rise.

(4) Economic value of tidal flats

The economic value of tidal flats is about 10,000 yen/m^2. The economic loss will reach as much as 5 trillion yen assuming tidal flats throughout Japan are impacted by sea-level rise.

By an estimation using the contingent valuation method (CVM), it was found that the per capita value of willingness to pay (WTP) to avoid the destruction of tidal flats is 1,554 yen/year/person. When this numerical value is converted to present value using a social discount rate of 4% per year, the per capita economic value of tidal flats (value of their biodiversity maintenance function) is 38,858 yen/person. Multiplying this value by Japan's total population of 127.74 million, the economic value of tidal flats nationwide becomes 4,963.7 billion yen. The total area of tidal flats currently confirmed along the coasts of Japan is 514 km^2; therefore, the asset value (economic value per unit area) of tidal flats is 9,657 yen/m^2.

Here, the above results are compared with the results of an assessment of the economic value of the Fujimae Tidal Flat by Washida, Kuriyama, and Takeuchi (1988) Washida et al. calculated the per capita value of WTP as 6,555 to 10,260 yen/person for conservation of the approximately 2.5 km^2 area of this tidal flat using CVM in the same manner as in the present study, with the total value amounting to approximately 296 billion yen. From this, the asset value of the Fujimae Tidal Flat is 118,400 yen/m^2, whereas the result of the assessment in the present study is one-twelfth of that value. The difference between the two values can be attributed to such factors as the specificity of the areas targeted for assessment (tidal flats in the whole of Japan: unspecified; Fujimae Tidal Flat: specified), the urgency of conservation (tidal flats in the whole of Japan: long-term global warming issue; Fujimae Tidal Flat: urgent waste disposal issue), etc.

Eiji OHNO (Meijo University)

Table I-IV-1 Questionnaire with respect to fair share for avoiding devastation of tidal flats

It is expected that tidal flats will be destroyed by global warming effects (sea level rise, etc.), and that all of their functions will be lost in the future. This study assumes that a national policy will be undertaken to collect a burden charge from the whole nation and allot it to measures to avoid devastation of tidal flats by global warming. The collection of that burden charge is assumed here for economic evaluation of the damage of tidal flats caused by global warming, and that no burden charge is actually collected. Then assume the following:

- **Enforcement** of this policy will **preserve** all tidal flats in Japan (about 514 km^2), and ecosystems living there are maintained.
- **Neglect** of this policy will **destroy** all tidal flats in Japan (about 514 km^2), and ecosystems living there will be lost.

The following 1) – 9) show examples of burden charges required for implementing the policy described above. Whether a person is affirmative or negative to enforcement of the policy is asked about each of 1) – 9). An applicable answer is checked for each question. This burden charge is applied for the period of residence in Japan. In addition, goods or services that a person can purchase will be reduced by that amount.

1) **100 yen** per person is charged for the policy every year
   1. Affirmative to enforcement of policy,
   2. Negative to enforcement of policy

2) **300 yen** per person is charged for the policy every year
   1. Affirmative to enforcement of policy,
   2. Negative to enforcement of policy

3) **500 yen** per person is charged for the policy every year
   1. Affirmative to enforcement of policy,
   2. Negative to enforcement of policy

(the remainder are omitted)

(5) Variation of liquefaction risk

Sea level rise and anomalous rainfall raise the groundwater level and expand areas that suffer geological hazard by liquefaction in the event of an earthquake.

Sea level rise raises the groundwater level not only on coastlines but on riversides. Therefore, liquefaction risk attributable to sea level rise increases concomitantly with the site's proximity to coastal zones and riversides. On the other hand, the variation of rainfall by climate change raises groundwater levels in inland regions, where rainfall increases. Consequently, liquefaction risk by the groundwater level rise increases in inland regions where local heavy rains increase. Ground liquefaction caused by an earthquake is a factor increasing building collapse risk and damage, such as a drop of building foundations or bridges and ground subsidence, accompanied by the lifting of underground structures such as sewer pipes or lateral flow of soil. It is important to assess the grade of effect of climate change on this liquefaction risk to understand geological hazards by an earthquake in the area.

Among areas where precipitation increase caused by climate change is expected, the areas of Kawasaki and Yokohama between the Tsurumi and Tama Rivers on the Tokyo Bay coastal zone were selected as our study object. Ground structure modeling using a ground information database in the object region was performed. Then the groundwater level rise in coastal zone grounds accompanying sea level rise and climate change was analyzed using the 2-D unconfined groundwater flow analysis method with FEM. The effect of climate change was evaluated (Murakami et al. 2005, Yasuhara et al. 2007). The change of liquefaction risk before and after sea level rise and climate change was computed using this procedure; vulnerability assessment was carried out in the event of an earthquake in coastal zone grounds because of the sea level rise. The PL value (see **Table I-IV-2**) computed using the soil condition including a groundwater level was used for estimating the liquefaction risk. The climate unification scenario by Meteorological Agency, RCM20, was used for the assumed rainfall. The sea level rise was assumed to be 88 cm in 2100.

Figure I-IV-11 (a) is a liquefaction hazard map for the present day, whereas **Fig. I-IV-11 (b)** is a liquefaction hazard map considering sea level rise. The maps collectively reveal that liquefaction risk near the coastline is enhanced accompanying sea level rise, and that liquefaction risk is encouraged in areas near rivers. This fact suggests that areas where the coastal zone ground is influenced by sea level rise are influenced not only in near the coastline, but in river downstream areas along the shore, which undergo tidal floating. **Figure I-IV-11(c)** is a liquefaction hazard map considering rainfall: compared with the case of sea level rise only, liquefaction risk has increased more in inland on riverside areas. Climate change affects differently in places: the sea level rise is influential on seashore and riversides, as is the change of rainfall characteristics on inland.

The variation of rain intensity and frequency increases in areas of high liquefaction risk. **Table I-IV-2** summarizes rate of area change for each liquefaction risk area.

In practice, climate change alters sea level rise and rain intensity and frequency simultaneously. Accordingly, **Fig. I-IV-11 (d)** considering the effect of both is considered to represent the situation of the future most. **Figure I-IV-11 (e)** portrays regions in which liquefaction risk rank changes. In the object region, the variation of sea level rise and rain intensity and frequency by climate change will increase areas of high liquefaction risk.

Kazuya Yasuhara and Satoshi Murakami
(Ibaraki University)

Table I-IV-2 Area change of liquefaction risk level to present.

P_L value	After sea level rise	Variation of rainfall	After sea level rise and variation of rainfall
0 < P_L < 5 (Rank1)	1.03	0.98	0.93
5< P_L < 15 (Rank2)	0.98	0.95	0.87
15< P_L < 25 (Rank3)	1.09	1.11	1.06
25< P_L (Rank4)	1.14	1.27	1.42

P_L value and the effects due to the liquefaction

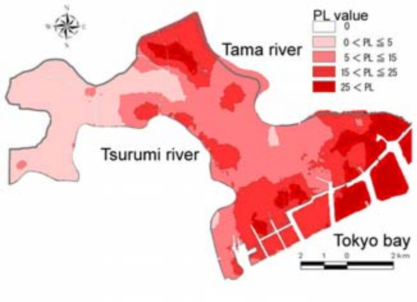
*(*Specifications for highway bridges(1966))

P_L =0 : no effect due to liquefaction

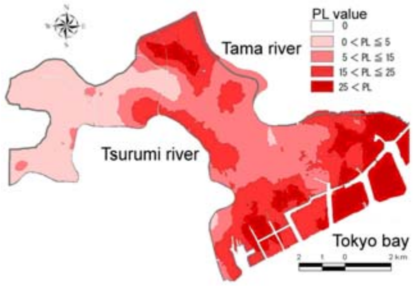
0< P_L <=5 : small effect

5<P_L <=15 : large effect

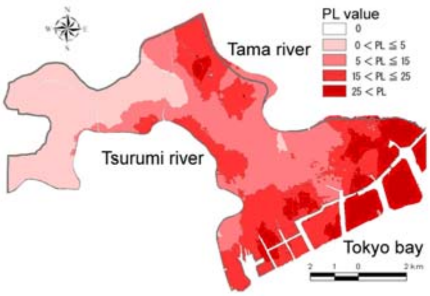
15<P_L : considerably large effect



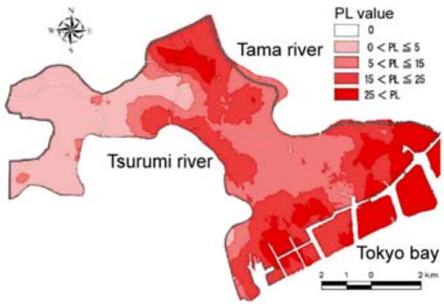
(a) Present(1990)



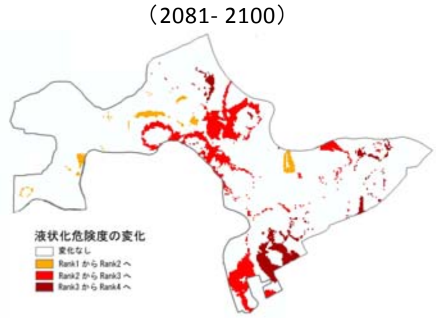
(b) due only to sea level rise(2100)



(c)due only to changes of rainfall characteristics（2081-2100）



(d) due both the sea level rise and the change of rainfall （2081- 2100）



(e) liquefaction risk index varied area from (a) to (d)

Fig. I-IV-11 Variation of liquefaction risk (Murakami)

(6) Risk of slope disaster

Global warming enhances the risk of slope disaster. It is important to examine the slope recovery plans with a risk index.

(a) **Figure I-IV-12** presents the slope disaster risk (product of the failure probability of a slope and economic loss by failure) attributable to global warming in Fukuoka. Trial calculations were performed for Fukuoka based on this map. The following results were obtained.

- Slope disaster risk in the present rainfall condition: loss of 36,000 million yen/year
- Slope disaster risk in the rainfall condition attributable to global warming in 2050: loss of 61,430 million yen/year

Consequently, the increase in slope disaster risk in Fukuoka posed by global warming is 70.6%.

(b) An assessment method of slope disaster risk considering the compound effect of heavy rain and an earthquake was developed; it was then applied to the risk evaluation of a collapsed slope in Shikashima caused by the Fukuoka west coast earthquake in 2005. Because of a cave-in geography of large deformation made up in the upper part of the slope by this earthquake, the possibility of large-scale landslides in future earthquake and heavy rain is of great concern. The magnitude of potential collapsed slopes is classified in three cases represented in **Fig. I-IV-13**. The expenditure for the measures varies widely from hundreds of millions of yen to billions of yen with the assumed failure magnitude. Therefore, risk analyses are conducted in these three cases and the results are depicted in **Fig. I-IV-14**. The results suggest the following.

1) In the event of an earthquake, rainfall and an earthquake after rainfall, the risks of surface sliding and mid-depth middle-scale sliding become high, but that of deep large-scale sliding is quite small.

2) When rainfall and an earthquake are combined, the risk of mid-depth middle-scale sliding and surface sliding becomes high too, but that of depths large-scale slide does not affected much.

Therefore, the following were revealed:

1) The risk of deep large-scale sliding in Case C is small.

2) The risks of surface sliding in Case A and mid-depth middle-scale sliding of Case B are comparable.

3) If countermeasure work costs are taken into account, measures against surface sliding, considering a partial mid-depth slide, are the most efficient. This proposal has been adopted in the recovery plan of Fukuoka city.

Guangqi Chen and Yasuhiro Mitani
(Kyushu University)

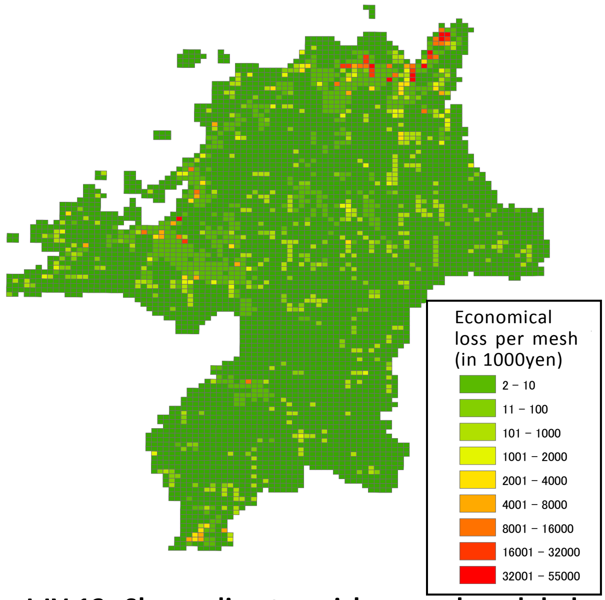


Fig. I-IV-12 Slope disaster risk map by global warming in Fukuoka

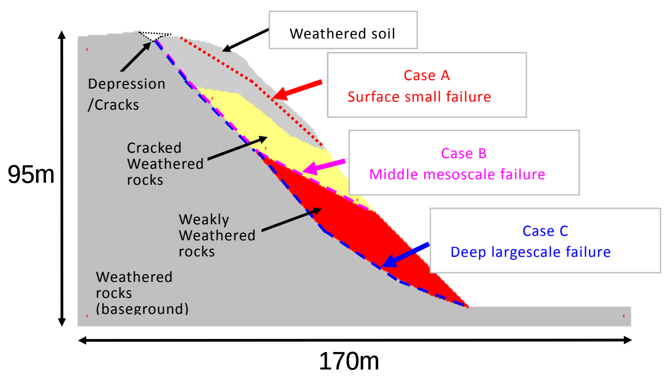


Fig. I-IV-13 Model of assumed landslide mode.

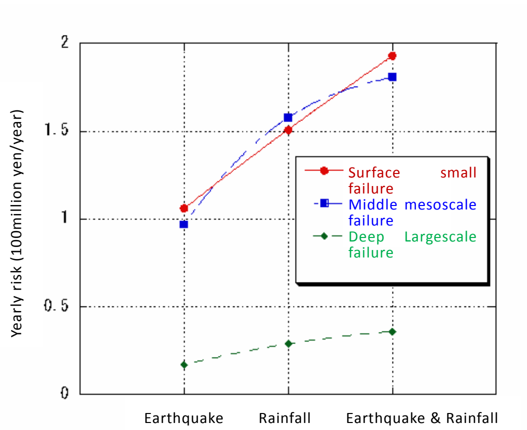


Fig. I-IV-14 Slope disaster risk under each condition.

Topic **Climate change accelerates geological hazards.**

A worst-case scenario of the effect of global warming teaches us that, when phenomena attributable to global warming and other phenomena, such as earthquakes, occur simultaneously, they might cause unprecedented complex disasters. Moreover, they might take place frequently.

For instance, the Niigata Chuetsu earthquake in 2004, in which a huge earthquake occurred after a long rain that continued for about one month, is a typical example of a complex disaster. Until immediately before the earthquake, unusual rainfall continued. Then rain was accumulated in hills and mountains, which caused them to collapse easily. Then the large earthquake occurred, and landslides occurred in about 4,000 locations. **Figure I-IV-15** portrays that the frequency of landslide disasters is increasing with latest increases in local heavy rains.

The earth is now in "the age of ground disturbance" (Prof. Katsuhiko Ishibashi, Kobe University); it is presumed that events caused by abnormal weather attributable to global warming are overlapping.

On the other hand, short-term and long-term factors can engender different variations of groundwater levels: in the former, groundwater level rises temporarily according to local heavy rains; by in the latter, groundwater levels rise slowly over many hours, as in a recent case where underground station structures of Ueno and Tokyo Stations might be lifted. Furthermore, when local heavy rains increase because of global warming, the groundwater level rises abruptly. Accordingly, the possibility of liquefaction might increase not only in coastal zones, but also in inland. Consequently, global warming presents the risk of exacerbating disasters.

Kazuya Yasuhara (Ibaraki University)

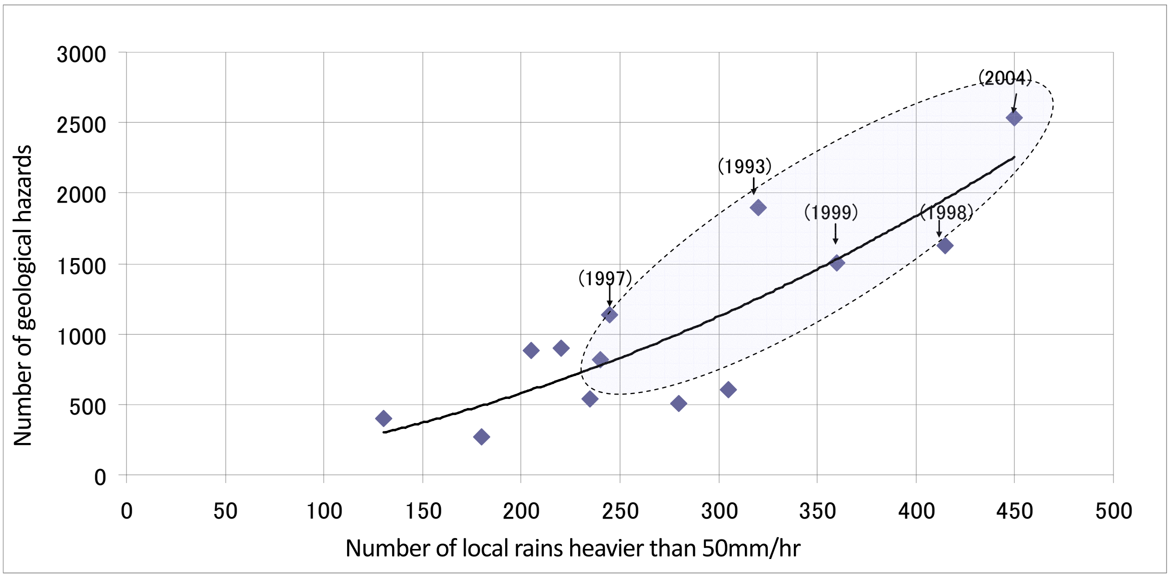


Fig. I-IV-15 Local heavy rain and landslide disaster.

5. Impacts on Human Health

5.1 Outline

According to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), the health impacts of global warming can be divided into direct impacts, indirect impacts, and impacts due to the collapse of socioeconomic systems. For example, the report cites increases in diseases caused by malnutrition; increases in deaths and diseases due to heat waves, floods, storms, fires, and droughts; increases in diarrheal diseases; increases in cardio-respiratory diseases due to higher concentrations of photochemical oxidants; and increases in vector-borne infectious diseases. In the present research, (1) mortality risk due to heat stress and (2) risk of heatstroke incidence, which is a representative disease arising from heat stress, were studied as direct impacts; while (3) mortality risk due to photochemical oxidant pollution, which is expected to worsen with global warming, and (4) factors related to incidence of dengue, Japanese encephalitis, and malaria, as representative diseases among arthropod vector-borne infectious diseases due to increased spatial distribution of vectors, were studied as indirect impacts.

In various countries, particularly the developing countries, the risks of health disorders due to malnutrition, diarrheal diseases, water-borne infectious diseases, etc. are considered to be large, whereas in the industrialized countries including Japan, these risks can be considered to be relatively small in terms of the present scope of global warming projection. With regard to the incidence of arthropod vector-borne infectious diseases, not only the temperature but also social and public health conditions are closely related; therefore, as long as present social and public health conditions are maintained, the possibility of epidemics of dengue, malaria, etc. reemerging can be considered to be small. From the biological standpoint, however, increased spatial distribution of vector mosquitoes is certain to occur and potential risks accompanying global warming can be considered to be large.

5.2 Targets and Methods of Impact Assessment

(1) Heat stress mortality risk

As regards the health impacts of global warming in the industrialized countries including Japan, the direct impact of heat stress is considered to be a more significant issue than the impact of infectious diseases. Heat stress impact is often assessed in the form of the excess mortality (rate) due to high temperature. In Japan as well as in Europe and the U.S., the relationship between temperature and mortality is known to form a V-shaped curve (the mortality rate reaches its lowest value at a certain temperature (optimal temperature), and rises when the temperature is either higher or lower than this optimal level. This relationship is also reported to vary according to the climate, with a lower optimal temperature seen in cold climates and a higher optimal temperature in warm climates. The excess mortality rate due to high temperature is the difference between the mortality rate on a day when the temperature exceeds the optimal temperature and the mortality rate on a day of optimal temperature; that is, all mortality caused by the high temperature. Heatstroke, described below, is a typical example of this, although it does not necessarily account for a large proportion of heat stress impacts. The temperature with the lowest mortality rate in the V-shaped curve showing the relationship between the daily maximum temperature and mortality, namely, the optimal daily maximum temperature, was estimated by prefecture using past data (observed temperature values and mortality statistics) and future excess mortality rates due to high temperature were projected on the assumption of no future change in the optimal daily maximum temperature.

(2) Heatstroke

For heatstroke, which can be expected to become more prevalent due to rising temperatures, it is necessary to study the levels of increasing risk, namely, threshold values, as well as to formulate temperature-impact functions.

In order to conduct impact assessment of heatstroke, basic information on ambulance transportation cases was collected in cooperation with the fire offices of major cities in Japan. In addition, based on a survey of hospitals regarding heatstroke cases, the number of heatstroke cases other than those transported by ambulance was estimated. The relationships between heatstroke incidence and temperature indexes (daily maximum temperature, etc.) as well as differences due to regions and other characteristics were studied, and a preliminary assessment of risk associated with global warming was made.

(3) Atmospheric pollution risk

Among atmospheric pollutants, photochemical oxidants (Ox), which are generated by a reaction that is promoted by temperature rise, are directly impacted by global warming. In urban areas with a high Ox concentration due to a high density of factories and automobile traffic, it is projected that Ox concentration will further increase as a result of global warming, the occurrence of photochemical smog will become more frequent, and health damage will increase.

Various health impacts of ozone, which accounts for the majority of Ox, are known, including eye symptoms (irritation, watery eyes, etc.), respiratory symptoms (sore throat, coughing, breathing difficulty, etc.), and in serious cases, nausea, headache, etc. The latest epidemiological studies have also found that there is an increase in mortality, although only slight, on days with a high ozone concentration or on the following day.

Therefore, on the assumption that emissions of pollutants remain the same as at present, increases in Ox compared with the current situation and the levels of health impacts according to changes in the frequency of occurrence of weather patterns due to global warming were studied targeting the summer season (June to August). In determining the health impacts, relationships between increased mortality and concentrations already elucidated in past studies were used, and the future population was estimated based on the populations under two types of social scenarios.

(4) Dengue, malaria, and Japanese encephalitis

Various scenarios have been described concerning the effects of global warming and extreme weather events on human health. Increasing occurrence and epidemics of viral infections transmitted by arthropods such as mosquitoes are projected to have a particularly significant impact. However, sufficient data to support such hypotheses and projections have not been yet obtained in Japan nor in other countries. A pressing need therefore exists for clarification of the impacts of global warming and extreme weather events on arthropod vector-borne infectious diseases, and for studies on adaptation measures taking the economic assessment of such events into consideration.

In this research, the potential risk was studied based on investigations of the actual and potential habitat distribution ranges of main vector mosquitoes. For dengue vector mosquitoes, the distribution range was investigated by collecting larvae from human-related breeding sites such as flower stands in graveyards and old tires in urban areas centering around the Tohoku region. For the vector mosquitoes of Japanese encephalitis, imagoes (the adult insects) were collected by light traps and black light traps of CDC (Centers for Disease Control and Prevention) type, and the differences in the number collected by area were studied. With regard to the *Anopheles* mosquito, an analysis was conducted of larvae and imagoes collected on the island of Ishigakijima in Okinawa Prefecture.

5.3 Future Projection of Health Impacts
(1) Mortality risk due to heat stress

With rising temperatures, the mortality risk due to heat stress will increase.

Estimates of the relationship between the daily maximum temperature and daily mortality rate by prefecture using a smooth curved line revealed that, in any prefecture, the mortality rate is lowest at a certain daily maximum temperature and rises when the temperature is either higher or lower than that temperature (**Fig. I-V-1** shows the example of Hokkaido). It was also found that the colder the area, the lower the temperature at which the mortality rate is lowest (hereafter referred to as the “optimal temperature”).

The excess mortality due to heat stress under projected future climates was assessed assuming that the optimal temperature of each prefecture remains unchanged in the future. **Figure I-V-2** shows a mapping of the probability of a person dying due to heat stress during a year in various periods, projected using a model for estimating excess mortality due to heat stress by prefecture and future temperature distribution scenarios (RCM20). With rising temperatures, the probability of mortality due to heat stress was projected to increase to about double even in prefectures whose changes are small, and by fivefold or more in prefectures with large changes. It should be noted that in this research, only changes in excess mortality at high temperatures due to rising temperatures were studied, and changes in excess mortality at low temperatures were not targeted for analysis.

The heat wave in Europe in 2003 is still fresh in people’s memories as a past case of increased mortality during a heat wave in industrialized countries. At the time of the European heat wave, it was pointed out that inadequate preparations had been made for extremely high temperatures, such as insufficient dissemination of air conditioning, lack of warning systems for heat stress, etc. as the cause of the aggravation of damage. In the future, taking the increase in excess mortality due to heat stress accompanying global warming into consideration, the adoption of additional measures to deal with heat waves should also be studied in Japan.

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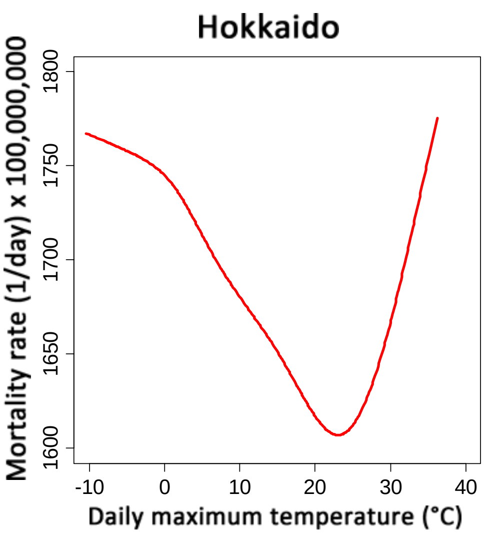
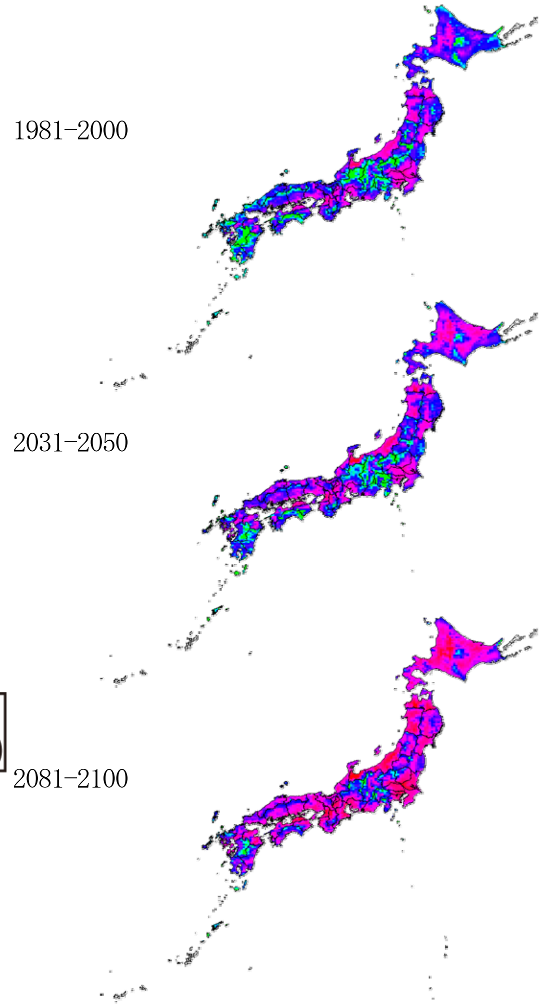


Fig. I-V-1 Relationship between daily maximum temperature and daily mortality rate (Hokkaido)



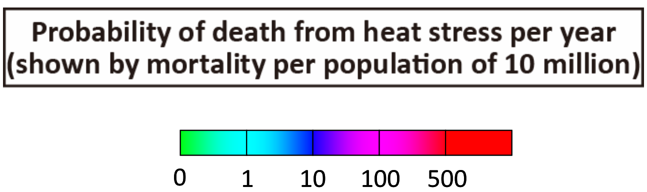


Fig. I-V-2 Probability of a person dying from heat stress during a given year

(2) Future projection of heatstroke

The incidence of heatstroke will drastically increase as the daily maximum temperature becomes higher. A steep increase in cases is seen in people aged 65 years or older on days when the temperature exceeds 35°C.

Figure I-V-3(a) shows heatstroke incidence rate at various daily maximum temperatures in major cities in the Kanto region (Saitama City, Chiba City, Tokyo Metropolis, Yokohama City, and Kawasaki City). A trend of increasing heatstroke incidence is seen at daily maximum temperatures of around 27-28°C and higher, with a drastic increase appearing at temperatures of around 31-32°C and higher. Even at the same daily maximum temperature, considerable differences between cities are seen in the heatstroke incidence rate. This can be considered to be caused by factors other than the daily maximum temperature, such as weather conditions (humidity, insolation, wind speed, etc.) as well as the daytime population, particularly the population working outdoors, etc.

When the heatstroke incidence rate at various daily maximum temperatures is examined by age group (**Fig. I-V-3(b)**), it is found that (1) the incidence rate for people of advanced age is high overall, and (2) an especially pronounced increase is seen when the temperature exceeds 35°C. Many people of advanced age suffer from heatstroke indoors, unlike the case of other age groups, which is considered to be due to a lack of appropriate adaptation measures being taken, even in a high-temperature environment exceeding 35°C. This means that the impact of global warming is conspicuous in people of advanced age, while on the other hand, there is a possibility of prevention if appropriate measures are taken.

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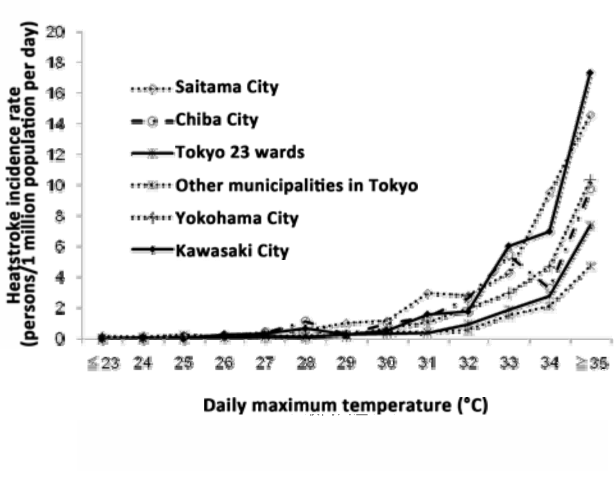
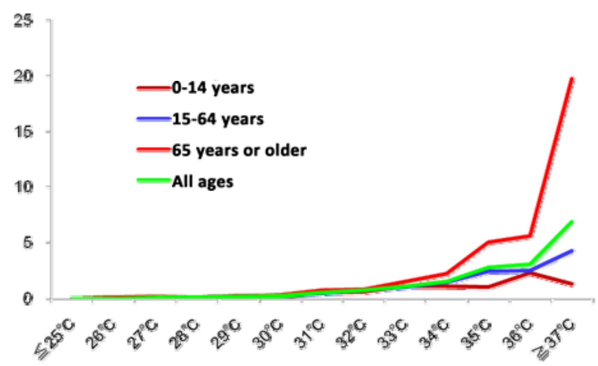


(a) By region (2007, selected urban cities in Kanto region)



(b) By age group (2007, Tokyo 23 wards)

Fig. I-V-3 Heatstroke incidence rate at various daily maximum temperatures by region and age group

(3) Atmospheric pollution risks

Accompanying the changes in weather due to global warming, higher concentrations of photochemical oxidants and consequent increases in mortality are expected. However, the impact of this will be smaller than that resulting from an increasing occurrence of transboundary photochemical oxidant pollution.

In studying the risks of photochemical oxidants (Ox), Ox concentrations were obtained for the present condition of each weather pattern by region, and these concentrations were applied to the projected future weather patterns. Future increases in concentration due to transboundary pollution were not taken into consideration. Detailed estimations were made for the Kanto zone, Kansai zone (Osaka Prefecture), and Tokai zone (Aichi Prefecture), where weather data and past measured Ox values necessary for estimation were available. The results showed that in most areas of the seven prefectures in Kanto (including Tokyo Metropolis), future increases in Ox concentration and consequent increases in mortality can be expected. In Osaka and Aichi prefectures as well, although local differences were seen within the prefectures, Ox concentration was found to increase overall. As shown in **Fig. I-V-4**, to determine the corresponding increases in mortality, the increment in Ox concentration was calculated for each mesh, and the increment in risk for each mesh was calculated from the relative rate of mortality risk and multiplied by the projected total mortality. Since such mortality risk data are not available in Japan, the values were determined based on the results of epidemiological studies in Western countries. Numerical values estimated based on data from Western countries must be interpreted carefully, however, in view of the differences in lifestyle and environment. Nevertheless, studies on mortality risk in relation to particulate matter in Japan have confirmed almost the same trends as in Western countries, and Japan is therefore assumed to have a similarly increasing trend to those countries in terms of mortality due to increased Ox concentrations.

Increased mortality accompanying increases in Ox concentration was calculated by estimating the future populations aged 65 years or older and under 65 years old by regional mesh, and multiplying these values by the Ox mortality risk. **Figures I-V-5** and **I-V-6** respectively show the future increases in mortality rate and mortality by prefecture of people aged 65 years or older, for whom the mortality effect is pronounced, using future populations of the urban concentration type social scenario (A) case. **Figures I-V-7** and **I-V-8** show Ox concentration projection maps and risk maps, respectively, for the Kanto region. It should be noted that the population of Japan is projected to rapidly decrease, with the total population in 2100 estimated to be lower than 50 million, representing not more than 40% of the population in 2000.

The advection of atmospheric pollutants from the Asian continent to Japan is increasing every year, and the Ox concentration from April to May is reported to have already increased by 5-20 parts per billion (ppb) Tanimoto et al., 2005). The increase in Ox in Japan brought about by changes in weather due to global warming was estimated to be not more than 10 ppb from 2081 to 2100, even in areas with a large increase. Transboundary pollution from the continent will continue to increase for the next several decades, however, and the increase in Ox concentration due to this transboundary pollution is expected to far exceed the impact of global warming. The projections made in the present study do not take future increases in Ox concentration due to transboundary pollution into consideration, but when there is a rise in the actual Ox concentration, which was the basis for the projections, the increase in concentration due to global warming will become larger.

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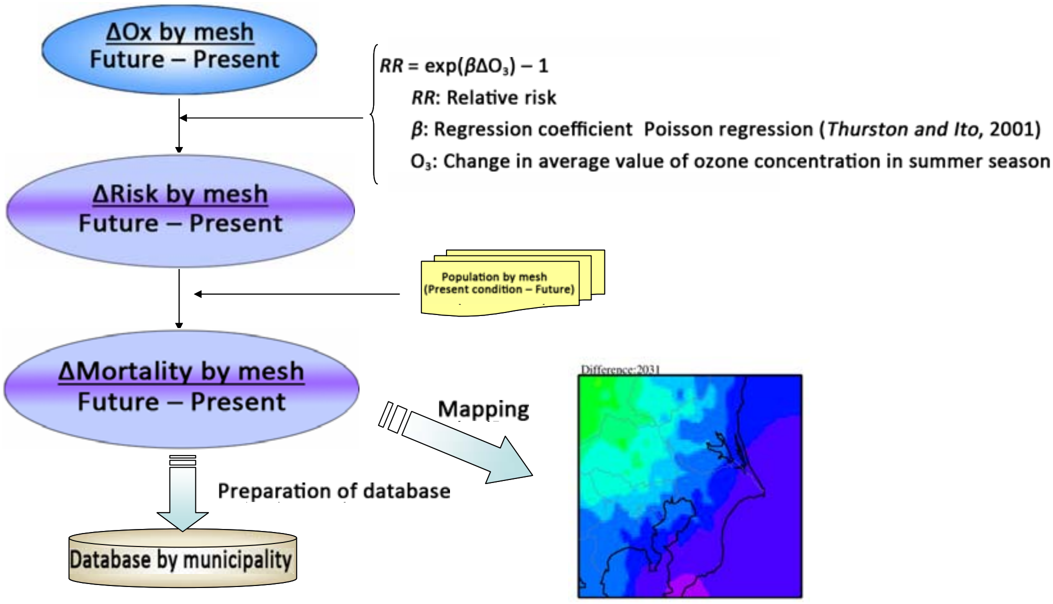

Fig. I-V-4 Method of assessing mortality risk accompanying future increases in Ox concentration

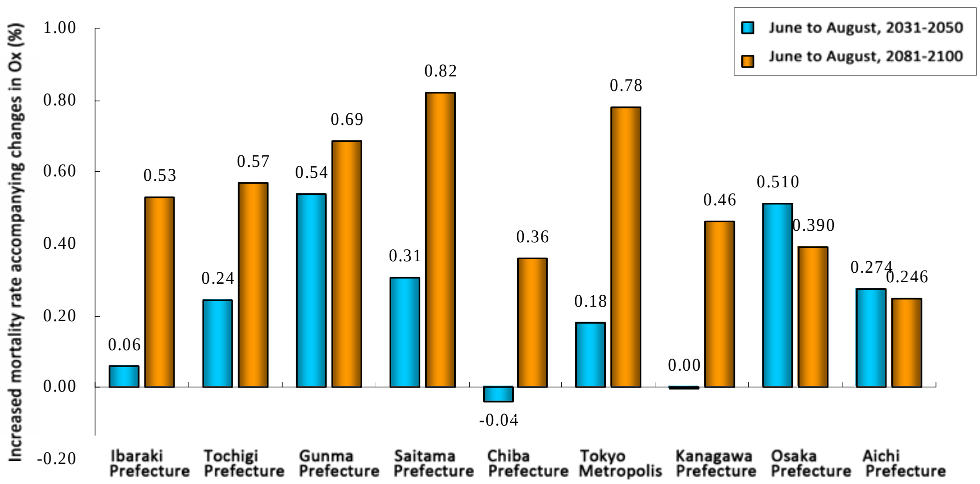

Fig. I-V-5 Increase in mortality rate accompanying increases in Ox concentration due to global warming Increased mortality rate of people aged 65 years or older in the summer season over a 20-year period, using the urban concentration type social scenario. Accidental deaths are excluded.

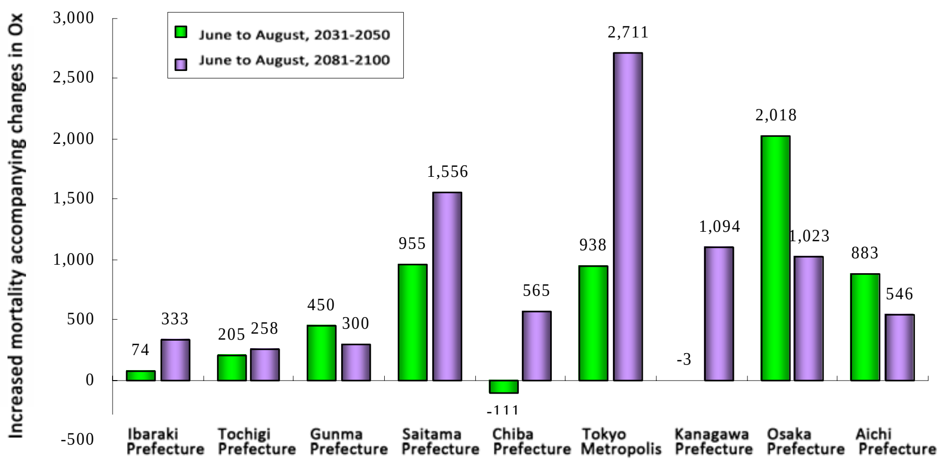

Fig. I-V-6 Increase in mortality accompanying increases in Ox concentration due to global warming Increased total mortality of people aged 65 years or older in the summer season over a 20-year period, using the urban concentration type social scenario. Accidental deaths are excluded.

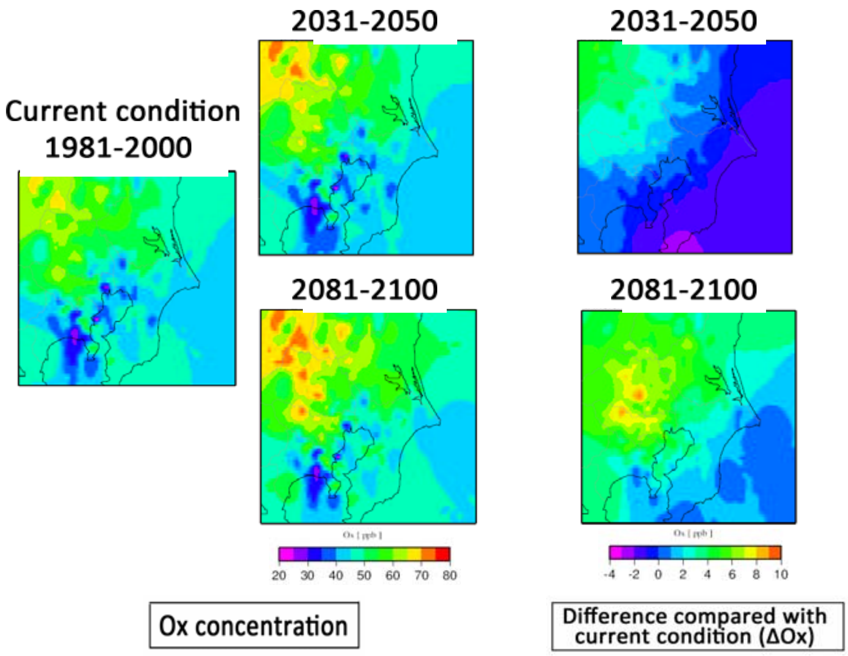

Fig. I-V-7 Projected Ox concentrations and differences in concentration compared with current condition in Kanto region (ΔOx)

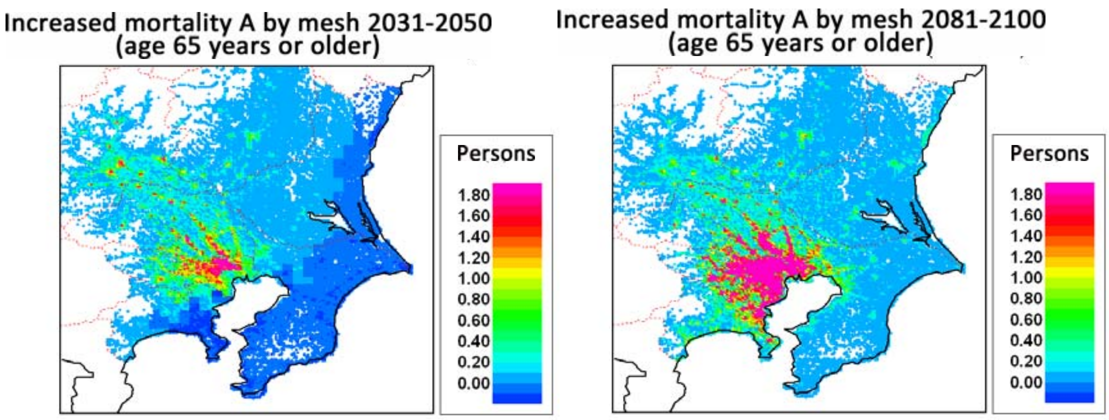

Fig. I-V-8 Impact projection for Kanto region (Increase in total mortality in the summer season over a 20-year period with respect to ΔOx)

Note: The impact on mortality due to exposure to Ox is assumed to be $\Delta M = Y_0$ (exp($\beta\Delta$Ox) – 1) x (Population), where ΔM is the change in daily mortality, Y_0 is the baseline value of the non-accidental daily mortality rate, and ΔOx (ppb) is the increment from the baseline of the one-hour maximum value. With regard to *β,* the average value of $\beta = 7.65 \times 10^{-4}$ (1/ppb) in three meta-analysis cases (Ito et al., 2005; Bell et al., 2005; Levy et al., 2005) was used for all ages, and with regard to people of advanced age (65 years or older), the value of $\beta = 1.33 \times 10^{-3}$ (1/ppb), which was estimated based on these reports, was used. For $Y_{0,}$ the mortality by mesh was estimated by proportionally distributing the mortality by municipality (the mortality by prefecture for people of advanced age) using the national census population ratios by mesh. For the future population by mesh, the estimated values by age group based on scenario A, in which the population is concentrated in the Tokyo metropolitan area, and scenario B, in which the population is dispersed in regional cities, were used. Combining the above-mentioned results and ΔOx concentration by mesh, the estimated values of the future mortality increment by mesh ΔM were calculated.

Rererence： Tanimoto et al. 2005, Ito et al. 2005, Bell et al. 2005, Levy et al. 2005

(4) Future projection of dengue and malaria

The potential distribution range of the yellow fever mosquito *(Aedes aegypti*), a vector for dengue, will expand to a wide area encompassing the southern part and the eastern and western coastlines of Kyushu, Kochi Prefecture, the southern part of the Kii Peninsula, Shizuoka Prefecture, Kanagawa Prefecture, and the southern part of Chiba Prefecture by 2100.

Although dengue has been considered to be a global pandemic occurring every two to three years, recently epidemics have been occurring almost every year centering around Southeast Asia, the South Pacific countries, and Latin America.

Among the effects attributed to global warming are a shortening of the growth period of the larvae of vector mosquitoes and an increase in the number of viruses that propagate in the bodies of vector mosquitoes, etc. In the case of malaria, on the other hand, it is known that the growth of plasmodia carried by mosquitoes is inhibited at elevated temperatures of 30°C or higher. It is therefore projected that the distribution range of vector mosquitoes will expand to higher altitude regions in African countries, and as a result, malaria epidemics will occur in highland areas.

It has been reported that the possible distribution of the yellow fever mosquito *(Aedes aegypti*), the principal vector mosquito of dengue, occurs in areas with the mean temperature of 10°C or higher in January. Therefore, in order to study the potential distribution range of the yellow fever mosquito due to global warming, the mean temperature in January 2100 was estimated using the MIROC model and employed (**Fig. I-V-9**). It was found that from Okinawa to the island of Tanegashima, the mean temperature (approximately 17°C) will become almost the same as that in the cities of southern Taiwan where dengue is currently prevalent. It was also found that the regions of potential distribution of the yellow fever mosquito will expand to a wide area encompassing the southern part and the eastern and western coastlines of Kyushu, Kochi Prefecture, the southern part of the Kii Peninsula, Shizuoka Prefecture, Kanagawa Prefecture, and the southern part of Chiba Prefecture.

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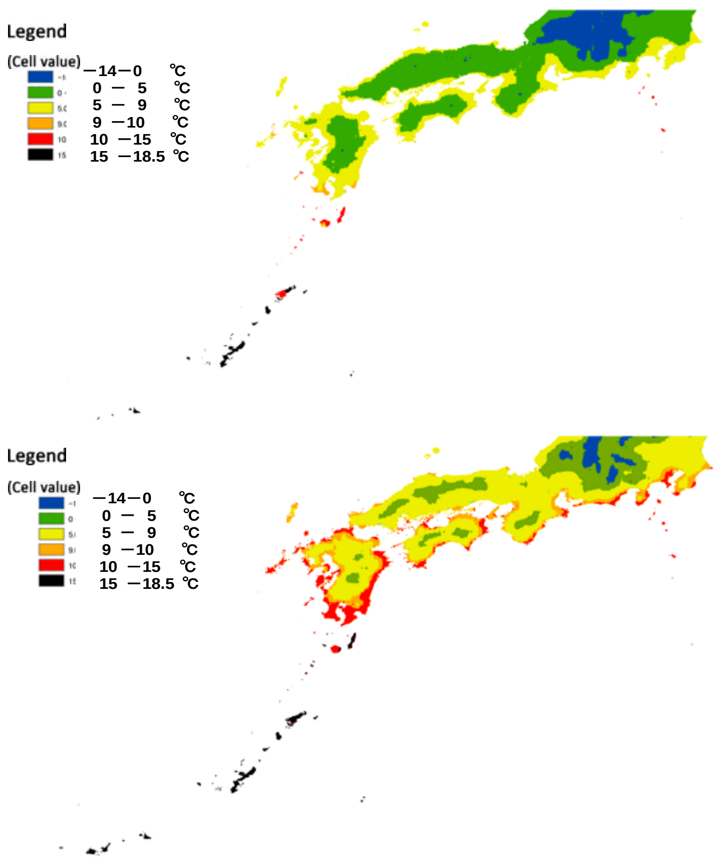

Fig. I-V-9 Distribution of mean temperatures in January (top: 2035, bottom: 2100)
(Projected expansion of distribution range of yellow fever mosquito)(From Kobayashi et al., 2008)

The distribution range of the Asian tiger mosquito *(Aedes albopictus)* has now reached Iwate and Akita prefectures.

The Asian tiger mosquito *(Aedes albopictus)*, a vector mosquito of dengue, Chikungunya fever, etc., originated in Southeast Asia. In 1950, Tochigi Prefecture was the northern limit of its distribution in Japan(**Fig. I-V-10**). Its distribution range has gradually expanded, however, reaching Akita and Iwate prefectures in the 1990s. This mosquito causes great damage, persistently sucking blood from humans from morning to evening, and outdoor gardening activities are not possible from May to September in residential areas with large numbers of breeding mosquitoes. Its blood-feeding preferences are wide; it is known to collect blood not only from humans but also from dogs, cats, rodents, and other mammals as well as wild birds such as ducks, sparrows, etc. Moreover, in the U.S. it is known as one of the vector mosquitoes of West Nile virus.

The Asian tiger mosquito can be transferred long distances when its larvae bred in stagnant water in old tires or its eggs adhering to the inside of old tires are carried to distant locations. Old tires exported from Japan were the cause of the migration of this mosquito to the U.S. It is highly adaptable to new environments, and its distribution range has now expanded to various regions including North America, Latin America, Europe, and Africa. It is necessary to promote renewed understanding that the Asian tiger mosquito is a vector for dengue, Chikungunya fever, and West Nile fever, and not merely an unpleasant biting insect that causes itching. Measures such as the regular control of larvae and suppression of breeding density to the greatest extent possible are required to prevent the occurrence of mosquito-borne infectious diseases.

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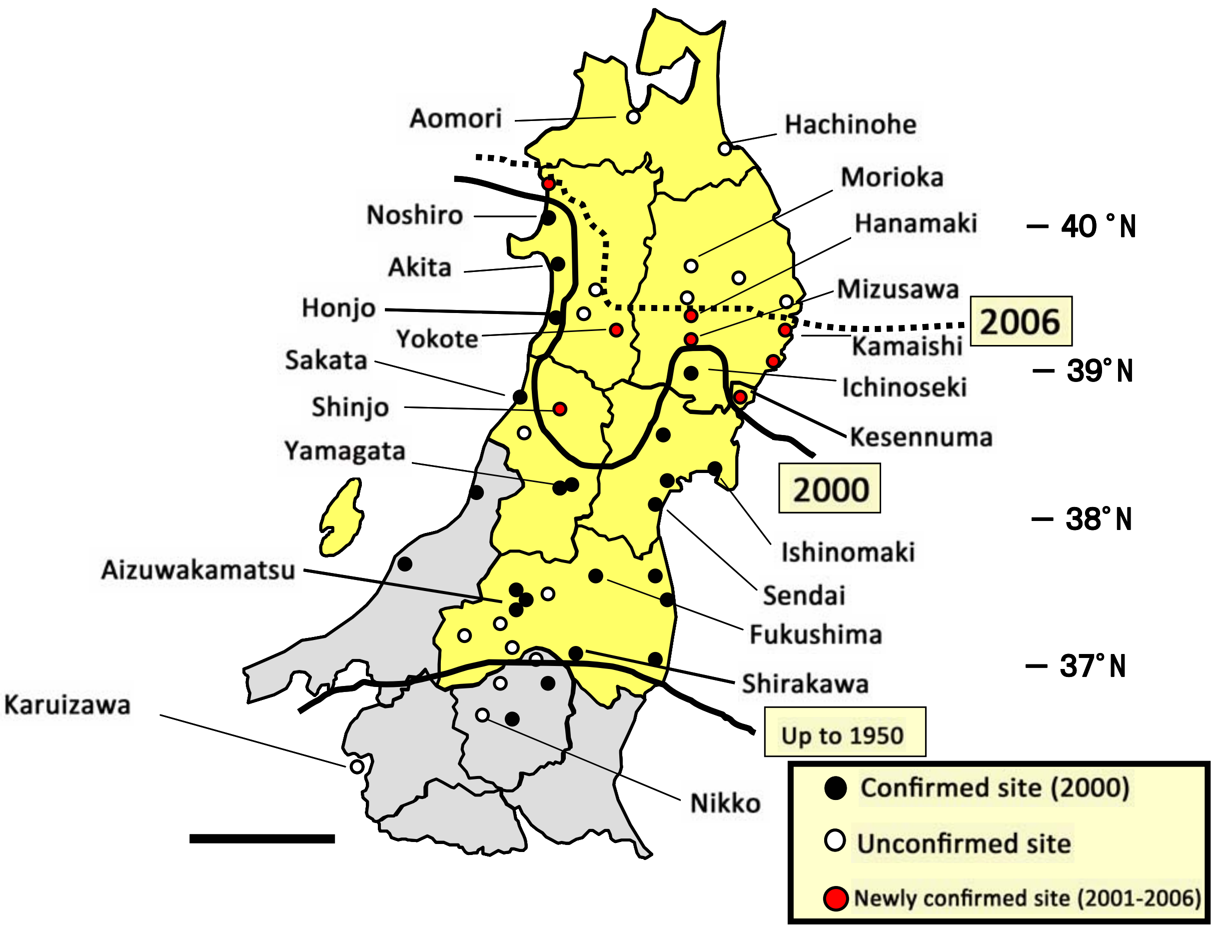

Fig. I-V-10 Northern limit of distribution of Asian tiger mosquito (*Aedes albopictus*) in Tohoku region (2000-2006)
(From Kobayashi et al., 2008)

The distribution range of the Asian tiger mosquito *(Aedes albopictus)* will expand to the whole of the Tohoku Region and part of Hokkaido by 2100.

According to the future projections of annual mean temperature using the MIROC climate scenario, areas with an annual mean temperature of 11°C or higher where the Asian tiger mosquito (*Aedes albopictus*) is stably distributed will expand to the Tsugaru Plain in Aomori Prefecture, Aomori City and its environs, and Hachinohe City and its environs by 2035(**Fig. I-V-11).** By 2100, its distribution range will spread to almost all flatlands in the Tohoku region, and may also expand to the coast of southern Hokkaido including Hakodate and the coastline from Muroran to Tomakomai, as well as the flatlands of Sapporo City and its environs including Otaru. From the expansion of the distribution range of this mosquito seen in northern Italy, it has become clear that high latitudes do not affect the timing of oviposition of dormant eggs, suggesting the possibility that the distribution range may expand to areas at northern latitude of 42-43°.

Although it is difficult to project the breeding density of imagoes, by 2100 the breeding density of this mosquito in the Tohoku region is expected to become equal to that in Tokyo and westward, and the areas at risk of dengue and Chikungunya fever will undoubtedly expand in the future.

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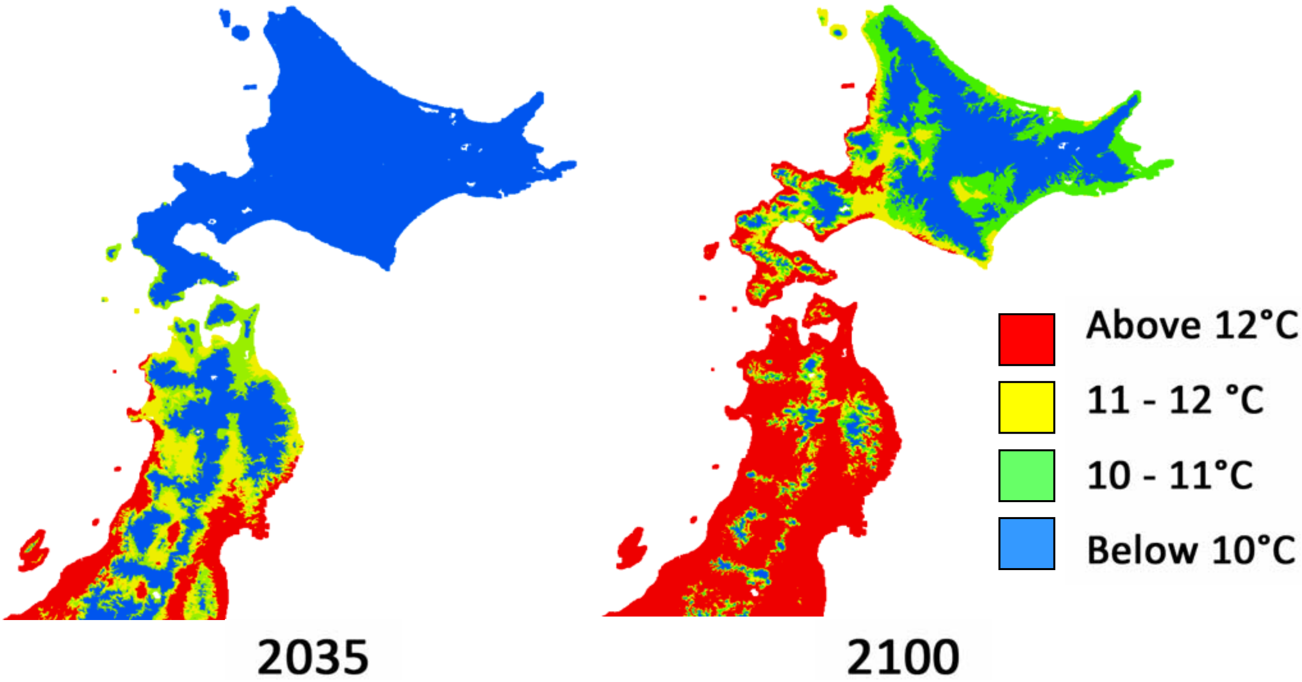

Fig. I-V-11 Distribution of projected annual mean temperature by MIROC data (From Kobayashi et al., 2008)

The possibility of a new malaria epidemic due to global warming is low.

Two types of malaria, tertian malaria and tropical malaria, were a problem in Japan in the past, but no epidemics of either type have been reported in the country since 1961. Malaria invasions and new malaria epidemics occur when malaria plasmodia carriers penetrate into areas inhabited by vector mosquitoes at more than a certain density. In consequence an investigation of the present habitat conditions of tropical malaria vector mosquitoes in Japan was carried out and the results were compared with those of past studies to make projections of invasions and new epidemics of tropical malaria, which is considered to be directly susceptible to the impact of global warming. It was found that the distribution of *Anopheles minimus* has remained virtually unchanged from the past, and is limited to the Yaeyama Islands in Okinawa Prefecture. The flight range of this mosquito is short, so even if the area satisfies the temperature condition for habitation expansion there is little possibility of habitat expansion from island to island. If the global warming trend continues, however, there is a high possibility of an increase in the larval density of *An. minimus* in its present habitat (**Fig. I-V-12**). On the other hand, if global warming progresses further and there is an increase in the number of days on which the minimum temperature exceeds 23-25°C, which is the optimal temperature for the growth of malaria plasmodia and *An. minimus,* the larval density is expected to decrease.

One of the future issues of concern in Japan is the secondary infection via mosquitoes from patients with imported malaria. The tropical malaria epidemic in the village of Ohama village on the island of Ishigakijima in Okinawa in 1951, which broke out from 10 carriers, is an example of the expansion of malaria infection from a small number of cases. This epidemic was mathematically modeled and 1,000 simulations were performed (**Fig. I-V-13**). If there are 10 or more imported cases and the measures taken are similar to those in the 1950s, the possibility of a small epidemic taking place in the Yaeyama Islands cannot be denied even under the present climate conditions. In recent years, however, generally only one or two actual cases of imported malaria have sporadically appeared and received medical treatment after being diagnosed. Therefore, based on the assumption that two malaria carriers simultaneously return home to a current habitat of *An. minimus,* and start to receive medical treatment one month later, epidemic patterns were mathematically modeled and 1,000 simulations were performed. The results showed virtually no possibility of secondary infection and a new epidemic taking place under these conditions (**Fig. I-V-14**). Hence, in the current situation in Japan, if there are a small number of cases of imported malaria, the possibility of a new malaria epidemic can be considered to be very low.

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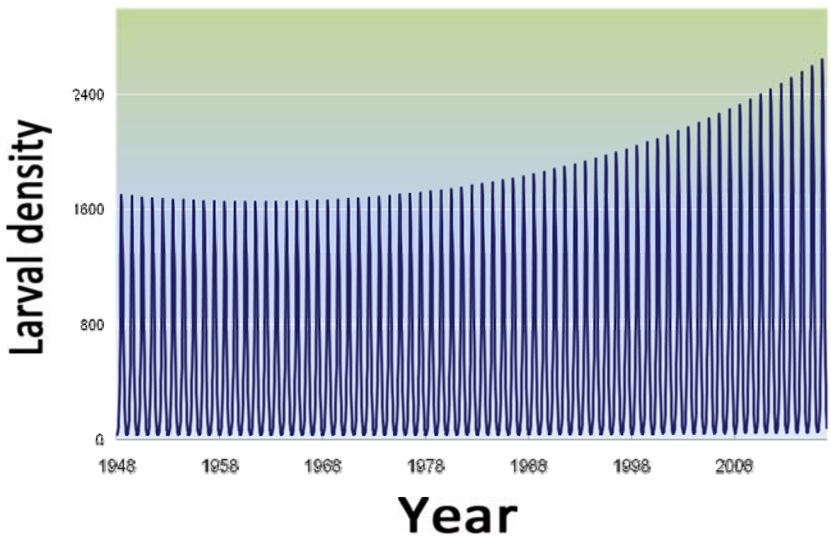

Fig. I-V-12 Projection of changes in larval density of *An. minimus* in Yaeyama Islands accompanying global warming and precipitation changes
(Figure by Hirofumi ISHIKAWA, Masao UEKI, and Kaoru FUEDA, Graduate School of Environmental Science, Okayama University)

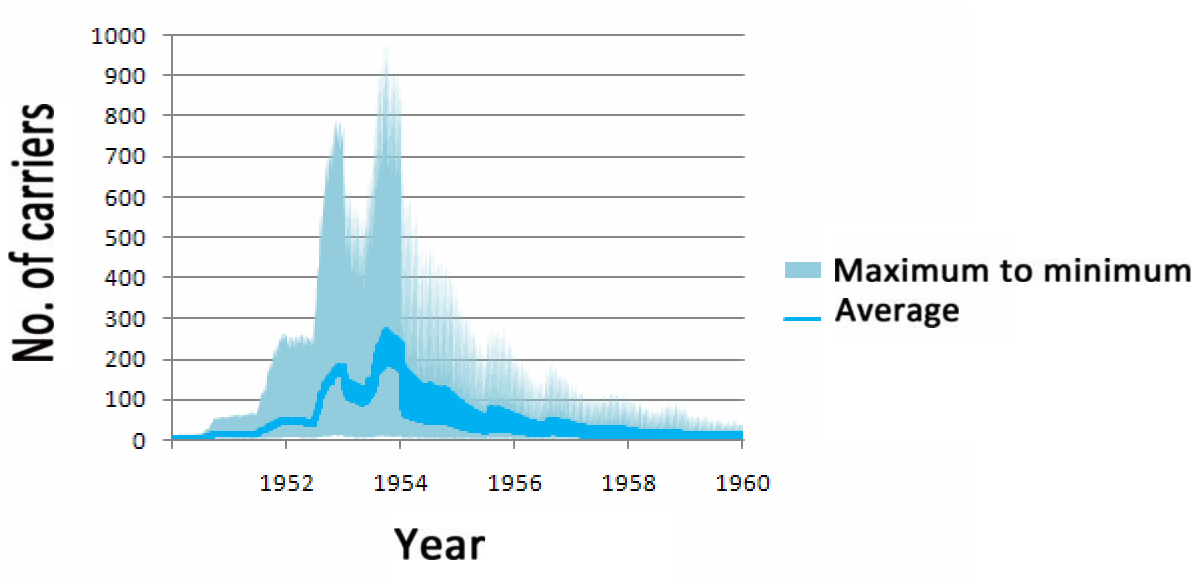

Fig. I-V-13 Example of model of invasion and new epidemic of tropical malaria in Japan (Simulation of tropical malaria epidemic originating from 10 cases in the village of Ohama village on the island of Ishigakijima in the 1950s. 1,000 simulations)

(Figure by Hirofumi ISHIKAWA and Yuhki NAKAGAWA, Graduate School of Environmental Science, Okayama University)

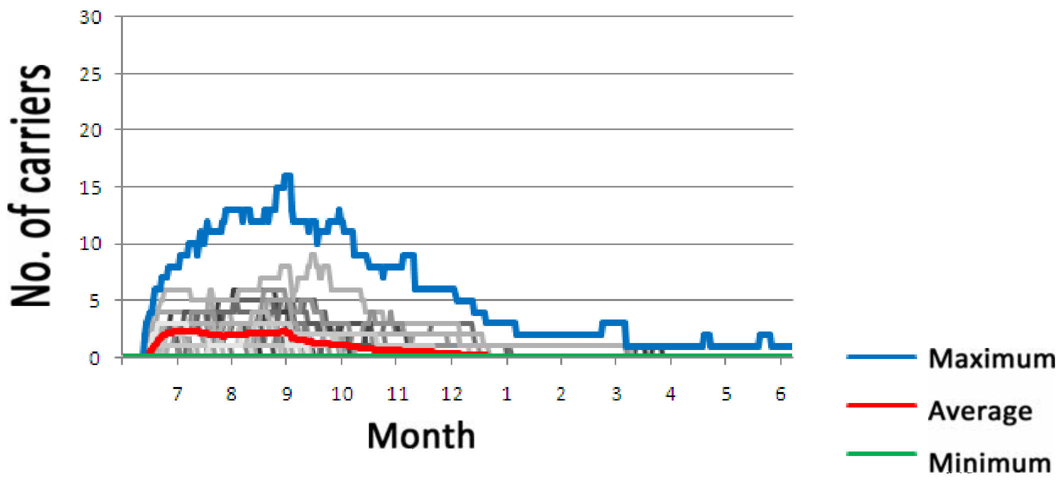

Fig. I-V-14 Example of model of invasion and new epidemic of tropical malaria in Japan (Based on Fig. I-V-13, the case of two carriers moving into the habitat of *An. minimus* on Ishigakijima is considered. It is assumed that the period until diagnosis gradually becomes shorter. 1,000 simulations.)

(Figure by Hirofumi ISHIKAWA and Yuhki NAKAGAWA, Graduate School of Environmental Science, Okayama University)

Topic Present distribution of Asian tiger mosquito (*Aedes albopictus*), and Chikungunya fever epidemic in Europe

Chikungunya fever is a viral infectious disease transmitted by mosquitoes, mainly the Asian tiger mosquito (*Aedes albopictus*) and the yellow fever mosquito *(Aedes aegypti*). From 2005 to 2006 a major epidemic occurred in the island countries of the Indian Ocean, India, Sri Lanka, etc., with more than 1.7 million cases.

In 2007, a sudden epidemic of Chikungunya fever occurred in a small village in northern Italy originating from one patient who had been infected in India, and about 300 cases were recorded (including one case of death). The existence of the Asian tiger mosquito in Italy was confirmed for the first time in 1990, and during the subsequent period of about 16 years the distribution range expanded to almost the entire country. The breeding density of this mosquito is also high. Depending on the progress of global warming in the future, the distribution of the Asian tiger mosquito is expected to expand throughout the European countries, with a possible expansion of areas at risk of infectious disease.

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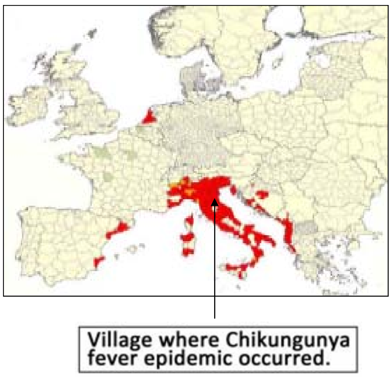

Fig. I-V-15 Present distribution of Asian tiger mosquito (*Aedes albopictus*) in Europe (From ECDC Mission Report, 2007)

Topic Expansion of distribution range of redback spider in Osaka Prefecture (1995-2006)

The redback spider is a member of the widow family of spiders that has a venom of neurotoxic protein, and a significant number of bite cases died in Australia before an antivenom serum was developed. The existence of this spider along the shore of Osaka Bay was confirmed for the first time in 1995, and since then the distribution range has been expanding rapidly. From 1997, when a worker at Kansai International Airport was bitten, up to 2005, there were four cases of people being bitten. Subsequently, there was a dramatic increase in bite cases, with six cases in 2006 and a further six cases in 2007. This indicated that these widow spiders, which had hitherto appeared in new land sites prepared for housing development, had started to invade general housing areas, and a trend of injury to people of advanced age in particular has appeared.

As a matter of fact, there are many cases of people being bitten without realizing that one of these spiders was to blame, such as when putting on sandals or long boots that have been kept in the yard, when inserting a hand into a shutter case, etc.

In addition to Osaka Prefecture, distribution of the redback spider has now been confirmed in various other prefectures including Hyogo, Kyoto, Wakayama, Mie, and Aichi. The annual mean temperature of Brisbane, Australia, where there is a high density of widow spiders, is higher than that of Osaka Prefecture, and the mean temperature in the winter season (July) is approximately 15°C, which is close to the mean temperature (in January) of Amami-Oshima Island. With the future progress of global warming, the breeding density of the redback spider is expected to further increase.

Mutsuo KOBAYASHI (National Institute of Infectious Diseases)

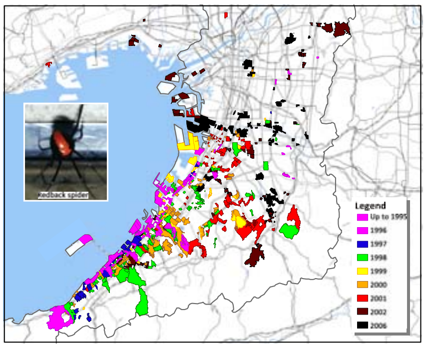

Fig. I-V-16 Expansion of distribution range of redback spider in Osaka Prefecture (1995-2006) (From Kobayashi et al., 2007)

Topic Dengue epidemic situation in Taiwan

Dengue, a viral infectious disease transmitted by mosquitoes, ranks as a mosquito-borne disease with the largest number of cases in the world. Prior to 1990 there had been no epidemic of this disease in Taiwan, but in recent years dengue epidemics have appeared (**Fig. I-V-17**). Most of the cases are seen in southern Taiwan (the area colored in red in **Fig. I-V-18**), and this area closely corresponds with the distribution range of the yellow fever mosquito *(Aedes aegypti*). Taiwan is experiencing an increase in annual mean temperature, and with the northward movement of the distribution range of this mosquito, the range of dengue epidemics is also expected to move northward in the future.

Ichiro KURANE
(National Institute of Infectious Diseases)

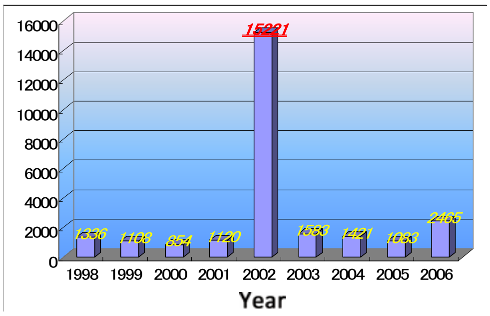

Fig. I-V-17 Incidence of dengue cases in Taiwan

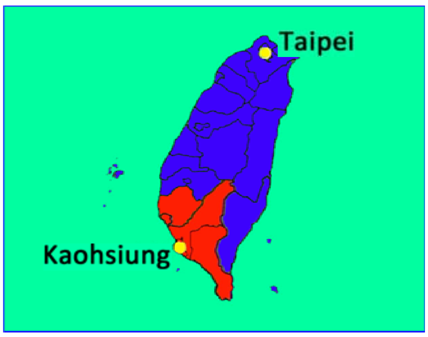

Fig. I-V-18 Dengue epidemic area in Taiwan

Topic Activity of Japanese encephalitis virus and global warming

Japanese encephalitis is a type of encephalitis transmitted by the *Culex tritaeniorhynchus* Giles mosquito. The activity of the Japanese encephalitis virus is known to be reflected by Japanese encephalitis antibody in swine. In **Fig. I-V-19**, the top figure shows the ratio of Japanese encephalitis antibody-positive swine in 1993, when the summer was cool, while the bottom figure shows those in 1994, which was a year with a hot summer.

In 1994, even the Tohoku region showed a high antibody-positive ratio. This indicates the possibility of the Japanese encephalitis virus becoming more active, with Japanese encephalitis also occurring in the Tohoku and Hokkaido regions as summer temperatures rise as a consequence of global warming.

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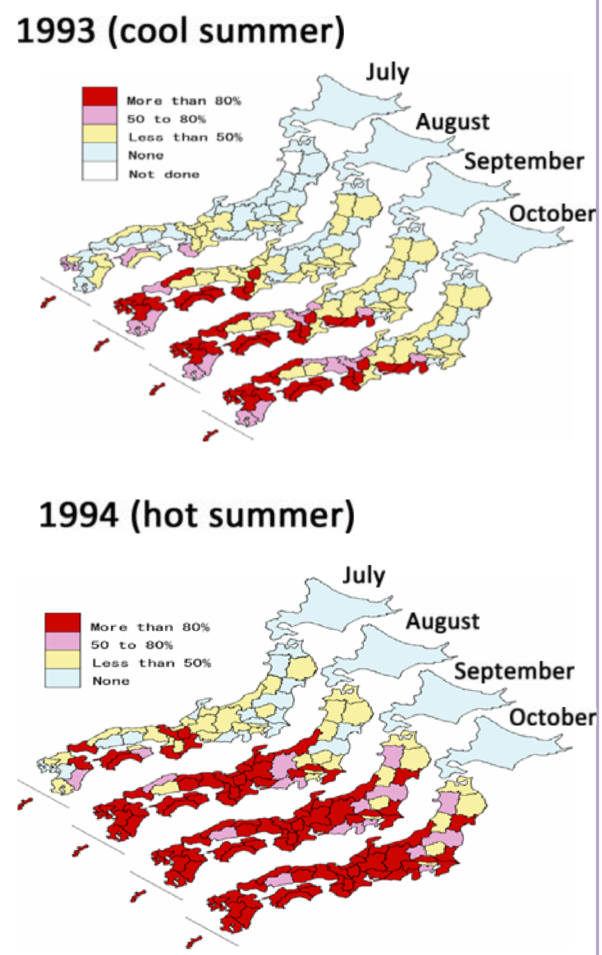

Fig. I-V-19 Ratios of Japanese encephalitis antibody-positive swine

Topic Study on the impact of global warming on malaria in Japan

Although the results of various projections concerning global warming and the expansion of malaria epidemics have been released globally, this is still a contentious area of research. A model of epidemics expanding in wide areas with increasing temperatures was prepared from experience obtained in African highlands, where the limit of latitude habitable by malaria-vector mosquitoes is rising with global warming. Large corrections are necessary, however, when applying this model to other areas. In particular, when applying this model to Japan, which is an island nation in the temperate zone, it is necessary to fully consider vegetation, land use, characteristics of vector mosquitoes, etc. by region.

The possibility of a new epidemic occurring in Japan was studied with the primary emphasis on tropical malaria, which is susceptible to the impact of temperature conditions. An investigation of the habitats of *Anopheles minimus,* which was the main vector mosquito of tropical malaria in Japan in the past, showed that it still inhabiting the Yaeyama Islands and that there is no particular trend toward expansion of the habitat range. If the mean temperature increases by 3°C in the future, Kyushu and a part of Shikoku will become habitable areas for *An. minimus* in terms of temperature conditions. From the standpoint of vegetation and the land use situation, however, the possibility of these regions actually becoming habitable areas is low in the short term. Moreover, since the flight range of *An. minimus* is limited, even if the temperature conditions for habitat are satisfied, the possibility of this mosquito actually expanding its habitat from island to island in the future is low. No particular relationship was found between the small malaria epidemic seen on the island of Ishigakijima in the 1950s and the changes in mean temperature. Recently, however, the trend of global warming has also become evident on Ishigakijima, and based on the results of research conducted in the 1990s, there is a possibility of increases in the larval density of *An. minimus* if changes in precipitation and temperature progress in the future. Even in this case, in order for tropical malaria to invade and take root in Japan and cause a new epidemic, various other conditions must overlap with each other. The possibility of a new epidemic actually occurring is therefore very low.

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6. Comprehensive Assessment of Impacts by Field

Changes in impacts by field and climate change were consolidated applying MIROC as the climate scenario and using the integrated assessment model for global warming impact assessment, taking 1990 as the base year for representing temperature rise on the x-axis (**Figs. I-VI-1 to I-VI-3**).

With regard to the impacts of floods (refer to 1.3 (1)), an estimation was made of the damage caused by extreme rainfall once every 50 years (hereafter referred to as "extreme rainfall") projected by the MIROC climate scenario for each period. Changes in extreme rainfall can also be expected in the future. The flooded area and amount of damage will gradually increase as the temperature increases up to about 2°C and will show a worsening trend at temperatures exceeding 2°C, with an even more pronounced trend of increase in the amount of damage. Such a trend reflects the occurrence of flooded areas closer to urban areas (areas with high economic value). This is clear from a comparison of changes in the flooded area and amount of damage; at around 2.5°C, when the flooded area expands by 5%, the amount of damage roughly doubles, which is about 40 times the rate of change of the flooded area.

For the impacts of slope disasters (refer to 1.3 (2)), an estimation was made of the damage caused by extreme rainfall once every 50 years (extreme rainfall) projected by MIROC for each period, similarly to the method used for the impacts of floods. The impacts of slope disasters will be within the range of 2% as the temperature increases up to about 2°C, and will show an increasing trend at temperatures exceeding 2°C.

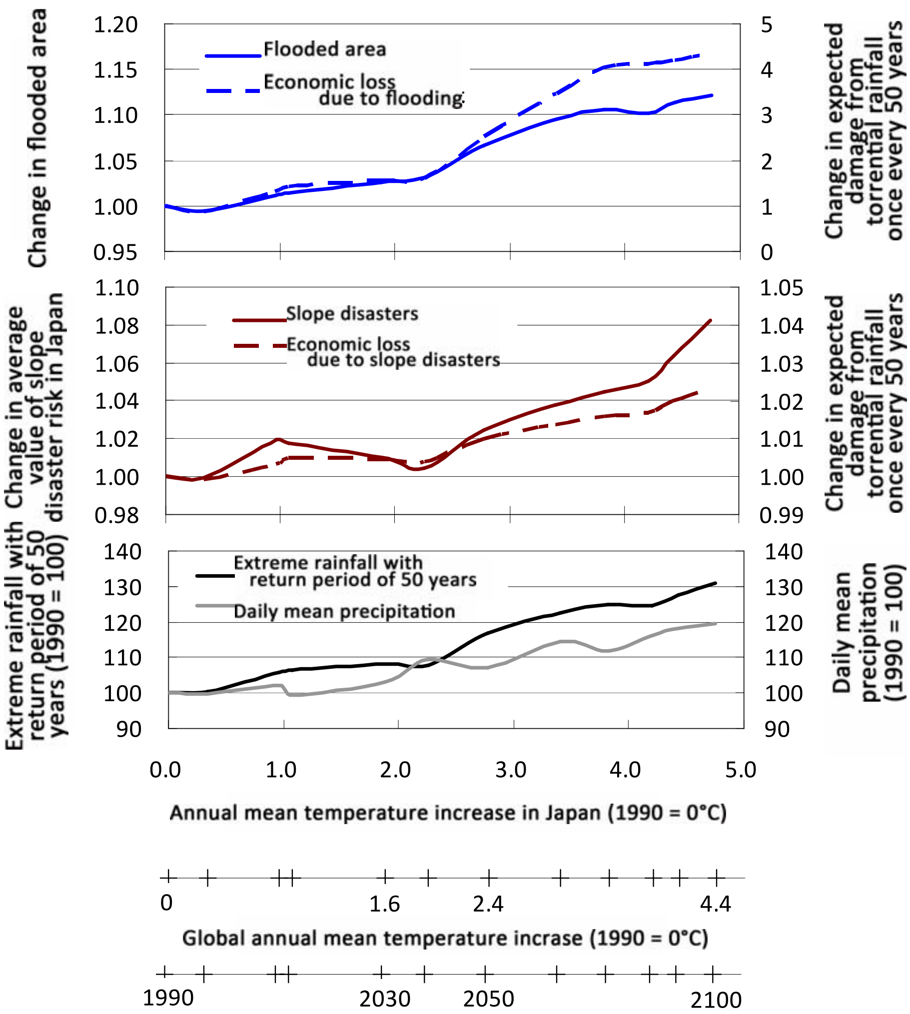

Fig. I-VI-1 Temperature increase and impacts on floods and slope disasters

Suitable habitats for *Fagus crenata* (Japanese beech) forests (refer to 2.3 (1)) are greatly affected by global warming, and will shrink by 30% at a temperature increase of about 1.5°C, by 50% at about 2.5°C, and by almost 80% at about 4°C. Similarly to the case of *F. crenata* forests, the area at risk from pine wilt damage (refer to 2.3 (2)) will also be greatly affected by global warming, expanding to about 1.3 times at a temperature increase of about 1.2°C, to about 1.5 times at about 2.0°C, and to almost double at about 4°C. In either case, it can be seen that significant impacts will appear even at a temperature increase of about 1°C.

The rice yield (refer to 3.3 (1)) shows a different trend from other indexes. Productivity is found to improve as the temperature increases up to about 2°C, after which it turns to a decreasing trend. Up to about 2.6°C there is no decline in productivity compared with the present condition, but as the temperature increases further, productivity falls to below the present level. It is known that the annual mean temperature alone is not sufficient information for determination of yield, and even with the same annual mean temperature, results greatly vary depending on the summer conditions. It should be noted that the values shown here for rice yield, insolation, and CO_2 concentration were not obtained using the integrated assessment model; in these cases, the results presented in 3.3 (1) were averaged at temperature increases in increments of 1°C.

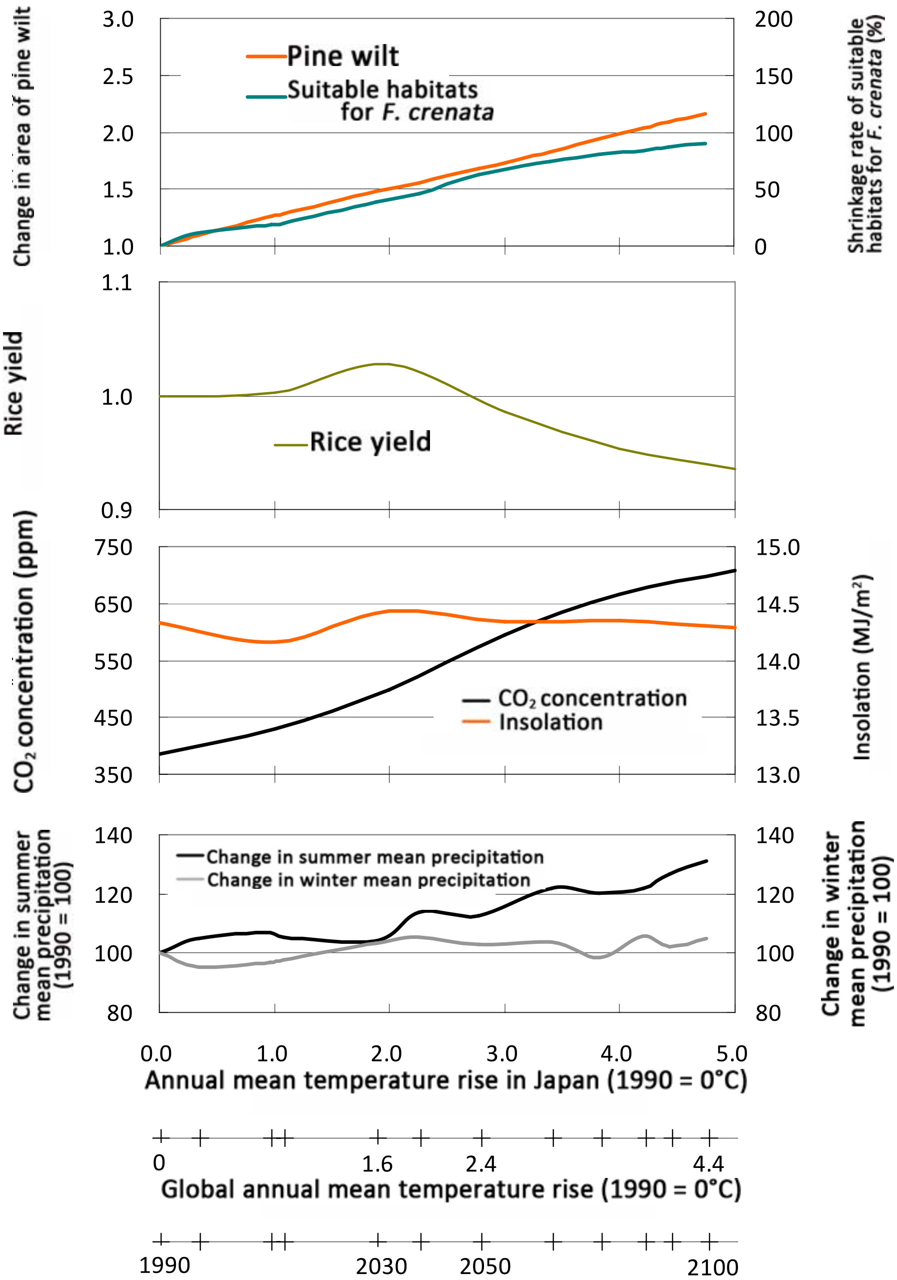

Fig. I-VI-2 Temperature rise and impacts on suitable habitats for *F. crenata*, risk area of pine wilt, and rice yield

The area of storm-surge flooding and affected population are the total values for western Japan and Japan's Three Big Bays, and are calculated on the assumption of typhoon intensity reaching the level of 1.3 in 2100 with 2000 as the base year. The impacts of storm-surge flooding (refer to 4.3 (1)) show a gradually increasing trend as the temperature increases. With a temperature increase of about 2°C, the area of storm-surge flooding increases to about 1.4 times and the affected population to about 1.7 times; with a temperature increase of about 3°C, the area of storm-surge flooding increases to about 1.7 times; and with a temperature increase of about 4°C, the affected population increases to about 3.2 times.

The mortality risk due to heat stress calculated in the present study can be regarded as a quantitative indication of the negative effect of heat on people's lives using the difference between mortality on hot days and that on days of optimal temperature. Therefore, the mortality risk due to heat stress (refer to 5.3 (1)) increases linearly with an increasing number of hot days accompanying temperature increase. Although people are taking measures against heat according to the present climate conditions, such as the installation and use of air-conditioning systems, etc., the heat stress mortality risk under the present climate conditions shows that negative effects of heat on people's lives still remain despite such measures. The heat stress mortality risk calculated in the present study at the time of temperature increase shows an increase in the negative effect of heat on people's lives, assuming that the measures taken against heat at the level of balancing under the present climate are continued under the future climate. As shown in the figure, the conspicuous increase suggests that the implementation of further measures against heat compared with those at the present time will become necessary according to future temperature increases. However, to identify the appropriate level of additional measures in concrete terms, cost-benefit analysis of the implementation of such measures is necessary; this remains a future research task.

It should be noted that the results shown here were obtained using only the MIROC climate scenario. Changes in rainfall, insolation, etc. accompanying temperature rise differ according to the results of individual GCMs. It is therefore necessary to pay attention to the fact that impact assessment indexes using climate change factors other than temperature as a predictor variable will depend to a large extent on the results of the GCM used.

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(Note) For consistency with the results described in 4.3 (1), the area of storm-surge flooding and affected population are shown based on the impacts on sea-level rise calculated taking 2000 as the base year. The impacts described in the above text are in relation to the annual mean temperature rise in Japan compared with 1990; this information is shown in the bottom part of the figure so that the values can be easily read from the figure.

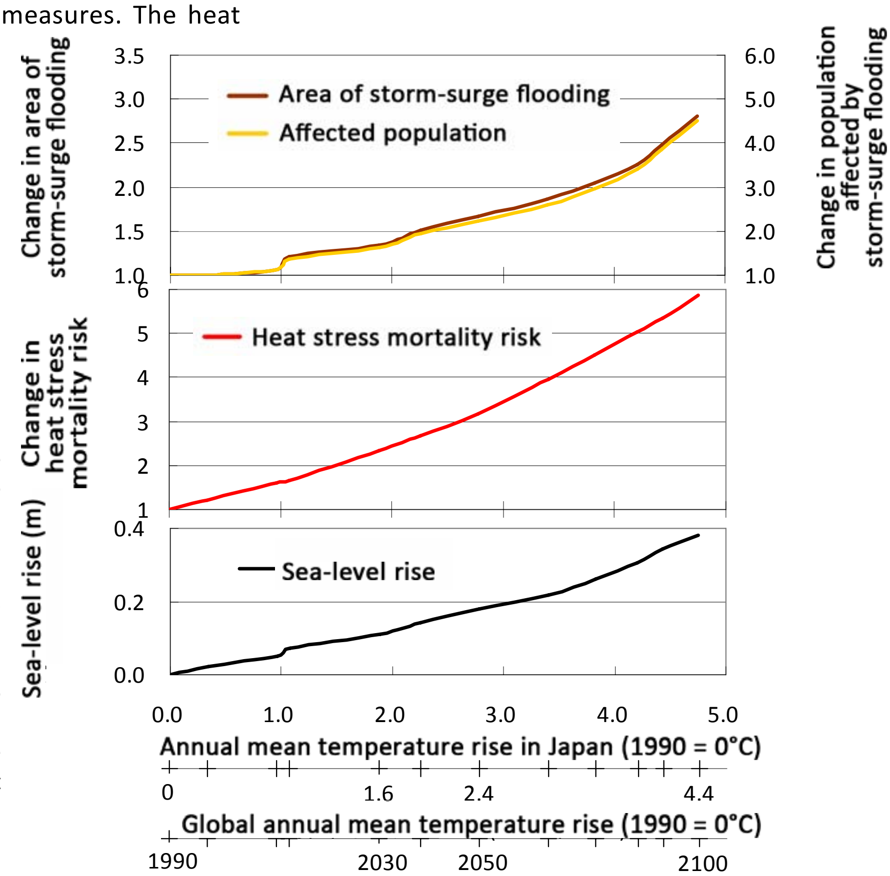

Fig. I-VI-3 Temperature rise and impacts on storm-surge flooding and heat stress mortality risk

II. Adaptation Measures and Future Tasks

The impacts of climate change on Japan are being elucidated in unprecedented detail in the present study. Measures to deal with global warming can be divided into two types: mitigation measures to reduce emissions of CO_2, etc., and adaptation measures to cope with adverse impacts. Since the progress of global warming cannot be avoided over the next several decades, the introduction of adaptation measures is necessary. Adaptation measures alone cannot control all of the impacts, however, and the implementation of both adaptation and mitigation measures is therefore essential. That is to say, in order to control the adverse impacts of global warming within certain limits, the optimal combination of adaptation measures and mitigation measures is necessary; this is becoming the consensus view throughout the world.

For adaptation measures, a wide range of measures can be considered such as policy and system measures, technological measures, social measures, and so on. Japan has long been implementing disaster prevention and environmental management, together with food production and public health maintenance, and has accumulated numerous actual results in terms of measures and technological tools. In the case of climate change-related adaptation measures, the task at hand is how to combine these so as to plan effective and efficient measures for adaptation to climate change in accordance with future climate projections. Moreover, when formulating such plans, it is also necessary to consider measures that concurrently provide other benefits and to avoid the creation of new environmental burdens.

Although research on concrete adaptation measures remains a future task, details of the research being conducted by field in the present study are described below.

1. Impacts on Water Resources

In the field of water resources, possible adaptation measures that can be considered to ensure the safety and security of people's lives include the establishment of facilities for disaster prevention and securing of water supplies, restriction of unnecessary use of dangerous areas through city planning and land use guidance, improvement of disaster prevention awareness by means of early warning systems and hazard maps, etc. As there is no single completely effective measure, however, comprehensive adaptation measures combining these individual measures is important. Details of possible measures for each type of impact described earlier in this report are again enumerated below.

With regard to floods, under conditions in which the provision of sufficient budgets is difficult, instead of the conventional water control improvement measures typified by large dams, super-embankments, etc., measures such as the construction of early warning systems and flood-withstanding type housing will be necessary.

It can be considered that, in areas with a large amount of damage, water control by conventional types of facilities that contain floodwater (embankments, dams, underground conduits) should be given priority, while in areas where less damage is expected, priority should be given to land use management and risk management response type adaptation measures; for example, the construction of early warning systems, promotion of flood-withstanding type housing, restrictions on new development in specified areas, etc.

As regards slope disasters, debris flow not only affects the site itself but may also extend to downstream areas. It is therefore necessary to consider disaster prevention systems from the perspective of the entire basin. Moreover, in the case of increases in sediment production, countermeasures that could be considered include "hardware" type measures such as sediment control works and the construction of pre-dams (dams for sedimentation built around the mouth of a river flowing into a dam lake), as well as dredging and flushing operations to remove sedimentation. Sand bypasses (to move sedimentation downstream) and flushing operations are important for the stabilization of riverbeds and coastlines, but careful planning is necessary because their impacts on downstream areas are large.

With respect to decreases in snow water resources, although no simple measures for adaptation are available, such adaptation measures as reviewing agricultural water rights, changing the time of rice planting, etc. could be considered. Moreover, the use of snow dams, which can concurrently serve as a measure against avalanches, is also a method of enhancing the storage effect.

2. Impacts on Forests

The establishment of green corridors is important for the smooth migration of wildlife in response to global warming. When establishing such a corridor, if artificial forests, artificial grasslands, cultivated land, etc. hinder the migration of wildlife, converting them to natural forests can be considered helpful as a means of enhancing the function of the corridor.

As a result of environmental changes due to global warming, the significance of nature reserves such as national parks and ecosystem conservation areas may undergo qualitative changes whereby they become an unsuitable environment for some of the species inhabit there. Therefore, to grasp their conditions, it will be necessary to carry out monitoring and reviews of these nature reserves as needs arises in the future.

In order to conserve natural forests and plant species in the global warming era, monitoring to identify what types of changes are occurring in the dynamics of natural forests will become particularly important. If changes are detected in natural forests, it will be necessary for the parties concerned to gather at conferences, etc. and discuss whether such changes should be accepted, or whether adaptation measures need to be taken. It is imperative, through such an approach, to carry out acclimative management by reviewing management methods when appropriate according to the changes occurring in natural forests.

When the decline of a specific plant species is considered to be due to the impacts of global warming, whether to leave natural changes to take their course and accept that the plant species will be replaced by a different species suited to the warming conditions is one of the main choices in the management of a natural forest. For example, with regard to *Fagus crenata* forests that are no longer in a suitable habitat due to global warming and whose decline is progressing, a decision is required as to whether to take adaptation measures such as planting, etc. to maintain these *F. crenata* forests. Even when the *F. crenata* trees decline, if they are replaced by *Quercus serrata*, *Abies firma,* and evergreen oaks that are suited to a warming climate, the ecological services of the forest can be maintained. The seeding and planting of wild plants has the risk of causing a disruption in genetic diversity, and its costs including nurturing are high. Hence, unless there is some reason why *F. crenata* forests must be maintained, the sensible course of action is to monitor the changes taking place in the forests rather than adding artificiality by planting, etc. Only when it becomes clear through monitoring that the regeneration of a forest is difficult should treatments for the promotion of natural regeneration (forest floor treatments, seeding, planting, etc.) be considered.

Excessive growth of the sika deer population has adverse impacts such as browsing damage to planted trees in afforested lands and to wild plants in natural forests, etc. Although increases in the sika deer population and changes in their habitations are considered to be affected not only by the impacts of global warming but also by other factors, in order to reduce damage it is clear that appropriate control of their population is necessary. In this case also, by monitoring the numbers and areas of distribution of these deer as well as their impacts, acclimative management of forest ecosystems becomes possible.

3. Impacts on Agriculture

(1) Basic approaches of adaptation measures

In response to the impacts of climate change, the principal measures presently considered as adaptation measures in the agricultural field are 1) shifting of transplanting times, 2) fertilization and water management, and 3) breed improvements. Important factors for the prioritization of adaptation measures are labor-saving efficiency (simplicity), cost, and effectiveness.

(2) Examples of concrete adaptation measures

1) Preventive adaptation measures that can be cited include selection of varieties for planting and transplanting times, and improvement of soil fertility by fertilization, while symptomatic treatment type adaptation measures include deciding the amount and timing of fertilization before heading, and water management according to the occurrence of high temperatures. By combining these with highly accurate weather projection (forecast) information at an early stage, a high degree of effectiveness can be expected.
2) Surface drainage (midseason drainage) approximately one month before heading followed by intermittent irrigation continuing for about one and a half months (repeating a cycle of flooding for three days and drainage for two days) is a method traditionally used by farmers. This greatly reduces methane emissions by lowering the activity of methane-producing bacteria compared with continuous flooding of fields. Such water management can also serve as a measure for dealing with high temperatures by maintaining activation of the plants' roots, making it a

technique both for adaptation to and control of global warming.

(3) Future tasks

1) It is necessary to promote studies concerning not only impacts due to average changes but also the impacts of year-by-year changes due to extreme weather events such as droughts, heavy rainfall, typhoons, etc., as well as natural disasters.
2) There are concerns that the frequency of occurrence and level of incidence of diseases and insect pests will increase accompanying global warming, and it is necessary to promote studies on the resultant damage.
3) With regard to paddy rice, it is becoming clear that high temperatures during the ripening period affect the growth and appearance of the unmilled rice, while high temperatures at the time of flowering time affect fertilization. The interactions of these high-temperature impacts with weather conditions such as insolation, humidity, etc., as well as with CO_2 concentrations, nitrogen fertilizer, soil moisture, etc., have not yet been fully clarified. It is therefore necessary to promote studies on the impacts of combinations of high temperatures and other environmental conditions.
4) It is necessary to elucidate the physiological mechanism of the heat tolerance of crops. Then, in order to develop breeding materials and selection methods taking this mechanism into consideration, the development of new varieties through the use of DNA markers, identification of heat tolerance genes, etc. should be promoted.
5) It is also necessary to elucidate the mechanism of the effects of shifting cultivation periods, and to clarify suitable soil conditions such as soil fertility, fertilization, water, etc., in order to realize cultivation techniques that offer both labor saving and low cost.

4. Impacts on Coastal Zones

(1) Comprehensive menu of adaptation measures

A comprehensive menu of measures for adaptation to compound disasters in coastal zones has been formulated. First, the relationships between external forces of climate change and disasters in coastal zones are shown in **Fig. II-IV-1**. Due to climate change caused by global warming, external forces such as rises in sea level, typhoons, changes in rainfall, etc. affect disasters in coastal zones. Earthquakes are a natural phenomenon independent of climate change; however, when they overlap with changes in rainfall due to climate change, there is a possibility of a compound disaster occurring such as slope failure, etc.

Next, measures for adaptation to these disasters in coastal zones are compiled in **Table II-IV-1**. These adaptation measures, broadly divided into withdrawal, acclimation, and protection, encompass a wide array of measures ranging from technological measures such as raising of embankments, use of floodgates, etc., to social measures such as migration, disaster insurance, etc. For the implementation of comprehensive adaptation measures, not only technological measures but also social and economic responses are required.

(2) Study on adaptive capacity

One method of reducing vulnerability to climate change is to enhance resistance (i.e., adaptive capacity) to external forces such as sea-level rise, etc. In the present study, the human development index (HDI) by prefecture was measured in order to grasp potential adaptive capacity. The HDI, which is often used as a proxy variable of adaptive capacity, is calculated from the life expectancy index, education index, and GDP index as follows:

$$\text{HDI} = (1/3)\ (\text{Life expectancy index} + \text{Education index} + \text{GDP index}). \quad (1)$$

Although differences in the HDI by prefecture in Japan are relatively small, certain prefectures such as Tokyo, Aichi, and Shiga rank higher while others such as Aomori, Okinawa, and Nagasaki rank lower. This is considered to be reflecting per capita GDP as well as life expectancy. HDI is one of the representative indexes for adaptive capacity, and here, as a preliminary study, it was treated as a proxy index. Toward the impact assessment of concrete adaptation measures, it is necessary to perform analyses incorporating technological levels as well as information infrastructure and capacity, and analyses limited to specific areas.

(3) Future tasks

The results of efforts up to now to clarify the impacts of global warming on disasters in coastal zones have primarily been expected to show how the nationwide of Japan will be affected. Depending on the impact phenomenon concerned, however, there are cases in which this may be possible and others in which it may not be possible. Moreover, application of the obtained methodologies and findings is also expected to expand to the Asia-Pacific region, which is overall more vulnerable compared with Japan. Based on these aspects, future tasks are summarized below.

1) With regard to the impacts of storm surges accompanying global warming: (i) it is necessary to move ahead with calculations for the remaining areas in the national model, and to conduct flooding projections for the whole of Japan; (ii) it is important to improve the national model and the Three Big Bays model, to calculate the amount of damage due to flooding, and to formulate impact functions (amount of damage) due to storm surges on a national basis; and (iii) in order to consider measures for adaptation to storm surges, estimations of the costs of strengthening embankments must be advanced.
2) There is a need to make estimates of areas subjected to flooding in the lower reaches of representative rivers throughout Japan, as well as to analyze the land use characteristics of those areas and assess flood risks, applying methods developed so far for the estimation of future river flow rates and for the estimation of areas subjected to flooding.
3) There is also a need to improve the database on the vulnerability of embankment materials by establishing a wider range of test conditions, to express the vulnerability of actual embankments in the form of an index by utilizing this database, and to refine the river embankment vulnerability map by utilizing a geographic information system (GIS), etc.
4) Judgment of the degree of liquefaction risk is difficult in areas for which there is little or no ground information, and it is therefore necessary to study a method of preparing ground models in such areas and to implement impact assessments on liquefaction at the time of an earthquake in wider areas (Osaka plain, Nohbi plain, Niigata plain, coastal area around Tokyo Bay).
5) In order to assess increases in slope disaster risk due to global warming, it is necessary to elucidate the impacts of extreme weather events accompanying global warming on the form of occurrence of torrential downpours that cause slope failure, and also to identify the ratio of damage to assets surrounding slopes due to slope failure.
6) Toward the impact assessment of concrete adaptation measures, it is necessary to perform analyses incorporating technological levels, information infrastructure and capacity, etc., and analyses limited to specific areas. Moreover, it is necessary to formulate individual adaptation measures for compound disasters caused by global warming and to carry out respective economic assessments.
7) Since the Asia-Pacific region has many vulnerable areas, it is necessary to conduct quantitative vulnerability assessments. Particularly in Asia, population growth is projected to proceed more rapidly than global warming and sea-level rise, necessitating vulnerability assessments in the case of disasters occurring in the region and the formulation of adaptation measures taking economic growth into account. In the Pacific island countries there are many populations living in small areas with low elevation, which are the most vulnerable to sea-level rise. There are not many data on elevation, storm surges, etc., so it is necessary to both improve the data and to be able to perform highly accurate assessments of vulnerability with the limited data available. It is also necessary to identify possible adaptation measures with limited resources. For both areas, further introduction of adaptation measures utilizing the traditional technologies of the respective countries is of great importance.

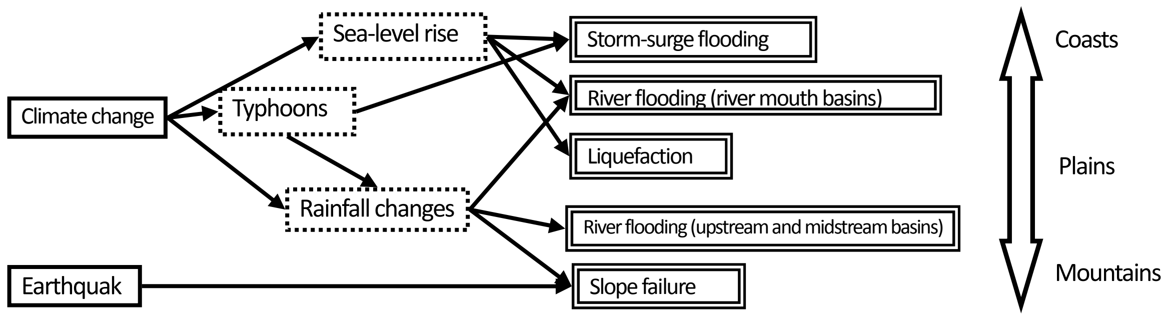

Fig. II-IV-1 Relationships between external forces of climate change and disasters

Table II-IV-1 Adaptation measures in coastal zones

	Adaptation Measures		
	Withdrawal	Acclimation	Protection
Storm-surge flooding	Avoidance of development in coastal areas Control of development by urban planning and land use planning Migration from coasts with high risk Public subsidies for migration	Hazard maps Change of land use forms Protection of coastal ecosystems such as mangroves, etc. Strict regulations in areas of risk Disaster insurance	Raising of embankments Coastal vegetation Large-scale floodgates Early warning system and evacuation system
River flooding	Control of development by urban planning and land use planning Migration from areas with high risk Public subsidies for migration	Hazard maps Change of land use forms Strict regulations in areas of risk Disaster insurance	Raising of embankments Seepage control work Early warning system and evacuation system
Liquefaction	Control of development by urban planning and land use planning Migration from areas with high risk Public subsidies for migration	Hazard maps Change of land use forms Strict regulations in areas of risk Disaster insurance	Groundwater level monitoring Lowering of groundwater level/use of embankments Ground improvement and ground reinforcement
Slope failure	Control of development by land use planning Migration from areas with high risk Public subsidies for migration	Hazard maps Risk maps Strict regulations in areas of risk Disaster insurance	Landslide prevention piles Early warning system and evacuation system

5. Impacts on Human Health

(1) Mortality risk due to heat stress and heatstroke

Since exposure to a high-temperature environment constitutes a direct risk, avoidance of high-temperature environments in daily life is the most effective measure. Moreover, it is important for each individual to pay appropriate attention in their daily life to the prevention of heatstroke or mortality due to heat stress. Keeping simple measures in mind such as avoiding heat (outdoors and indoors), wearing appropriate clothing, diligently drinking liquids, maintaining physical condition, etc., as well as refraining from exercise on hot days, is effective (from *Manual for health guidance to prevent heat stroke,* Ministry of the Environment, 2005 (in Japanese)).

From the social perspective, on the other hand, the provision of appropriate preventive information to local communities is important. By disseminating information on heat stress disorder and susceptibility to heatstroke (for example, through heat indexes issued by the Ministry of the Environment) and preventive measures via websites, etc., as well as notifications using various forms of publicity, it is considered possible to promote appropriate changes in the behavior of residents.

In order to prevent mortality at the time of a heat wave, particularly among people of advanced age and people with respiratory and circulatory system diseases, air conditioning should be appropriately used as an act of necessity. In cold areas where the spread usage of air conditioning is low, the preparation of community halls, etc. as shelters should also be considered. It is necessary to reduce heat stress at the time of a heat wave even through the use of energy, despite the negative effect in terms of CO_2 emissions.

As future tasks, in addition to the enhancement of cooling efficiency by structural improvements to houses and improvement of air-conditioning systems themselves when air conditioning needs to be used, it is also important to promote the use of electric fans, cold baths, and other techniques that make it possible to moderate the use of air conditioning.

(2) Oxidants

1) Measures to suppress increases in oxidant concentration due to global warming

It is necessary to suppress the generation of nitrogen oxides (NOx), volatile organic compounds (VOCs), etc. from automobiles, factories, and so on, as sources of oxidants (Ox). The diffusion of electric vehicles is particularly effective in this regard.

Efforts are also required to reduce transboundary pollution through cooperation in the implementation of measures against sources of generation in the Asian Continent, particularly China.

2) Adaptation measures under conditions of increased Ox concentration

Systems for monitoring Ox concentrations and forecasting the occurrence of high Ox concentrations are necessary, as well as improvement of the accuracy of such systems. The usual measures (voluntarily refraining from outdoor work, driving, etc.) are also required when a high concentration of Ox is forecast.

However, for people of advanced age with high risk (particularly those in poor health), who account for the majority of increased mortality due to high Ox concentration, not only simply avoiding going out but also the control of indoor air is important. In areas with a high Ox concentration, it is preferable to reduce to intake of outdoor air into rooms during the daytime when the concentration increases, and to rely on air conditioning. The condition of high insolation promotes Ox generation but at the same time it is also suited to photovoltaic power generation; hence, promoting this method of adaptation will be effective.

(3) Infectious diseases

As adaptation measures differ for each of the three mosquito vector-borne infectious diseases of dengue, Japanese encephalitis, and malaria, it is not possible to make generalized statements concerning these.

With regard to dengue, for which no vaccine is available yet, early diagnosis of infected people, chemical extermination and control of vector mosquito imagoes that may be carrying the virus in areas surrounding the residences of infected people, regular extermination and control of larvae in areas surrounding residences, and individual protective methods such as wearing of clothes offering protection against mosquito bites, etc. are effective

In the case of Japanese encephalitis, because an effective vaccine exists, vaccination is the most effective adaptation measure. The Japanese encephalitis virus is still actively transferred between the *Culex tritaeniorhynchus* Giles mosquito and swine, particularly in western Japan, and it is important to take protective measures against mosquito bites when planning to engage in outdoor activities at night in areas where it is endemic.

Malaria-transmitting *Anopheles* mosquitoes breed in paddy fields and swamps surrounding cowsheds and pigpens in rural areas, so residents of urban areas in Japan have little contact with them. Therefore, at the present time there is a low probability of even 70-100 patients annually with imported malaria being bitten by *Anopheles* mosquitoes at night in rural areas, and the probability of infected mosquitoes feeding on blood from other humans in succession is even lower. In this sense, except for the basic measures of early diagnosis and treatment of infected people, malaria is unlikely to become a target for consideration of adaptation measures in the future.

Chikungunya fever, for which the Asian tiger mosquito (*Aedes albopictus*) is the main vector mosquito, has been endemic in various countries and regions including the island countries of the Indian Ocean, India, Sri Lanka, and Southeast Asia since 2005. Continuous surveys on the breeding condition of vector mosquitoes, as well as environmental improvements and the chemical extermination and control of larvae taking the environment into account, can be expected to lead to a lowering of the breeding density of these mosquitoes.

Reference Material

1. Environmental valuation and valuation method

Environmental valuation is the converted expression of various damages caused by global warming in money metric values (yen/year). In environmental valuation, the conversion is consolidately and consistently performed with the amount of money which an economic entity who suffers the various damages is willing to pay (yen/year) to avoid the damages. The evaluated value converted through the amount of willingness to pay (yen/year) is called a damage cost (yen/year). This damage cost includes the adaptation cost to the global warming, but does not include the mitigation cost against the global warming. The benefit which results from global warming mitigation measure equals the decrease in the damage cost. Here the target damages include not only those directly recorded in monetary units (market impact) but also the ones which do not have direct market prices that reflect their social value (non-market impact). As for the market impacts this report focuses on the impacts and damages of flood caused by global warming and its adaptation cost, geological hazard and its adaptation cost, storm surge damage caused by the sea level rise and its adaptation cost, and impact on the rice crop productivity, and as for the non-market impacts, it focuses on impacts on health and life caused by heat stroke, impacts on ecosystems, and the decrease of sands and tidal flats.

The concept employed in monetary conversion is the concept of 'willingness to pay', the minimum amount of money an economic entity is willing to pay (expressed in an amount of money per year that will be paid every year on) to avoid damage and/or loss. Here the economic entities consist of households, businesses, and governments, and each entity is assumed to act to maximize its surplus. The surplus of change in cost between at the time of damage and at no-damage equals the willing to pay amount. In consequence, it is necessary to estimate the difference of surplus caused by damage. In the field of environmental economics, public economics, and the cost-benefit analysis, the method for the estimation of the difference of surplus has been studied and developed for years. In recent years, on the occasion of evaluating a public project, the cost-benefit analysis is required and manuals are to be maintained. The following methods are the ones employed in the manuals of flood control projects, coastal projects, cultivation field maintenances, and parks and roads.

The first method targets the damage of decrease in asset and income, and increase of the adaptation cost. In both cases the damage value equals the amount of willing to pay to avoid the loss. The target damages include flood, storm surge, and ground hazard. It is assumed that the frequency of disasters and the intensity of damage become larger because of global warming, and the government takes the appropriate adaptation measures so as to maximize the net benefit. In consequence the damage cost caused by disasters of over a certain scale becomes larger, and the governmental adaptation cost grows larger. The former cost occurs only at the time of disaster and is the decrease of the surplus which is in turn the increase of the expected value of the amount of damage cost due to over scale disasters, and the latter cost leads to the tax increase which then is ultimately the loss of the people's surplus.

The second method is to evaluate the damage by using the rise of the price which results from the decrease of the productivity. In a competitive market which suffers the decrease damage of rice productivity, it becomes zero regardless of the average cost. The decrease of the productivity caused by global warming leads to higher production cost, which leads to the formation of a price equal to the average cost. Thus the price becomes higher and the demand becomes smaller, and the productivity decreases but by the assumption the consumer's surplus does not change. The loss of a consumer after the price rising is the product of the amount of price rise and the amount of demand. This loss is indicated by the shaded squared area in **Fig. III-1**. In addition to this, it is necessary to add the loss of a consumer who gives up consumption. A consumer who gives up the consumption of rice produce is thought to have designated a value in between of that of before and after the change of price, with its average value equals to the median value of prices before and after the change. And as the consumer paid the previous price before the change, the consumer's surplus before the change is the product of the difference of the prices and the decrease amount of consumption. This surplus is lost and therefore this is the loss of the consumption which is given up. This loss is indicated by the shaded triangular area in **Fig. III-1**. Eventually the decrease in productivity leads to the rising of prices, and the amount of produce decreases. This loss can be calculated as the product of the amount of price rise and the median value before and after the change of consumption pattern. It is indicated by the shaded trapezoidal area.

The third is the travel cost method (TCM) and it is used in this report in the estimation of recreational value of sand beaches. At a certain sand beach, we focus on the behavior of trips that people make from a certain place to the beach, as a function of the cost of a trip. **Figure III-2** shows a travel demand curve to a beach. An individual is considered to have visited the beach because he or she values the outdoor resource higher than the necessary cost of travel. The demand curve is formed by arranging the visitor's travel cost in large order. The vertical height of the demand curve at a certain travel cost indicates that there are these numbers of people who visit the site and value it at that travel cost. When X number of people are visiting at a cost of P yen, the amount of willing to pay by X people is indicated in the area under the demand curve up to the X people. The actual amount paid is the product of P and X, so the visitors' surplus is expressed in the area surrounded by the price line and the demand curve. This is called the consumers' surplus. The value of this specific sand beach is the total of consumers' surplus in each area. The lost damage of sand beaches due to sea level rise is calculated by multiplying the value of sand beach with the rate of lost area, assuming that the damage is proportional to the rate of the lost area.

The fourth method is called the contingent valuation method (CVM). This method administers a survey and directly asks people the amount of willing to pay. CVM is utilized in damage evaluation where the surplus and willingness to pay cannot be estimated through actual behavior in real market. In this report the CVM is employed to measure the willingness to pay to avoid the increase of human illness and mortality, the willingness to pay to avoid the loss of tidal flats, and the willingness to pay in order to avoid the increase of pine wilt disease.

An appropriate empirical method for valuating the environment is applied depending on the form of damage, so as to estimate the objective damage cost by recovering estimates of individuals' willingness to pay for environmental quality by observing their behavior. When it is not possible to observe individuals' behavior in real markets, the CVM method is applied. **Table III-1** describes the target damages which are valuated by the appropriate method to estimate the damage cost due to global warming.

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2. TCM survey concerning the economic valuation of sand beaches

In applying the TCM method, the demand function of transport for the purpose of utilizing a sand beach is defined as follows:

$$\ln(x_{ij}) = \alpha + \beta \cdot p_{ij} \tag{1}$$

Where x_{ij} is the traffic for the utilizing of a sand beach from point *i* to point *j*, p_{ij} is the traffic for the recreational use from point *i* to point *j, i-j* is the departure and arrival point (prefecture), and α, β are the unknown parameters. The traffic demand function for a recreational shell gathering is given as follows:

$$x_{ij} = \exp(\alpha + \beta \cdot p_{ij}) \tag{2}$$

In TCM, a recreational value is defined by the consumers' surplus in traffic market which is a substitutional market to the concerned activity. Therefore, the value of recreational sea bathing at a sand beach is evaluated with the consumers' surplus *CS* of the traffic demand for the utilization of the sand beach given in equation (2).

$$CS = \sum_{ij} \int_{p_{ij}}^{\infty} x_{ij}\, dp_{ij} \tag{3}$$

$$= -\frac{1}{\beta} \cdot \sum_{ij} x_{ij} \tag{4}$$

Equation (4) states that the consumers' surplus in the whole traffic market is expressed in constant multiple of the whole traffic. According to (4) the consumers' surplus per visit *CS* is given in the following equation.

$$cs = \frac{CS}{\sum_{ij} x_{ij}} = -\frac{1}{\beta} \tag{5}$$

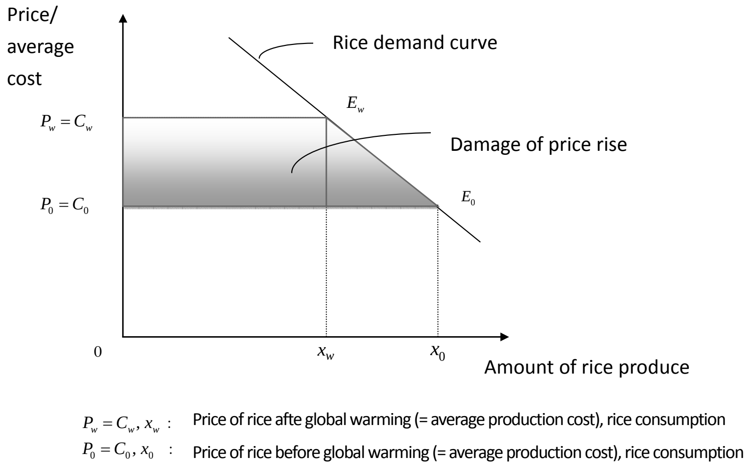

Figure III-1 Damage of price rising.

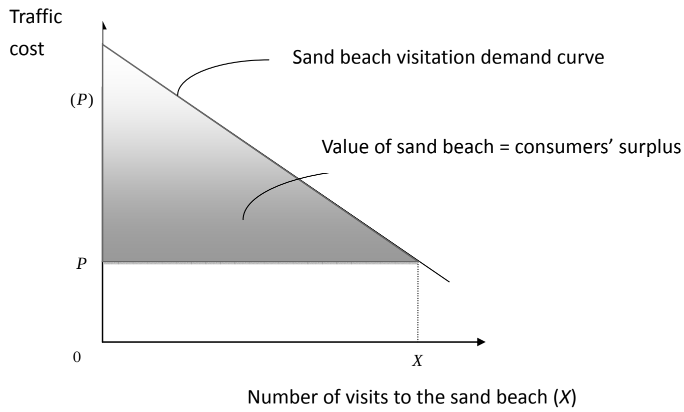

Figure III-2 Value of a sand beach.

The equation (5) states that the consumers' surplus per visit is constant regardless of the distance or the frequency of travel. This means that when surveying the recreational value of a sand beach, the counting of the number of visitors to the sand is required but it is not necessary to specify the departure point of the visitors.

3. CVM survey concerning the economic valuation of tidal flat

The following questions were presented in a CVM survey using computer internet network. Question 1: What is your degree of interest in the issue of global warming, Question 2: What is your degree of concern against the ecocide due to global warming, and Question 3: What is your willingness to pay to avoid the devastation of tidal flats.

The main part of this CVM survey laid in Question 3, which is described in **Table I-IV-1**. The evaluation target was limited to the value of the tidal flats' ability to maintain the biological divergence in nationwide of Japan (tidal flats approximately 514 km^2). The form of the questionnaire was double-bounded dichotomous choice, the method of payment was money charged, the form of payment was annual payment, and the unit of payment was personal.

From the response data of questionnaire described in **Table I-IV-1**, the rate of answer yes to each indicated amount of money was aggregated, and the cumulative density function *F(t)* of the rate of answer yes to an indicated amount of money *t* was specified as follows:

$$F(t) = \frac{1}{1+\exp(a+b\cdot\ln(t))} \quad (1)$$

Where *a,* and *b* are the unknown parameters.
The median and the mean value of willingness to pay per person is given in the following equations.

$$Median = \exp\left(-\frac{a}{b}\right) \quad (2)$$

$$Mean = -\int_0^{\infty} t\cdot dF(t) \quad (3)$$

Here the median value was adopted as the value per person.

4. Target impact valuation field and target index

General fields and indices of global warming impacts as well as the indices evaluated in this report are described in **Table III-1**.

Table III-1 Global warming impact index by field and the target indices evaluated in this report

field	Impact index	Impact assessment in this report
Water resource	Flood (area/damage cost)	1.2・1.3(1)
	Geological hazard	1.2・1.3(2), (3)
	Snow water resource	1.2・1.3(4)
	Drought (municipal water, water for agriculture)	1.2・1.3(5)
	Water quality (rivers, lakes, dam lakes), groundwater	—
ecosystem	Forest ecosystem	2.2・2.3(1),(2),(3),(6)
	Alpine ecosystem	2.2・2.3(5)
	Natural grasslands, wetlands	2.2・2.3(4)
	Marine ecosystem, coastal ecosystem	—
Agriculture (food)	Agriculture (rice)	3.2・3.3(1),(2)
	Agriculture (cereal other than rice)	—
	Fruit, tea, vegetables, animal husbandry, fisheries	—
Coastal zone	Storm surge flooding	4.2・4.3(1)
	Flooded river (upstream and middle stream, estuary basin)	4.2・4.3(2)
	Liquefaction	4.2・4.3(5)
	Slope failure	4.2・4.3(6)
	Sands, tidal flats	4.2・4.3(3),(4)
health	Heat wave	5.2・5.3(1),(2)
	Air pollution	5.2・5.3(3)
	Infectious diseases	5.2・5.3(4)

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Assessment of Impacts on Coastal Zones

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Assessment of Impacts on Economics

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Comprehensive Assessment

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