Registration Number
11-1480000-001692-01

ISBN 978-89-93652-60-4
978-89-93652-57-4 (세트)

Summary for Policymakers

Korean Climate Change Assessment Report 2020

- Climate Change Impact and Adaptation -

Ministry of Environment

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1. Introduction

1.1 Background and Procedure

To reduce and adapt to the damage caused by climate change, identifying and responding to the climate change impacts and vulnerabilities that vary from region to region are necessary. To this end, the Ministry of Environment published the Korean Climate Change Assessment Report 2010 and Korean Climate Change Assessment Report 2014, in 2011 and 2015, respectively. The Korean Climate Change Assessment Report 2020, the third report issued, has been published as a compilation of new studies accumulated over the past six years, as per the schedule for establishing the third national climate change adaptation policy.

This report is based on the results of 880 domestic and international studies on climate change, vulnerability, and adaptive policy in the Korean Peninsula. It consists of a total of ten chapters, namely, introduction, water resources, ecosystem, forestry, agriculture, maritime and fisheries, industry and energy, health, human settlements and welfare, and adaptation policies and plans. The present report summarizes the key results of the above mentioned assessment report for policymakers and presents confidence levels for the study results according to the three agreement levels, illustrated in Table 1.1.

The lead author and contributing authors for each section were selected based on their academic and research expertise. Once the first draft of the report was written by the lead and contributing authors, the supervising author proofread the document, and a final review was conducted by each respective ministry. Subsequently, the Korean summary report and English summary report were prepared based on this supplemental report.

Table 1.1 Classification of Confidence Level Assessment of Research Results (Level of Agreement)

01 Substantial Level of Agreement	Cases involving a considerable number of papers in related fields that are consistent with each other without any major conflicts or where the expert opinion is consistent
02 Moderate Level of Agreement	Cases involving a considerable number of papers that express difficulty in assessment based on the evidence owing to its status as a minority opinion, etc. or in which other minority opinions are present among the experts
03 Limited Level of Agreement	Cases involving very few papers or expressing difficulty in providing reliable assessment owing to significant differences in opinions among the experts

1.2 Research Topics of the Korean Climate Change Assessment Report 2014

The topics covered in the Korean Climate Change Assessment Report 2014 (hereinafter “2014 report”) are first reviewed to identify the differences in studies related to vulnerability assessment and establishment of adaptation policies, in addition to providing studies on surface runoff, flood, and drought in the water resources area.

In the ecosystem section of the report, studies on changes in the plant phenological phases, plant/animal distributions, and species composition were presented.

The forestry section included investigations on changes in the forest distribution, forest carbon stocks, and forest disasters, based on climate change. In the agricultural sector, many studies were performed regarding changes in the time and region necessary to cultivate crops and in pest occurrence. For maritime activities and fisheries, the sea surface temperature and sea level rise, changes in the ocean current and ocean acidification, reduction in the dissolved gas, and the biological characteristics due to such changes were predicted. In the case of industry and energy, whereas research has been performed related to the direct and indirect impacts of each sector on climate change and their effects on human life, different characteristics were considered, and the business types for each industrial sector could not be considered in its entirety. In the health field, while the findings of joint multidisciplinary studies on the increase in mortality and hospitalization due to climate change were verified, the limitations of setting up adaptation measures based on such studies have had to be addressed. In the area of human settlements and welfare, discussions were presented on urban disasters, vulnerable areas, climate change adaptation research, and urban planning methodology, as well as the effect of energy use in rural villages. In particular, the necessity of a climate change adaptation strategy for socially vulnerable groups was emphasized. Finally, in the adaptation strategy section, the development process of national-scale adaptation measures and measures set by local governments were described. The capability for implementation, risk assessment reinforcement, adaptation policy prioritization, consideration of vulnerable groups, bolstering of spatial planning, systematization of adaptation measures, and linkage between adaptation and reduction were reviewed to enhance the effectiveness of the adaptation measures.

As a result of a review of the 2014 report, additional details regarding Korea's climate change impact, vulnerability, and adaptation were presented as detailed in the following.

First, increasing the observation data and improving the quality of the data for each section were necessary to obtain confidence levels for the studies. Investigation of the quantitative impact of climate change was limited, owing to a lack of long-term observations, lack of quality data, or insufficient metadata. Furthermore, obtaining a confidence level was quite challenging in some cases. In addition, a review regarding the outlook and uncertainty of the climate change impact under various scenarios was necessary. In fact, additional studies are needed to analyze the impact and uncertainty of the prediction of the various IPCC climate and socioeconomic change scenarios to discover rational policy alternatives. Finally, a study on the connection between sustainable development paths and climate change adaptation, which is gaining interest across the globe, is needed.

Although the details above have not been entirely resolved, many quantitative impact studies have been performed since 2014. Adaptation policy has been increasingly studied but not without limitations in its realization in actual public policy.

1.3 Major Research Trends

As of July 2020, only an overview has been approved by the Working Group (WG II) (Impact, Adaptation, and Vulnerability) of the IPCC Sixth Assessment Report; the report is scheduled to be issued in 2021. The table of contents in the report primarily comprises three sections: (1) risks, adaptation, and sustainability of the systems affected by climate change (Chapters 2-8), (2) regions (Chapters 9-15), and (3) sustainable development paths: integration of adaptation and reduction (Chapters 16-18). Considering the currently emerging international issues related to climate change, an overview of each section is presented, which addresses the following issues. (1) For each section of the report, the dynamic risks of climate change are detailed, transitioning from the vulnerability of climate change to the assessment of risks to derive existing impacts and irreversible losses. (2) Discussion related to adaptation also involve climate resilience, and sustainability is included as an adaptation option to address limitations and sustainability from social, environmental, and economic perspectives. Another important issue in formulating adaptation options is impartiality, and a significant focus is placed on low-income groups and resident communities. Third, sustainable development paths are considered in decision-making and development of climate-resilient paths. The factors that affect decision-making for risk management are identified, and the appropriate decisions based on temporal and spatial scales are discussed. Regarding climate-resilient development paths, the synergies and compromise of sustainable development, adaptation, and reduction are analyzed.

Meanwhile, the IPCC 1.5 °C Special Report emphasizes the need for a powerful reduction mechanism to limit the increase in global-average temperature to 1.5 °C for the period since the industrial revolution to the year 2100. It emphasizes the fact that synergy with adaptation has to be maximized in conjunction with reduction to accomplish the 1.5 °C scenario, and a sustainable development path in which the social structure and system is transformed must be followed to achieve this limiting of global warming.

From this perspective, Korea also needs to determine specifically how sustainability will be managed after the realization of adaptation and reduction to solve the various problems caused by climate change.

2. Water Resources

2.1 Introduction

Studies of the water resources sector have been expanded to include a wide range of fields, including adaptation and economic feasibility, in addition to the existing studies on impact and vulnerability. Regarding the observed impacts, studies on floods and droughts using new indicators and techniques have increased, and studies that simulate the variation in runoff, intensity of flood or drought, and frequency of occurrence, according to the RCP scenario, were performed. In addition, research quantifying the uncertainty of climate change has increased, and studies to develop and apply various decision-making methods have been performed, as detailed in the adaptation options section. In this report, studies on water resources targeting the Korean Peninsula have been reviewed, and the direction for future studies on water resources related to climate change have been presented.

2.2 Observed Impacts

Over the past thirty years, summer rainfall has increased, along with the frequency of extreme rainfall (substantial agreement). The frequency and intensity of drought have also increased, with consequential social and economic damage, and significant regional variations in drought have also been observed (substantial agreement).

In general, the annual average rainfall has increased, and in particular, summer rainfall has clearly increased, as indicated by the analysis of trends in rainfall data over the past thirty years in eight major cities throughout the country, namely, Seoul, Incheon, Daejeon, Daegu, Ulsan, Gwangju, Busan, and Chuncheon. Along with the annual average rainfall, the occurrence of extreme rainfall has increased by 3.1%-15%, and as a result, the probable maximum precipitation exhibits an increasing trend.

Drought-related studies have been widely performed to develop and verify new drought indicators or to combine numerous existing hydrological and meteorological drought indicators. Consequently, the drought trend analysis showed that the frequency and intensity of drought increased, with significant regional variations. In the five major river areas, drought was most severe in 1988 and 1994, with a return period of drought to be approximately 30-50 years. In particular, the 2014 drought centered on the Han River area was rated as one of the most extreme droughts in history, with a return period of 100 years.

Research on drought was mainly focused on analyzing the increase in rainfall probability (PR) and flooding and analyzing the resulting damage according to the scale and frequency of flooding using probability statistics. Although studies to verify changes in the river stage and subterranean water levels have been performed using primarily hydraulic/hydrological modeling, such studies have been few in number.

2.3 Impact Outlook

Vulnerability to flooding is expected to increase owing to the increase in extreme and sudden storm events (moderate agreement). Flood magnitudes in the Han River and Geum River areas are particularly expected to increase (moderate agreement). The occurrence frequency and scale of drought will generally increase, and drought damage will be exacerbated, owing to increases in both the frequency and scale of drought over time (moderate agreement). In particular, damage will be likely increased in the Han River area and southern region of the country (moderate agreement).

In Korea, the maximum rainfall and design rainfall will also likely increase in the future in addition to the average rainfall. The proportion of rainfall observation points with a greater than 300-year return period for the maximum daily rainfall value is expected to increase by 14% in the 2020s (2011-2040), 28% in the 2050s (2041-2070), and 35% in the 2080s (2071-2100). (Figure 2.1). Analysis of probable maximum rainfall reveals an increase of 13.3% in the future over that in the past, from 915.5 mm (up to 2013) to 1030.1 mm in 2011-2100 (Figure 2.1). Similarly, future discharge tends to increase in general,

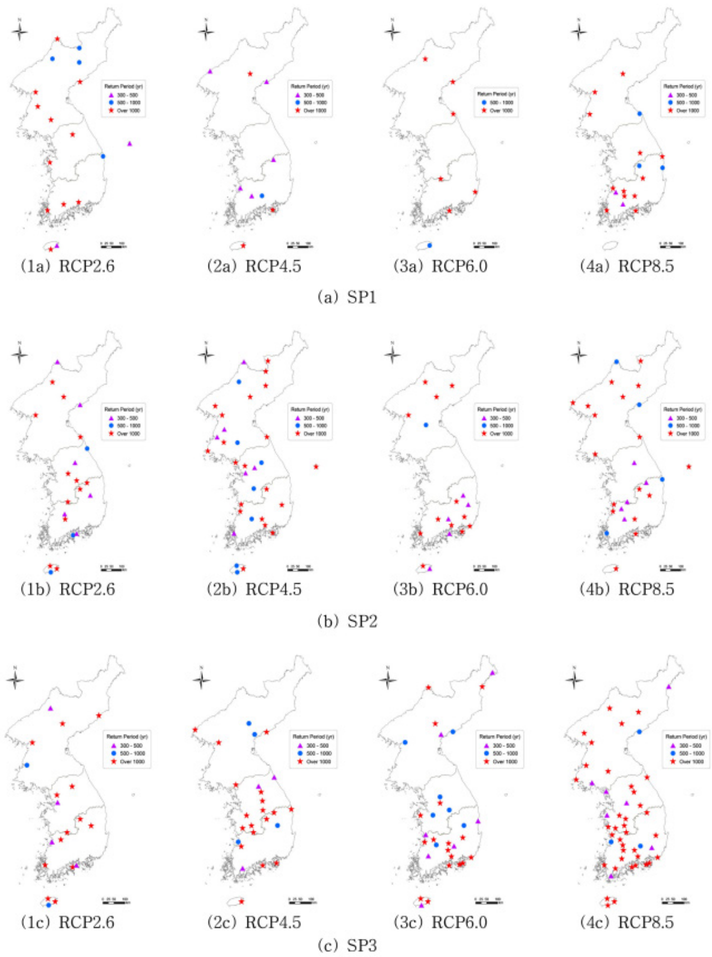

Figure 2.1 Points where the return period of the maximum daily rainfall, according to the RCP scenario, is more than 300 years (Kwon et al., 2015). The return period of the maximum daily rainfall value by period for the 2020s (SP1, 2011-2040), 2050s (SP2, 2041-2070), and 2080s (SP3, 2071-2100) (▲ 300-500 years, ● 500-1000 years, ★ 1000 years or more)

particularly in summer. However, the uncertainty of results for each region/period also varies depending on the selection process for the runoff models and the emission scenarios employed.

The frequency and level of flooding is projected to gradually increase, owing to changes in emission characteristics, which are, in turn, attributable to land-use changes and anticipation of increases in probable rainfall. In addition, vulnerability to flooding will likely increase, owing to the development of extreme storm events and increase in sudden storms. However, the projection results varied, owing to the application of different models and downscaling techniques, and the uncertainty of the results was shown to increase as the projection period increased. The frequency and scale of drought will generally grow increasingly in the future, yielding more severe damage due to drought. In particular, damage is expected to increase in the Han River area and southern part of the country (Figure 2.2). In RCP 2.6 and RCP 4.5, hydrological drought will generally become more severe in the future (2012-2100) than in the past (1971-2000), RCP 6.0 projections indicate that drought will become less severe than in the past and that projected by RCP 8.5, which shows a similar pattern as in the past.

2.4 Primary Causes of Vulnerability

The scope of research in the vulnerability outlook and flood analysis has been extended to analyze the basin-scale flood damage ensuing from increased extreme rainfall, regional vulnerability due to sudden floods in creeks and mountain areas, and flood vulnerability in urban areas (moderate agreement). Various types of flood-vulnerability indices have been developed, and methodologies have varied for different drought research purposes (moderate agreement).

Since the first and second assessment reports, research has increased in the areas of vulnerability outlook and analysis. The scope of flood analysis and vulnerability-outlook studies have widened to include regional vulnerability due to sudden floods in creeks and mountain areas and vulnerability to urban flooding. Additional research has included the assessment of estimated flood damage in each basin due to the increased frequency of rainfall. Many analyses classify the northern Gyeonggi-do and Gangwon-do areas as areas vulnerable to flooding and indicate that the amount of flooding will increase owing to the increased probability of rainfall, along with the expansion of the areal extent of individual floods.

To assess vulnerability and the drought outlook, primary methodologies include analyzing vulnerability according to the frequency and intensity of drought through the use of probability statistics and evaluating vulnerability by calculating the drought-vulnerability index values. A common prediction from drought-vulnerability projection research is that damage due to drought will become more severe, because the frequency and scale of drought will further increase in winter. Owing to an assessment of the future drought risks using the three-month Standardized Precipitation Index (SPI3), it was projected that the areas highly vulnerable to drought will be the central and southern areas in the 2030s, Nakdong River basin in the 2050s, and entire Korean Peninsula in the 2080s. Considering the reliability of the dam-based water supply, while the water supply is currently stable with a drought frequency of ten or fewer years, water shortages were predicted to gradually intensify in the future in the southern part of the country. Vulnerability research regarding subterranean water has been notably inadequate, and further study is required. In particular, while subterranean water utilization planning is increasingly important for sustainable water supply, the subterranean water level is expected to decrease. Hence, studies on the spatial and temporal management of subterranean water are urgently necessary.

2.5 Adaptation Options

The number of studies that have been recently conducted to formulate adaptation measures in the field of water resources has increased by more than a factor of two. However, these studies remain insufficient for realization in actual policy (moderate agreement).

Various studies on decision-making methods, flood defense, and drought adaptation have been performed to develop water resource adaptation strategies for climate change. Recent drought-adaptation strategies have seen an increase in unstructured measures regarding water supply. Compared with the 2014 assessment report, the proportion of adaptation-strategy studies has increased from 8% to approximately 20%. Nevertheless, more active research and insightful result are required for implementation into policy.

3. Ecosystem

3.1 Introduction

Climate change has a wide range of continuous repercussions on nature and the entire socio-economic system. The impact of climate change or damage in an area could be reversed, with the reproduction or restoration of the original state of the area through sufficient time, finances, and effort. However, if the biodiversity of ecosystem, manifested by the presence of a wide variety of organisms, is lost, the loss would be permanent. Therefore, irreversibility would be unavoidable in many cases.

However, the difficulties experienced by an ecosystem due to climate change may be beyond the public interest, since these difficulties do not cause direct damage or inconvenience to humans, unlike situations in other socio-economic fields. Instead, it is common to accept the knowledge of the actual circumstances that the ecosystem is experiencing burdensome and inconvenient situations.

In this report, the potential for a symbiotic relationship between nature and humans was examined by analyzing the impact of climate change caused by humans on plants, animals, and vulnerable ecosystems in each habitat to search for countermeasures with observed impact, outlook of impact, cause of vulnerability, and adaptation options.

3.2 Observed Impact

Because the studies on observed impact are limited in explaining the correlation, as they were analyzed based on specific ecosystems and plant species, continuous long-term studies on various species and research topics are required (limited agreement). Regarding the impact on animal ecology due to climate change, many studies have reported trends in the movement of habitats (substantial agreement). In addition, studies were performed on various types of vulnerable ecosystems, such that the confidence level was improved (moderate agreement).

Examination of the changes in plant habitat, analyzing the relationship between climate change and plants, has become relatively frequent, and studies on plant growth or physiological changes have also increased. The typical growth period has increased due to global warming. The onset period has risen by an average of 2.7 days/10 years from 1970 to 2013, and the time of leaf abscission has increased by 1.4 days/10 years; thus, the total growth period has increased by 4.2 days/10 years. With respect to plant distribution, the proportions of northern plants, such as subalpine species, and rare/endemic plants have increased along with their altitudes above sea level, whereas the diversity of species was shown to decrease.

As in the 2014 report, there were many studies reporting trends in habitat movement highlighting the impact on animal ecology due to climate change. Reportedly, the distribution became wider in the north, in which an inflow of new southern species was evident, reflected by relatively conspicuous southern butterflies and birds. In fact, the northern boundary line of 63 southern butterfly species in Korea has moved further north by 1.6 km each year for the last sixty years; meanwhile, the southern boundary line of the northern species has also been extended south. This spread was also clearly demonstrated on a national scale for exotic species, such as Vespa velutina and Ricania shantungensis, and pests, including mosquitoes and ticks. For example, the presence of Vespa velutina, which is an exotic species, had expanded to 103 cities and counties nationwide, with the exception of some areas of Seoul, Gyeonggi Province, and Chungcheong Provinces in 2014, and later to 155 cities and counties nationwide, whereas it only appeared primarily in the Busan area up to 2008.

Since vulnerable ecosystems exhibit greater sensitivity to climate change than ordinary ecosystems, the change in the species composition or distribution range was shown to be quick and extreme.

Research on the observed impacts on these vulnerable ecosystems related to the distribution range of species and their ecosystem structure, among others, has been published, targeting alpine regions, subalpine regions, coasts, islands, and inland wetlands.

In the 2014 report, most of the research was related to the alpine and subalpine zones. However, studies related to various ecosystem structures have been recently conducted, and the proportion of studies related to coastal and island regions has increased significantly. Consequently, the confidence level of studies has also increased.

3.3 Outlook of Impact

The prediction of the impact of climate change was concentrated on the change in habitat distribution, such as the simulation of the impact of changing patterns on the habitat and population of a target classification group, according to a future climate scenario. To predict the impact of climate change on Korea's ecosystem, balanced research study on various topics, including species diversity, physiology/growth, and plant phenology is necessary (limited agreement).

The prediction of the change in plant physiology/growth was considered with other environmental factors, such as global warming and the level of soil moisture/nutrients, in which growth increases were predicted to occur when other conditions were satisfied. In the case of changes in plant phenology, the flowering time of some target species was predicted to decrease. For instance, cherry blossoms were predicted to flower 6.3 days and 11.2 days earlier after 2090, according to the future climate scenarios RCP 4.5 and RCP 8.5, respectively. Furthermore, future changes in the distribution pattern of habitats, such as habitat movement, reduction, or extension, depend on the species. The mortality of *Pinus densiflora* was characterized as increasing by 1 ℃ for every 1.01% increase in temperature in winter. In the case of *Larix Kaemferi Carr* and Pinus koraiensis, mortality increases of 1.43% and 2.26% have been verified for each 1 ℃ increase in temperature in spring. It was determined that the distribution of polar tree species, including polar evergreen broad-leaved trees and conifers, in most polar areas will be reduced (Figure 3.1). The distribution of *Abies koreana W*. could be extended owing to an increase in rainfall, and warm temperate species will apparently exhibit various changes in distribution patterns, such as extension or reduction, depending on the species.

Since the outlook on the impact of climate change is significantly related to changes in habitat distribution, active research on physiology/growth and plant phenology would be desirable. Plant distribution studies are also limited to specific species, and uncertainty in the prediction of future distribution areas is high due to a lack of actual measured data.

In studies on changes in habitat distribution and animal richness due to climate change, simulations of the distribution of the habitat of the target group or the population change pattern after 2050 were actively performed according to future climate scenarios (RCP 4.5, RCP 8.5) based on the current

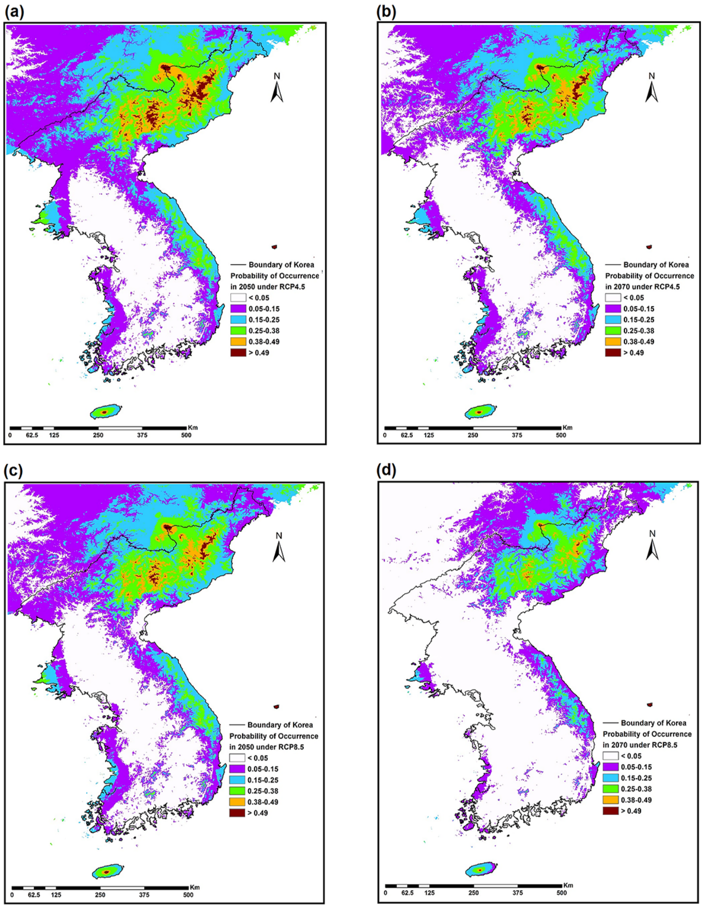

Figure 3.1 Prediction of change in the distribution of the suitable habitat of polar evergreen broad-leaved trees due to climate change (Koo et al., 2015). Prediction of change in the distribution of the suitable habitat until 2050 under (a) RCP 4.5 and (c) RCP 8.5; prediction of change in the distribution of the suitable habitat until 2070 under (b) RCP 4.5 and (d) RCP 8.5, according to the climate change scenario.

distribution data. It was shown that habitat reduction due to climate change would most affect endangered species. The population richness of insects was also shown to be reduced by 13%-36% due to increases in temperature. The richness of aquatic insects will also be reduced, and in the case of *Plecoptera* inhabiting alpine streams, it was found that up to 62% will disappear. However, Odonata was predicted to increase by more than 30% owing to temperature rise. The distribution range of the insects that are infectious disease vectors is expected to move northward, and the domestic settlement of Aedes albopictus, which can spread dengue or Zika virus, will be possible if the average temperature of Korea in winter rises to 10 ℃ or higher in 2050. It was reported that *Hynobius leechii* has a high possibility of population reduction, as the reduction in temperature difference in spring due to the rising temperature increases energy consumption.

As the existing studies on the impact of climate change on vulnerable ecosystems have mainly focused on alpine and subalpine areas, the confidence level of these studies has improved, as studies have targeted a wide range of ecosystems and plant species, such as wetlands and stream-water ecosystems.

3.4 Primary Causes of Vulnerability

In terms of the vulnerability assessment, climate change was observed and analyzed as a crucial factor. For more reliable vulnerability analysis, an integrated analysis that has applied a multilateral research method to various species is necessary.

In terms of the vulnerability assessment of plant physiology/growth, plant phenology, and changes in habitat distribution, climate change was observed and analyzed as a crucial factor. As increases in temperature and carbon dioxide were determined to increase plant growth, the level of impact differs depending on other environmental conditions, such as soil conditions. Plant phenology was found to be very sensitive to climate change, with the hastening of the flowering time and the delay of the abscission time in most plants, due to global warming.

In the animal ecosystem, environmental and climatic considerations, such as temperature rise, act as crucial factors that affect the increase and decrease in the species diversity of arthropods. However, a combination of variables such as the positive effects due to the extension of the forest extension or negative effects such as the decline in the quality of habitats, along with the climatic factors, impacted the diversity of the species, depending on the animal. In the case of pests, the distribution range could be further increased, owing to the distribution or density change in food factors, various gene expressions involved in the temperature stress, existence of physiological adaptation mechanisms, and interspecific interactions. However, finding a common cause targeting all species would be difficult because there are many cases in which the habitat extension or population increase of each animal species is unique.

In the study of vulnerable ecosystems, there few results are related to the primary causes of vulnerability; however, progress has been made on the development of a regional vulnerability assessment index based on climate change. In addition, new research regarding the future prediction and adaptation measures under a climate change scenario have been presented.

Regarding the cause of vulnerability, studies that have stereoscopically considered additional diverse factors such as soil environment in addition to climate factors have increased. The confidence level of such studies has improved, as abundant research results providing prediction of distributions and policy recommendations have been derived, which go beyond the construction of a basic dataset.

3.5 Adaptation Options

Climate change impacts the ecosystem through a complicated interaction, with various factors that make up the ecosystem. Studies performed since 2014 only provide very limited information for understanding such complicated ecosystems and formulating adaptation measures. In addition, although the studies related to the estimated scenario on the extension of the species distribution extension have been actively in progress, additional research is necessary because relatively few studies address ecosystem impact, vulnerability, and adaptation measures (limited agreement).

Among the plant ecology studies since 2014, studies on plant habitat/distribution impact and outlook of impact were relatively active, compared with other studies. This can be considered to be the result of the increased demand for predicting the impact of climate change on an ecosystem in a habitat unit, with the increase in the availability of various prediction models. In addition, ecophysiological research, including molecular ecological research or research to identify the impact of climate change by extracting secondary metabolites, and integrated research on the impact of ecosystem changes on other fields, such as health and agriculture, have been conducted. However, studies performed for the last five years only provide very limited amount of information for understanding such complicated plant ecosystems and formulating adaptation measures.

In addition, most of the studies on animals based on climate change scenarios used the distribution data of various animals in Korea since 2014. However, even though there were many scenarios that presented the extension of the distribution of the animal species, few studies addressed the impact of the distribution extension on the ecosystem and on vulnerability and adaptation measures.

In addition, the studies related to adaptation measures, which exhibited relatively incomplete conclusions in the 2014 report, are gradually being supplemented through the introduction of cases on the adaptation and measures of ecosystems vulnerable to climate change and the introduction of new studies that can be used to direct the policies of Korea.

4. Forestry

4.1 Introduction

According to the Special Report on Climate Change and Land (SRCCL), published by the IPCC in 2019, land use, including forestry, accounts for 23% of the greenhouse gas emissions due to human activity. This has presented serious global ramifications, such as reduced species diversification of the forest ecosystem and a predicted increase in forest-related disasters due to climate change. This report has described the impact of climate change and change in forestry in the future through the results of studies performed in Korea and verified scientific facts. In addition, planning has been undertaken by reviewing the cause of vulnerabilities and adaptation options, such that those vulnerabilities might be mitigated from various perspectives.

4.2 Observed Impact

The changes in forest growth, distribution, and patterns of disaster occurrence were shown for each region and tree species according to the change in temperature and rainfall (substantial agreement). In addition, reduced growth rates and distributions of coniferous forests were observed in large areas (moderate agreement).

Climate change impacts forest growth, and such impacts were verified to be different for each tree species. In general, while the growth rate of the main conifer species (e.g., red pine, Japanese larch, and Korean pine) has decreased owing to the impact of climate change, an increase in oak trees has been extensively observed. The growth reactions toward changes in climate have been found to differ based on the heterogeneity of environmental and locational factors, even for the same tree species. In addition, as the average annual temperature has increased over the past thirty years, changes in the forest composition, such as reduction (or increase) in area for each tree species or change in flowering time, could be verified. Meanwhile, the warm-temperate evergreen broad-leaved forest area has increased by a factor of 2.7 over the last 20 years (1988-2007), as compared with the previous 20-year period (1968-1987).

The total forest carbon stock and sequestration have increased in Korea dramatically through a successful reforestation program, and changes in the annual carbon sequestration, soil carbon, and carbon storage pattern, due to the impact of climate change and aging of forests, are observed. To measure the amount of forest carbon stored above, the below-ground, dead-tree, litter, and soil areas of the tree are considered. Studies using satellite image analysis, spatial statistics, and modeling methods to quantify the forest carbon content according to the heterogeneity of space and environment are in progress. (Figure 4.1).

Forest disaster areas, including landslides/forest fires, and the corresponding recovery costs have gradually increased, and the vulnerability of landslides due to climate change is expected to increase continuously. The increase in dry periods and dryness intensity became the cause of the emergence of large-scale forest fires; meanwhile, many forest fires centered on urban areas took place in the 2000s. In particular, the number of forest fires and damaged

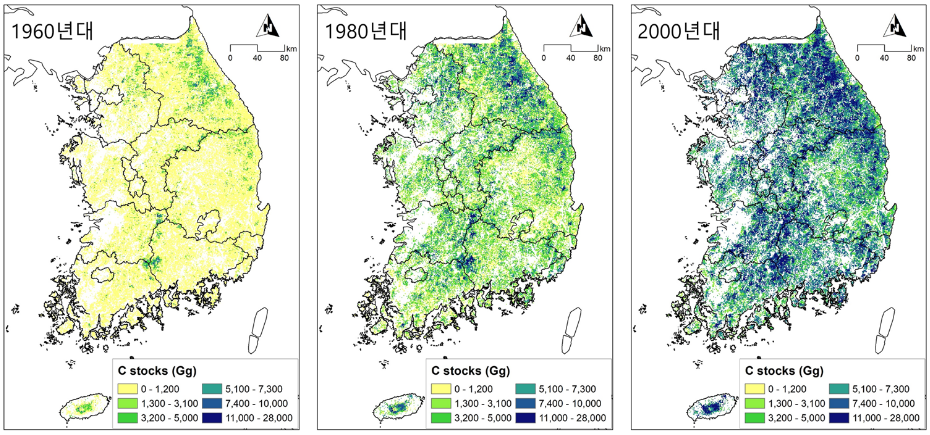

Figure 4.1 Estimated change in Korea's forest carbon storage (Kim et al., 2019).

areas in Gangwon Province and the Yeongdong area in the 2000s increased by factors of 1.7 and 5.6, respectively, compared with the 1990s. In the case of pests, pine wilt and oak wilt disease increased significantly after the 2000s. However, a decreasing trend was prevalent in the 2010s, owing to active pest control by the Korea Forest Service.

4.3 Outlook of Impact

While a decline in the growth rate in conifer forests due to an increase in temperature was predicted (substantial agreement), it was estimated that growth will increase in the case of the broad-leaved forests (moderate agreement). A sudden decrease in subalpine forests and the northward movement of the thermal belt forests are estimated (substantial agreement). While carbon storage is estimated to increase continuously, the annual carbon sequestration is estimated to decrease (substantial agreement).

As a result of predicting future forest growth, it was estimated that the growth of coniferous forests will decrease compared with that of the present in most areas, except in subalpine and alpine areas. However, the growth of oak trees was predicted to increase throughout the country. Furthermore, the mortality rate was predicted to increase by approximately 1.01%-2.26% for every 1 ℃ increase in temperature in spring and winter. However, for oak tree species, statistical significance was not verified. The climate impact on forest growth has accumulated, demonstrating that it will cause a difference in the volume stocks among forests. Therefore, the difference in climate change impact on forest dynamics is expected to be observed more clearly among the tree species and regionally as time passes by.

In the model simulation results for the long-term future on the potential tree species distribution, it was shown that subalpine and cool temperate forests will be significantly decreased, and temperate and subtropical forest areas will be significantly increased, owing to the overall rise in temperature and change in the climate of the coldest month each year. In the RCP 8.5 scenario, it was predicted that the red pine forest area will shrink by approximately 8% in the 2050s and by 15% in the 2080s, compared with the present. In assessing the habitat suitability of climatic conditions for each forest type, the northward movement of warm-temperate evergreen forests was predicted to extend the distribution toward both the east and west coasts of North Korea. In addition, the suitable habitats of the subalpine forest area trees in South Korea was predicted to continue to shrink, such that survival will only be possible in a very limited area in the distant future (Figure 4.2).

While the overall carbon stock in forests is estimated to continuously increase, the annual carbon sequestration was estimated to decrease compared with the present because of the rise in temperature and aging of the overall forests. While most simulation studies predicted soil carbon to decrease, the climate change impact was predicted differently, depending on the model, for the above-ground tree carbon stock.

From the perspective of forest disasters, it was predicted that significant deviations in disaster occurrence will be exhibited annually and regionally, with high annual variability, owing to hydrological change. The possibility of major landslides or fires will increase owing to the increase in heavy rains and dry periods. A change is also estimated regarding the emergence timing of insects due to climate change, and the possibility of a northward movement of pests and increased level of occurrence risks caused by such changes have been presented.

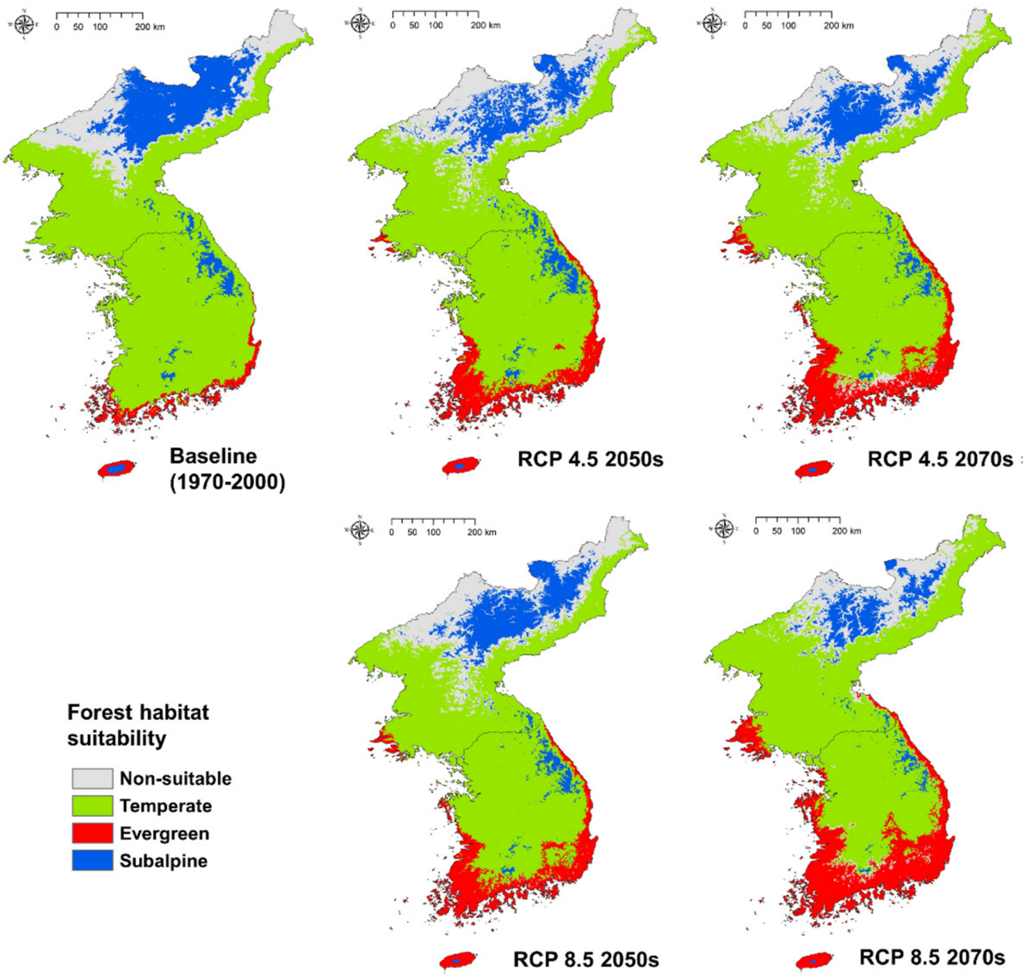

Figure 4.2 Prediction of the suitability of forest habitats in the Korean Peninsula (Lim et al., 2018)

4.4 Primary Causes of Vulnerability

Coniferous forests were determined to be quite vulnerable to climate change (substantial agreement). This is related to the change in the growth periods during the year and in the temperature of the coldest month. In terms of forest disasters, man-made activity, along with climate change, is becoming the cause of vulnerability (limited agreement).

For the assessment of vulnerability of forest growth to climate change, an equation subtracting the adaptation ability from the sensitivity was primarily utilized. For the sensitivity, different potential amounts of growth based on climate projections and the current climate were used. Meanwhile, for adaptation ability, social infrastructures related to forests and management intensity were utilized. In general, coniferous forests are more vulnerable to climate change than oak forests, the major broad-leaved forests of Korea. In particular, the growth vulnerability of coniferous forests are predicted to be high in the seashore and southern lowland areas, which are expected to experience relatively high temperature increases.

If the potential suitable areas for tree species that become reduced due to climate change are defined as places with high vulnerability, this vulnerability is expected to increase in the case of subalpine forests and coniferous forests. However, no significant change in vulnerability is expected in the case of thermal belt forests. The primary causes of the vulnerability to forest distribution have been determined to be the change in the annual growth periods and in the climatic conditions, which could be described as the warmth index and minimum temperature index due to global warming.

Since the vulnerability of forest carbon storage and absorption is closely related to the variation in the forest growing stock, it is predicted to have a high correlation with the vulnerability of forest growth. To assess the vulnerability of forest growth to climate change, an equation subtracting the adaptation ability from sensitivity was primarily used. In the case of sensitivity, different potential amounts of growth based on climate projections and the current climate were used. For the adaptation ability, social infrastructures related to forests and management intensity have been utilized. In general, coniferous forests were determined to be more vulnerable to climate change than oak forests, the major broad-leaved forests of Korea. In particular, the growth vulnerability of the coniferous forests were predicted to be high in the seashore and southern lowland areas, which are expected to experience relatively high temperature increases.

If the locations at which the potential suitable areas for tree species will become reduced due to climate change are defined as places with high vulnerability, the vulnerability is expected to increase for subalpine forests and coniferous forests, and no significant change in vulnerability is expected for thermal belt forests. The primary causes of vulnerability for forest distribution are the change in the growth periods of the year and in climatic conditions, which could be described as the warmth index and minimum temperature index due to global warming.

4.5 Adaptation Options

An adaptation plan to derive and implement the management policy for each field to lower vulnerability and risk is necessary (moderate agreement). Forest management and a spatial plan that considers climate change adaptation measures on the national level and requirements from the international society are required (moderate agreement).

Active management and forest treatment are predicted to have a positive impact in maintaining and improving forest growth and carbon storage. Active afforestation has been shown to not only improve forest health and adaption ability to climate change but also improve the unbalanced age structure of forests, invigorate the timber market, and contribute to the supply/demand of energy.

To lower the vulnerability of the forest tree species distribution, plans to protect highly vulnerable tree species or manage them through the renewal of optimum tree species can be considered in the future. To provide protection, a management plan to lower vulnerability by minimizing the negative impact of climate and increasing adaptation ability can be applied. This management plan would serve to improve the growth environment of the forest through artificial tree species management, such as afforestation or through the management of specially protected tree species.

Technological development to improve forest carbon absorption, which is decreasing due to the increase in forest age and temperature, can be an ideal adaptation option for the forestry sector. Research on forest carbon optimization strategies, such as maximizing the forest carbon stock and replacing other materials with harvested wooden products would also have to be implemented. Bio-energy with carbon capture and storage is one of the ideal adaptation options attempted by developed countries in the field of forestry and exhibits the advantages of being environmentally friendly and having a low technical barrier.

Risk monitoring and active response are commonly considered as the most important adaptation options for forest disaster mitigation. Plans such as the establishment of erosion control facilities and forest management are presented for landslides, and firefighting infrastructure and forest fuel management are presented for forest fires.

5. Agriculture

5.1 Introduction

Changes in geographical, seasonal, and climate conditions cause changes in the locations of the proper sites for crop production, exhibiting direct and indirect impacts on agricultural productivity, including changes in pest/weed type/generation, soil fertility, and drought intensity. In addition, increases in atmospheric CO_2 concentration and temperature have direct effects on crop productivity by affecting the photosynthesis and growth rate, partitioning to each organ, and water use efficiency. Such climate change and its impacts are expected to vary significantly with geography. In this report, the study summarizes and describes four topics that address these issues, namely, food crops, horticultural crops, pests, and weeds, in the Korean Peninsula area.

5.2 Observed Impact

While severe yield losses due to climate change have not yet been observed, the cultivation areas of some crops have shifted northward, and the outbreaks of overwintering/invasive pests have increased while the distribution patterns of weeds have changed (substantial agreement).

Severe yield loss of food crops has not yet been observed. However, an increase in temperature, decrease in solar radiation, and increase in drought are reported to have adversely affected crop yields according to statistical analyses using past data. Nevertheless, it is unclear as to whether the observed changes in crop yield are caused by climate change because of the difficulty in clearly distinguishing the level of impact on the yield. Statistical models display a high correlation between the climatic factors, which are explanatory variables, and cannot fully consider the advancement of crop technology or the genetic developments in crop yields.

For horticultural crops, increased temperatures, reduced sunshine hours, and increased frequency of abnormal weather affect the yield and quality of fruits and vegetables. The fruit cultivation areas have gradually moved northward. Owing primarily to the rise in temperature in the southern area, highland cabbage and radish cultivation areas have continued to decrease to half of the original area and the growth period of citrus trees has gradually progressed to earlier periods because of the temperature rise in spring (February-April).

Meanwhile, rising temperatures tend to increase the incidence rates of pests, such as pepper phytophthora blight, pepper anthracnose, and onion white rot. In addition, the outbreak of overwintering/invasive pests has increased. Although the potato tuber moth [*Phthorimaea operculella* (Zeller)] was discovered to exist only in the southern region in the latter half of the 1970s, the habitat has moved northward, owing to the rise in average temperature (0.9°) during the recent investigation (2009-2012). This has resulted in considerable damage, even in the north-central area.

Regarding the occurrence of weeds, increases in exotic/invasive and herbicide-resistant weeds were observed. In a 1971 survey, 2013 herbicide-resistant weeds, including Echinochlora crus-galli and Monochoria vaginalis, were presented as the top priority weeds, which also included Rotala indica and Eleocharis acicularis. By 2013, the occurrence rates of perennial weeds were also increasing. Such phenomena could have been attributed to changes in cultivated crops, cultivation methods, and the use of herbicides, in addition to climate change.

5.3 Outlook of Impact

The suitable areas for each crop will gradually move northward. By the end of the 21st century, the productivity of rice, soybean, maize, potato, pepper, and Chinese cabbage will have decreased, whereas the onion yield will have increased (moderate agreement).
The outbreak patterns of pests and weeds will continue to change over time (substantial agreement).

To assess the impact of climate change on food crops, various controlled-environment experiments and simulation studies using crop growth models have been performed. The productivity of food crops, including rice, soybean, maize, and potato, except for the overwintering crops, will be maintained at a certain level or slightly higher until the mid-21st century. However, dramatic yield losses are expected by the end of the 21st century, such as 25% or more for rice, 10%-20% for maize, and 30% or more for summer potatoes (Figure 5.1). Meanwhile, controlled-environment experiments suggest opposite results: warmer winter accelerates the transition from the vegetative stage to the reproductive stage, which reduces the number of tillers and panicles, and high temperatures during the grain-filling period adversely affect the yield and quality of barley. An explanation of this discrepancy between the controlled-environment experiments and simulation studies would require additional studies, such as an examination of the biological mechanisms of warming stresses in barely controlled environment experiments. Such experiments would verify whether such a mechanism is well reflected in the crop growth model and facilitate a reassessment of the climate change impact using the validated crop growth models.

In the case of fruits, the suitable areas for apple, pear, grape, and "shiranuhi" mandarin will be reduced, whereas those for peach, sweet persimmon, and satsuma mandarin will be increased. Pertaining to vegetables, high-temperature stresses are expected in pepper and Chinese cabbage. The suitable areas for northern-type garlic have gradually disappeared, whereas those for southern-type garlic have increased. The onion yield is predicted to increase under high-temperature conditions.

The outbreak risk is projected to be reduced for

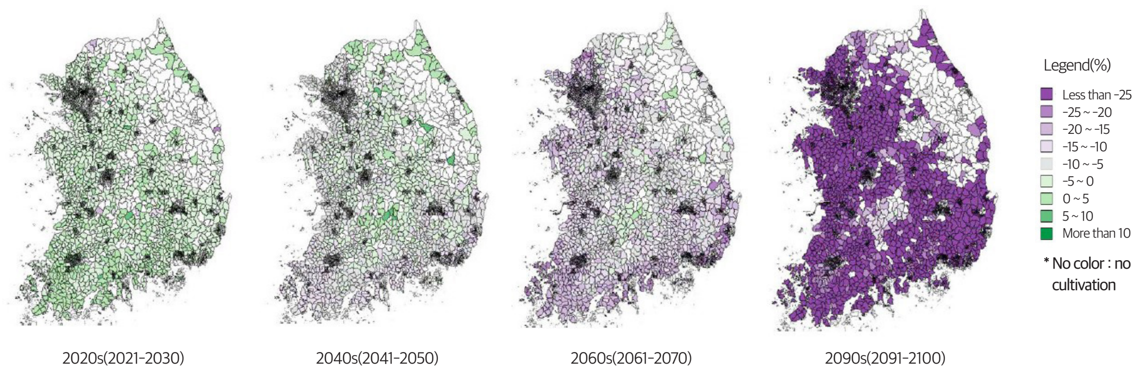

Figure 5.1 Change in the yield of mid-late maturing rice using the 1-km RCP scenario (Lee et. al, 2017).

some pests, such as *Riptortus clavatus* or *Halyomorpha halys*, whereas the opposite behavior is demonstrated for *Leptocorisa chinensis* and *Piezodorus hybneri* under climate change conditions. Thus, the pest outbreak patterns in the farmlands will be altered. In addition, the amount of pests generated throughout the year will increase with temperature. This may aggravate the pest problem in the future owing to increased outbreak of overwintering and exotic pests, such as *Lycorma delicatula*, as the minimum winter temperature rises.

Only a few studies about climate change impacts on weeds have been reported. However, invasive weeds, such as *Amaranthus viridis* and *Conyza bonariensis*, are expected to spread across the Korean peninsula; thus, an urgent need has been demonstrated to develop control methods for new weeds.

5.4 Primary Causes of Vulnerability

High temperatures during the heading stage and grain-filling stage of rice, tuber initiation stage of potato, initial stage of fruit coloring, and wintering period of fruit will adversely affect the yield and quality of crops (moderate agreement).

Climate change will alter the outbreak/growth pattern of crops/pests/weeds, virulence of plant pests, resistance of the host plants, and control efficacy of herbicides.

Food crops are vulnerable to high-temperature stresses at specific growth stages. For rice, poor grain filling under high temperatures is a primary problem; however, heat-induced sterility will be another significant issue under future climate conditions. For potato, the delay and inhibition of tuber development by high temperatures at the tuber initiation stage is a primary cause of vulnerability.

Examples of vulnerabilities in fruits are inferior coloring owing to high temperatures at the initial stage of fruit coloring and freezing/frost injury from the advanced phenology due to a warmer winter. Some studies evaluating cultivar differences in phenology in response to high temperatures have been performed to cope with the above-mentioned issues.

Under a future climate, the severity of pest damage will be determined by the synchronicity of the pest outbreak period and crop growth stage, in addition to the scale and frequency of the pest outbreak. In addition, the virulence of plant pests and resistance of the host plant will be affected by climate change.

There is a risk of vigorous weed growth climate change conditions, as problematic weeds in farmland often have excellent adaptability to the environment compared with that of crops. In some cases, herbicide efficacy might be decreased under climate change conditions. In addition, the phytotoxicity of herbicides on crops could be increased in some cases.

5.5 Adaptation Options

Climate change impact assessment should be improved by quantifying the responses of crop growth and pest/weed occurrence to environmental change and constructing agroecosystem models by integrating those quantified relationships. At the same time, adaptation strategies, such as cropping systems, cropping season implementation, crop management practices, pest/weed control technologies, and disaster-resistant varieties should be developed to minimize the environmental stresses that have been qualitatively assessed (substantial agreement).

Adaptation options related to food crops include the development of site-specific cropping systems, crop management practices, and disaster-resistant varieties that are suitable under climate change conditions. Recently, heat-tolerant rice and potato varieties have been developed, and these tolerant varieties are expected to gradually replace the current more susceptible varieties.

Results from studies addressing the impact of climate change on crops continue to be published, involving environmentally controlled crop experiments and simulations using a crop growth model. However, quantitative studies on the mechanisms by which environmental stress cause damage to crops have been demonstrated to be inadequate. As such, many environmental equations, used without verification, are included in the crop growth models in Korea. Improvements and verifications of these environmental equations in crop growth models must take place to perform a reliable climate change impact assessment.

Adaptation options to reduce the damage to horticultural crops caused by high temperatures may include a shift in the cultivation area, intensive irrigation, root-zone cooling with groundwater, and breeding of disaster-resistant varieties.

Adaptation options for pests include the construction of a national pest monitoring and forecasting system, considering an increased number of pest species and regions, selection of pesticides that are suitable for climate change conditions, and development of pest-resistant varieties. Recently, rice varieties with resistance to multiple diseases have been developed to alleviate pest problems.

In the case of weeds, most studies have focused on herbicide-resistant weeds, rather than climate change impact assessment. Monitoring and forecasting systems focused on the outbreak of weeds would have to be developed to provide adaptation options. It would be necessary to adjust the herbicide treatment pattern based on the change in weed outbreak pattern. In addition, for pests and weeds, the impact of weather variables on the occurrence of pests and weeds should be quantified using monitoring data and environmental experiment data. Afterward, the relationships need to be combined with crop growth models to construct agroecosystem models, which may be used to simulate the impact of climate change on the entire agroecosystem. Meanwhile, adaptation strategies, such as cropping systems, cropping season establishment, crop management practices, pest/weed control technologies, and disaster-resistant varieties, should be developed to minimize the damage from environmental stresses.

6. Ocean and Fisheries

6.1 Introduction

The ocean plays the role of climate controller within the earth system by absorbing and redistributing the carbon dioxide and heat in the atmosphere. Meanwhile, adaptation strategies, such as cropping systems, cropping season implementation, crop management practices, pest/weed control technologies, and disaster-resistant varieties, should be developed to minimize damage from environmental stresses. Under such limited circumstances, the state of change in the recently studied marine environment of Korean waters has been summarized, and the outlook of the impact has been described. An explanation of the vulnerability assessment methodology is included by referring to the literature published before 2014.

6.2 Observed Impacts

In Korean waters, the sea surface temperature rise and ocean acidification are progressing faster than the global average (solid agreement), and the surface salinity exhibits a decreasing trend (intermediate agreement). The rate of surface water temperature rise is higher than the global average (solid agreement), and the abnormal high water temperature phenomenon has been recently intensified (limited agreement). The rise in sea level at the coast of Jeju Island and the East Sea is relatively large (intermediate agreement).
As the nitrate concentration has been demonstrated to have been somewhat increased in the seas surrounding Korea, it is predicted that there will be a change in the primary productivity (intermediate agreement).
The amount of fish catch in each sea area exhibits a gradually decreasing trend (limited agreement), and the sea area suitable for the spatial distribution and aquaculture of fish species is migrating toward the north with increasing water temperature (solid agreement).

For the past 49 years (1968-2016), the sea surface temperature rise in Korean waters has been 1.23 °C, showing a high level of approximately 2.6 times that of the rise in global surface temperature. The tendency of water temperature rise is shown to follow the order of East Sea, West Sea, and South Sea. In addition, the higher rate of water temperature rise from lower to higher latitudes and the water temperature rise in winter is shown to be 2-3 times higher than that in summer. Since 2016, abnormal marine heat waves have continuously appeared in summer, and the average monthly water temperature at the time of marine heat waves has tended to be 1-4 °C higher than average.

The average rise in sea surface level of Korean waters over the past 30 years (1989-2018) is 2.97 mm/year. While a relatively high increasing trend was shown for Jeju Island and the East Sea, displaying a large difference in each region, a relatively low increasing trend is shown for the West Sea. However, there is a difference between the change in sea level observed from the tide stations and the satellite altimeter data.

The sea surface salinity exhibits a trend of gradual decrease, and the rate of sea surface salinity decrease in the West Sea and the South Sea was shown to be high in summer, which is determined to be due to fluctuations in the runoff of the Yangtze River. The

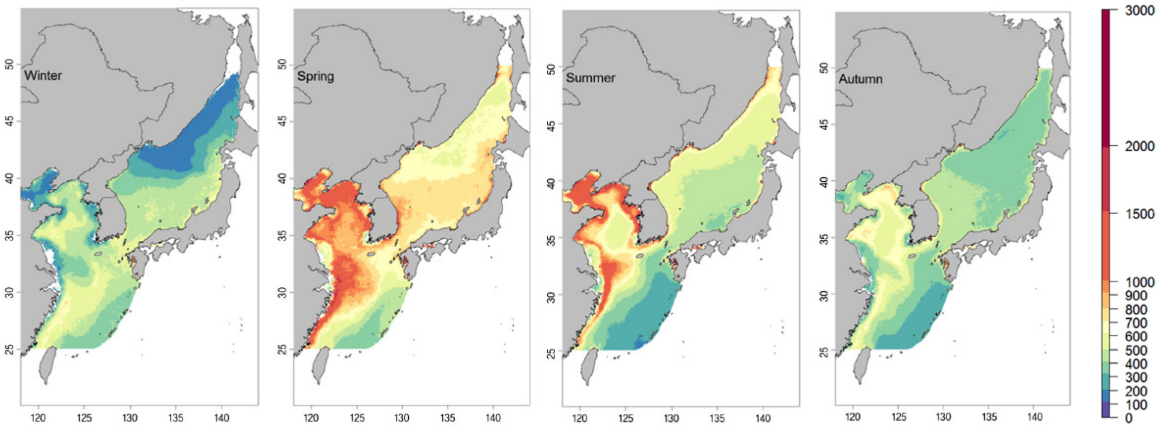

Figure 6.1 Annual primary productivity variation trend in the coasts surrounding Korea (1998-2014) (Ministry of Oceans and Fisheries, 2019).

partial pressure of carbon dioxide on the surface of the East Sea shows a high rate of increase compared with the global average, and the decrease in surface pH is much higher than that in other seas, indicating the rapid progression of ocean acidification.

Changes in the primary productivity of the waters surrounding Korea vary with sea area, and the occurrence of change is predicted to be caused by a significant increase in nitrate concentration, which has a direct impact on the change in productivity. From the perspective of the seasonal variation of primary productivity in the Korean waters, the variation was shown to be highest in the northern Yellow Sea, East China Sea, and southern waters of the East Sea (Figure 6.1).

The change in physical and chemical environment due to the oceanic regime shift causes changes throughout the entire marine ecosystem of the Korean waters, from plankton to fish, and such changes in the sea environment have an impact on the change in yield in addition to the distribution and species composition of the fishery resources. The total amount of fish catch in Korea's offshore and coastal fisheries follows a decreasing trend, totaling approximately 0.93 tons in 2017 from 1.52 tons in the 1980s, 1.37 tons in the 1990s, and 1.15 tons in the 2000s. For each sea area, the amount of fish catch is high, following the order of South Sea, East Sea, and West Sea.

The rise in water temperature causes a change in the spatial distribution of fish species and fishing grounds, including large fish types such as *Scomberomorus niphonius* and *Seriola quinqueradiata*, and is expected to move primarily toward the north. The shallow-sea culture yield continues to increase from 1 million tons in 2005 to more than 2 million tons in 2018. While seaweed aquaculture is gradually increasing, fish aquaculture exhibits a gradually decreasing trend. In addition, in the case of aquaculture target species such as *Patinopecten yessoensis*, the waters suitable for aquaculture exhibit a trend gradually moving toward the north. Meanwhile, the impact of climate change is analyzed as the primary cause of mass mortality.

6.3 Outlook of Impacts

The surface water temperature will rise at a far greater rate than the global average, and it is predicted that marine heat waves will occur more frequently (limited agreement). The reduction in surface pH, oxygen, and nutrients is expected to be severe (limited agreement).

If the rise in water temperature continues, the area where the red tide occurs is expected to gradually widen, as nutrient supply and primary production decrease owing to the enhanced ocean stratification in the future marine environment (intermediate agreement).

The sea surface temperature in the Korean waters is expected to rise by 2-6 °C by 2100, compared with today. In particular, the increase in water temperature was shown to be high, centered on the north-central area of the East Sea, and the waters to the north of the Yellow Sea. As this represents a level that is much higher than the prediction of the average rise in surface water temperature for the entire world, the change in water temperature until now was also shown to be high in Korea, and the water temperature rise is expected to continue to be high into the future.

The frequency, period, spatial range, and intensity of marine heat waves are expected to increase even more in the future global warming scenario. It is predicted that this phenomenon is expected to have a serious impact on marine organisms, fisheries, and ecosystems.

The future sea level rise in Korea is predicted to be 37.8-65 cm, which is similar to the outlook trend for the global average, with the sea level rise in the South Sea to be relatively significant and the sea level rise in the West Sea to be the lowest in comparison.

Throughout the globe, the decrease in surface pH will appear to be high in the Arctic Ocean, high-latitude Atlantic Ocean, and Pacific Ocean, and it was estimated that the fluctuation in seasonal variation and amplitude of the surface pH will be even greater in high-latitude areas.

The oxygen in the oceans was also predicted to undergo sudden changes in the future owing to physical and biogeochemical impacts, and it was concluded that the enhanced ocean stratification will have a significant impact on the reduction of nutrients near the sea surface.

With the progression of global warming, the supply of nutrients decreases, and primary production also decreases owing to the enhanced ocean stratification and weakened vertical mixing. It is expected that the ocean acidification and hypoxia phenomena will be more severe than that in the present, which will have various effects on the physiology/ecology at the population level, eventually leading to a decrease in biomass and species diversity.

Algal bloom, the most common harmful organism, along with large jellyfish, emerged throughout all coasts of Korea in an irregular cycle. The representative red tide algae, C. polykrikoides, has gradually widened since it first appeared in Jinhae Bay in the southern coast in 1982 and is known to cause considerable damage to aquaculture organisms.

6.4 Major Causes of Vulnerability

Along the southern coast of Korea, coastal fisheries were shown to be more vulnerable to climate change than offshore fisheries (moderate agreement).

In the case of aquaculture, marine seaweed, such as laver and sea mustard, was found to be the most vulnerable. Among the areas where marine seaweed aquaculture emerged, high vulnerability was shown, especially in the central region of the west coast (Seocheon) (intermediate agreement). This vulnerability is due to the high exposure to climate or high sensitivity of the aquaculture, combined with its low adaptability.

From the assessment of vulnerability of 20 major fisheries (14 offshore, 6 coastal) from the southern coast, vulnerability was shown to be vary significantly, depending on the level of climate exposure by business type according to the climate change scenario. With the vulnerability of coastal fisheries shown to be mainly higher than that of offshore fisheries in both the RCP 8.5 and RCP 4.5 scenarios, climate change adaptation measures for coastal fisheries are considered to be more urgently needed.

In the case of aquaculture, vulnerability assessment was performed by classifying each farming species by major aquaculture regions, targeting 14 farming species in Korea. Consequently, marine seaweed with significant climate exposure, such as laver and sea mustard, were found to be the most vulnerable. Among the areas that contain prominent aquaculture, the west coast area (Seocheon) exhibited vulnerability that was greatly affected by the damage, shown to be exceptionally high. To facilitate the supply from aquaculture of stable marine products, even in the climate change scenario, it is important to understand the mechanism adopted by the aquaculture, such that its exposure and sensitivity toward climate change might be reduced. Furthermore, measures to improve adaptation ability, such as the development of new farming species that can adapt to climate change, are necessary.

6.5 Adaptation Options

As a climate change adaptation option, the construction of real-time water temperature monitoring systems is expanded to contribute to the reduction of damage from marine heat waves (solid agreement). To manage the long-term rise in water temperature, varieties tolerant to high water temperature and new aquaculture technologies are developed to perform studies adapted to the actual site (intermediate agreement).

To handle the frequent occurrence of high and low water temperatures caused by climate change, a real-time fishing ground environmental monitoring network was constructed and operated by the National Fisheries Research & Development Institute. Through this network, real-time information regarding sea areas where aquacultures are abundant and water temperature damage is significant are provided to facilitate the effort to reduce the damage to fisheries, in addition to the issuance of alerts at high water temperatures and low water temperatures, which has been implemented since 2017.

In addition, the development of various aquaculture technologies and aquaculture species have been promoted to manage marine heat waves. The development of aquaculture varieties resistant to high water temperature is underway, targeting Paralichthys olivaceus, Haliotis discus, and Sebastes schlegeli, which are major commercial fish species. In addition, subtropical species, such as Seriola quinqueradiata, family Serranidae, and breams, are in plans for development as strategic aquaculture species in the future.

The development of technologies to deal with climate change, such as the bio-floc (aquaculture method using microorganisms) aquaculture system to determine the optimum growth conditions for each species and system management technology to extend the aquaculture species of sea fish, are in progress.

Adaptation activities in the field of fisheries, presented by the Food and Agriculture Organization of the United Nations (FAO), include the following: the reduction of land-based pollutants and development of fishing technology, protection and preservation of valuable fisheries, preparation of stable port and material mobilization sites, marine product disease risk management, stabilization of food products, establishment of financial mechanisms including insurance, development of new items that can be imported, linkage of national and local governmental policies and programs, implementation of a spatial plan, reduction of illegal fishing activity, and strengthening of international trade activities of marine products. It is clear that Korea also needs to support various industries to promote the climate change adaptation of fisheries.

7. Industry and Energy

7.1 Introduction

In Korea, an energy-guzzling and high greenhouse gas/contaminant emission economic structure has been prevalent owing to the existing large-scale centralized energy-supply policy, which supports economic growth. According to the energy statistical yearbook, 61.7% of Korea's total energy consumption comes from its industry sector (including raw materials), which is a very high standard compared with the OECD average of 31.3%. Unlike other countries that show a decreasing trend, the trend in Korea is one of continuous increase. For this reason, whereas the per capita energy consumption was approximately 50% of the OECD average in 1990, it increased to approximately 140% in 2017, exceeding that of Japan and Germany in 2001 and 2002, respectively, and the OECD average in 2008. Therefore, an energy-guzzling economic structure, similar to that of the United States, is predicted if the existing energy policy continues. This report seeks to determine the impacts of climate change and adaptation plans in Korea's industry and energy sectors by reviewing various literature and providing assistance in formulating policy objectives that correspond to the global reduction goals.

7.2 Observed Impact

Owing to the growth of the economy and population after the IPCC Fifth Assessment Report of 2014, the amount of artificial greenhouse gas emission from the era before the industrial age showed a continuously increasing trend. For this reason, abnormal temperatures, such as recent worldwide heat waves or cold waves, and natural disasters, such as typhoons, occur frequently.

Since the property damage from disasters can become severe in Korea, which exhibits an energy-guzzling economic structure, the advancement of vulnerability assessment in the industry section is taking place (moderate agreement).

This report seeks to identify the impacts of climate change and adaptation plans in Korea's industry and energy sectors through a review of various literature and provide assistance in formulating policy objectives that correspond to global reduction goals.

7.3 Outlook of Impact

The industry section is greatly affected by climate change, and climate change is causing damage throughout all aspects of society, including the industry sector. Nevertheless, there are still no climate change assessment tools specialized for the industry sector in Korea. Moreover, since studies on vulnerability assessment considering the actual industrial factors targeting industrial complexes are inadequate, climate change assessment methods and tools specialized for the industry sector are required.

In the energy field, studies regarding the increased use of energy due to heat waves and cold waves, impact of climate change on wind power generation, and risk factors such as destruction of power transmission and distribution infrastructures due to massive disasters, were conducted (substantial agreement).

The danger of heavy rainfall related to transportation facilities and buildings was shown to be high in the coastal areas of Gangwon, Chungcheongnam, and Jeolla Provinces. In the future, high-risk areas will have increased in the southern and inland areas of the Korean Peninsula under the climate change scenario.

The tour industry is greatly affected by severe weather, such as typhoons, storms, and localized heavy rainfall. The leisure industry, such as golf and ski resorts where visitors mainly perform outdoor activities, were shown to be the most vulnerable.

As a result of predicting the climate risks involving items of the mining/manufacturing and service industry sectors, 144 items, which is equivalent to 26.7% of the 539 mining/manufacturing industry items, and 64 business types, equivalent to 28.9% of the 229 service business types, experienced significant variation in the amount of sales and management performance, depending on the temperature conditions.

In the energy sector, research on the increased use of energy due to the presence of heat/cold waves, the impact of climate change on wind power generation, and risk factors such as the destruction of power transmission/reception infrastructures following major disasters, was mainly performed (Figure 7.1).

In terms of electricity consumption, a seasonal comparison between the increasing trend of cooling electricity consumption in summer and the decreasing trend of heating electricity consumption in winter due to global warming was clearly exhibited. From the mid-2020s, cooling electricity consumption in summer is expected to exceed heating electricity consumption in

Infrastructure Type	Temperature Change	Reduced Precipitation	Heavy Rainfall	Increased storm frequency	Increased gale frequency	Sea level rise
Waterworks	◎	◎	◎	◎	△	△
Sewage	△	◎	◎	◎	△	◎
Electricity	◎	◎	◎	◎	◎	△
Oil/gas	◎	△	◎	◎	△	◎
Telecommunication	◎	△	◎	◎	◎	◎
Wireless network	△	△	△	△	◎	△
Road	◎	△	◎	◎	△	△
Railroad	◎	△	◎	◎	△	△
Bridge	◎	△	◎	◎	◎	△
tunnel	△	◎	◎	◎	△	◎

Figure 7.1 Impact on key industries due to climate change (Kang, Hee-jeong, 2014). △: minor risk, ◎: clear risk

winter. The carbon fuel consumption for winter heating exhibits a trend of continuous decrease due to global warming.

7.4 Primary Causes of Vulnerability

Climate change may act as a risk factor to deter industrial growth. Among the various risk types, it was shown that the "regulatory risks" due to international treaties and policies and "risks due to reputation," in which the customer evaluation of a company's activities has an impact on the reliability and brand value of that company, are relatively significant. In addition, "physical risks" and "risks due to lawsuit" from climate change are prevalent as well (substantial agreement).

While climate change is related to various types of company activities, it has a strong relationship with the physical/geographical space, productivity, R&D investment, and management strategy of the company. In addition, the impact of climate change has been shown to be revealed differently, depending on the company's location, and there were also cases of company relocation due to climate change.

The increasing occurrence of heat waves and high temperatures may have an impact on the fundamental industries of the region as well as company profits by hindering the labor productivity of workers. In addition, climate change policies can attract investment of company R&D, and the change in technology caused by such investments enables the accomplishment of environmental goals at a lower cost.

Owing to the assessment of vulnerability to climate change by industry, it was determined that finance, health, aviation, tour, oil refining, gas, and transportation of equipment industries all fall under the climate change danger zone.

Although the maximum risk type was shown to vary by industry, the greatest number of companies considered regulatory risk as the highest risk factor. Industries that accept physical risk as the most serious are the agriculture/fishery, insurance, health, and tour industries.

7.5 Adaptation Options

On the level of the central government, the establishment of a climate change adaptation policy was actively encouraged for public organizations and local public enterprises that manage/own public facilities. Such policies were predicted to have a significant impact in the event of climate change among organizations that are likely to be significantly affected by climate change. In the case of private companies, short-term plans are being constructed through the introduction of high-efficiency equipment or investment support of energy conservation facilities (moderate agreement).

While climate change also has an impact on the various management strategies of enterprises, enterprises can strategically use the response to climate change to increase the current and future value of the enterprise.

A climate change vulnerability assessment in the industry sector can determine how sensitive a company is to climate change impact and predict how well it would adapt to such an impact, while also preparing measures to apply to vulnerable parts.

Currently, the Ministry of Trade, Industry, and Energy and the Korea Energy Agency have developed "Climate Change Vulnerability Assessment Methodology in the Industry Section" to support the formulation of climate change adaptation measures for Korea's industry sector. In addition, the Ministry of Environment, Korea Environment Institute, and Korea Adaptation Center for Climate Change have promoted a consulting program for the creation of climate change adaptation policies targeting vulnerable business types through the development of the "CRAS program," in operation since 2016.

A cooling process is essential for nuclear/coal/gas power generation, hydroelectric power generation, and photovoltaic power generation. However, experiencing a setback in power production is a concern, because of the cooling water shortage caused by drought due to climate change, and it is estimated that the power production efficiency will be reduced as the temperature of the cooling water increases.

The setup of maximum electric power in response to high temperature and heat waves implies the necessity of constructing additional power plants to handle just the peak load. However, since the power plants in charge of just the peak load are required only in the summer peak period, the high maintenance cost per power generation volume unit is passed on to society. Therefore, it is necessary to consider electricity storage technologies that would minimize the economic risks caused by an increase in the maximum electric power due to climate change.

With the implementation of the Second National Climate Change Adaptation Policy (2016-2020) in 2016, 20 central government ministries, 24 public organizations, and 24 local public enterprises that manage/own social infrastructure facilities were used to voluntarily formulate climate change adaptation policies and report to the Ministry of Environment. However, private companies are still unable to escape the need for conventional greenhouse gas reduction activities, such as the introduction of high-efficiency equipment or investment support of energy conservation facilities. Even now, the government must prepare institutional strategies and seek appropriate support plans to implement them to propagate the implementation of climate change adaptation policies to the private sector.

8. Health

8.1 Introduction

The impact of climate change on health depends on the regional physical environment and vulnerability of the social structure. In Korea, the possibility of global warming and abnormal weather due to climate change is increasing. There is a concern of damage to public health based on the existence of population groups with low ability to adapt to socioeconomic changes, leading to the predictions of an aging population, increase in single households, and income polarization. Therefore, an effort to identify mid- and long-term alternatives to provide fundamental solutions is necessary in addition to the preparation of measures to reduce the risks to health from climate change. This chapter addresses the domestic health impact, outlook, causes of vulnerability, and related national policies.

8.2 Observed Impact

The relationship between climatic factors and the impact on health due to heat waves (substantial agreement), meteorological disasters (substantial agreement), and air quality issues (moderate agreement), in addition to insect/rodent-mediated infectious diseases (moderate agreement) and waterborne/foodborne infectious diseases (moderate agreement), have been verified.

Regarding the impact on health due to heat waves, heat-related diseases such as heat stroke, heat exhaustion, and thermal fatigue occur more frequently during heat waves. In addition, kidney diseases, cardio-cerebrovascular diseases, and mental disorders were shown to have a strong relationship with heat waves. Reduced labor productivity occurs owing to the outbreak of heat-related disease patients and exhaustion, and this may lead to industrial damage. In addition, an increase in air pollutants and ozone concentration from continued high temperatures causes an increase in respiratory disease patients or decreased immune function. This may have an impact on the environment, industry, and all social infrastructures, in addition to health.

The impact on health due to heat waves depends on socioeconomic status, such as gender, age, health condition, income, education, and regional characteristics (e.g., urban/rural area, building density, geographical characteristics, and population density). In Korea, the risk of death increases by 5% for every 1 °C increase in temperature, and the risk of death during a heat wave period increases by 8% compared with other periods. In addition, the rise in temperature increases the risk of death in the population aged 75 years or older and in chronic disease patients.

Climate change may affect health by increasing the concentrations of ozone and particulate matter. Research related to its impact on fine dust and cardiovascular/respiratory diseases have been actively conducted. Recently, studies have claimed that even cerebral nerve diseases, such as kidney diseases, mental disorders, dementia, and cerebral infarction, are related to air pollution. The earlier occurrence of pollen blooming due to climate change and the increase in the blooming period of flowers cause an increase in the concentration of substances that cause allergies (Figure 8.1).

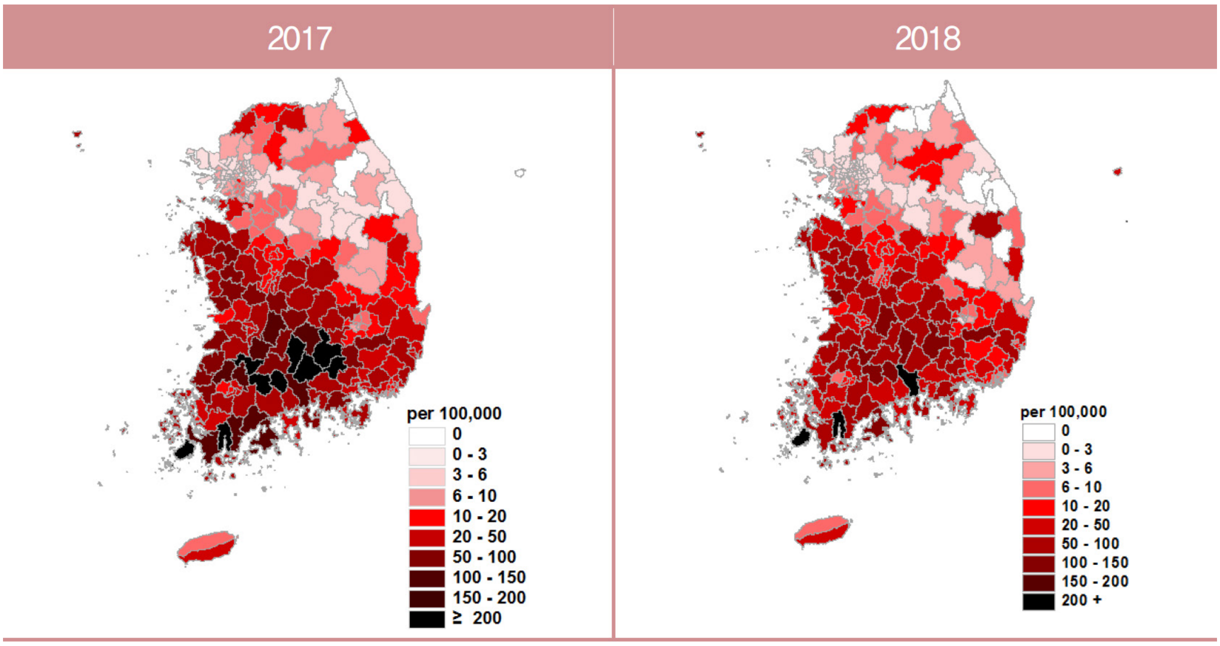

Figure 8.1 Incidence of Tsutsugosis per population of 100,000 by region (Korea Centers for Disease Control and Prevention, 2019).

The increased distribution of vectors and increase in density are closely affected by climatic factors, such as temperature, rainfall, and humidity. The outbreak of scrub typhus disease, a tick-borne infectious disease, has a close relationship with temperature. The population of adult mosquitoes has been shown to increase by 27% as the average daily temperature or maximum temperature rises by 1 ℃; furthermore, relative humidity and rainfall also showed a correlation.

Waterborne/foodborne infectious diseases exhibited a high positive correlation with the average temperature, and it was shown that the Vibrio infection was high during periods of increased temperature, rainfall, and flooding. The average outbreak of waterborne/foodborne infectious diseases will increase if the temperature rises by 1 ℃. It was shown that the number of outbreaks of food poisoning caused by Salmonella, Vibrio parahaemolyticus, and Staphylococcus aureus increased by 47.8%, 19.2%, and 5.1%, respectively, with an increase in temperature of 1 ℃.

8.3 Outlook of Impact

The future burden of deaths caused by heat-related diseases due to climate change (substantial agreement), risks due to the meteorological disasters such as typhoons, heat waves, and heavy snow (substantial agreement), allergic diseases (moderate agreement), mediated infectious diseases such as scrub typhus disease and malaria (moderate agreement), and waterborne/foodborne infectious diseases such as food poisoning (moderate agreement) will increase with time.

The number of heat wave days in Korea is predicted to increase by a huge margin, from the current value of 10.1 days per year to 35.5 days in the latter half of the 21st century (RCP 8.5). While an estimation of casualties due to heat waves must consider both climatic and non-climatic factors, including heat wave outbreaks, changes in population structure, health, and heat wave adaptation standards of the future, it seems that deaths due to heat-related diseases cannot be avoided because of climatic factors.

Ecosystem disturbance due to climate change is predicted to have a tremendous impact on the disease outbreak pattern of insect/rodent-mediated infectious diseases. The outbreak of scrub typhus disease is expected to increase owing to climate change, and there is also a possibility of an increase in the number of patients suffering from severe fever with thrombocytopenia syndrome (SFTS) and tertian malaria.

In addition, if the temperature rises as a consequence of global warming, there is the possibility of inflow and spread of dengue, Chikungunya fever, and Zika virus, even in Korea. This is because the habitat conditions of *Aedes aegypti*, which inhabits tropical zones, will be formed in such a case. The conditions under which adult *Aedes albopictus* can survive, even in winter, may also arise.

It is estimated that the number of food poising outbreak cases will increase by up to 42% in 2090 compared with 2002-2012, and the number of diarrhea patients will also increase owing to the rise in temperature.

8.4 Primary Causes of Vulnerability

Increase in casualties due to heat wave (substantial agreement), population groups vulnerable to meteorological disasters (substantial agreement), and adverse effects on health due to air pollution and allergies (moderate agreement) were shown to be more prevalent in people aged 65 or older, people with chronic disease, and population groups with low socioeconomic status. While scrub typhus disease, tertian malaria, salmonella, Campylobacter infection, and Vibrio infection increase owing to an increase in temperature, scrub typhus disease and SFTS were shown to be higher in the elderly population aged 65 or older (moderate agreement).

Casualties due to heat waves were shown to increase, with the increase intensity and duration as well as the earlier onset of heat waves in summer. In particular, it was demonstrated that elderly women, aged 65 or older; people in the low education level group; and people with chronic diseases, such as cardio-cerebrovascular diseases or respiratory disease, were more vulnerable to risk from heat waves. According to the RCP 8.5 scenario, Daegu is expected to be the most vulnerable to heat waves in Korea in the 2040s. In addition, the frequency of days in which the daily maximum temperature is higher than 33 °C, the daily relative humidity, and proportion of basic livelihood security recipients and population aged 65 or older had a significant impact on the vulnerability toward heat waves.

Although the impact of climate factors is greatest in the case of vulnerability of climate change to meteorological disasters, urban development and environmental factors such as the healthcare system, development of lowland areas, green coverage area, slopes within forest, and stream improvement rate, also contribute to the increase in vulnerability. Seoul, Gangwon-do, and Gyeongsangnam-do were found to be vulnerable to flooding, and the Gangwon-do, Chungcheongbuk-do, Jeollabuk-do, and Gyeongsangnam-do areas along the Baekdudaegan mountain range were vulnerable to heavy snow. Regarding the mortality rate due to meteorological disasters, it was shown that the lifestyles of small/medium sized cities, rural areas, coastal areas, and population with low socioeconomic status were more vulnerable to weather than large cities.

The impact due to the increased concentration of air pollutants was shown to depend on age, underlying disease, genetic predisposition, socioeconomic status such as education/income level, and region. Since the air pollutants absorbed into the body induce systemic inflammation, causing or aggravating cardiovascular diseases, people with cardiovascular or respiratory diseases are vulnerable. Most of all, there are many cases in which elderly people have such underlying diseases. They are more vulnerable owing to poor immunity or other resistances, such as a reduced ability to expel particulate matter from the body or eliminate toxicity. Allergic rhinitis and asthma are aggravated in the spring and winter. Meanwhile, infants with poor immune function are also vulnerable to allergic disorders.

Insect/rodent-mediated infectious diseases mainly broke out in the population aged 65 years or older living in rural areas with a high frequency of contact. Other than the time periods in which vectors are active, these diseases are also related to the social factors caused by autumnal work and outdoor activities due to harvest period or visits to ancestral graves. The risk of malaria increased owing to the rise in temperature, and the elderly group with a high frequency of contacting vectors in Jeju Island was vulnerable to SFTS.

The incidence rate of diarrheal diseases, including salmonella, Campylobacter infection, and Vibrio infection showed a high correlation with the average temperature. In particular, salmonella, which is a food poisoning bacterium, pathogenic coliform bacillus, and Campylobacter exhibit high separation rates during summer with high temperature and humidity. In this scenario, the incidence rate of food poisoning was shown to be high.

8.5 Adaptation Options

For the health adaptation measures on climate change, related systems were operating and the instructions were being publicized using various types of media in order to reduce the adverse effect on health that has impact on the vulnerable groups and the entire nation (substantial agreement).

In the Second National Climate Change Adaptation Policy, introduction of long-term forecasts on abnormal climate, improvement of environmental forecasts on particulate matter and ozone, development of a system to monitor heat-related diseases and cold-related illnesses caused by heat waves and cold waves, operation of a 24-hour emergency medical care situation room for disasters to cope with meteorological disasters and operation of waterborne/foodborne infectious disease monitoring systems have been prepared as health-related policies.

Since 2016, the Korea Centers for Disease Control and Prevention, Korea Meteorological Administration, Ministry of Public Safety and Security, and Coal Bank started a campaign to prevent the damage of groups vulnerable to heat waves. Instructions on meteorological disasters, such as floods, typhoons, heavy snow, yellow dust, earthquakes, and tidal waves, are sent via TV or text messages. In the National Disaster Safety Portal, information on topics such as wind/water disaster insurance, disaster information, and mental counseling on disasters, are included. Location information of related facilities, such as outdoor escape sites for earthquakes or cooling centers, can also be found on the map.

In addition, a general monitoring system of vectorborne diseases and the VibrioNet monitoring system, which involves monitoring programs for malaria and vector mosquitoes of Japanese encephalitis virus, disease infection fact-finding survey monitoring of vector insects, avian influenza examination of wild animals, forest pest monitoring with possibility of increased outbreak due to climate change, and monitoring of vectors flowing from overseas by the National Quarantine Station, have been implemented.

Most of all, the National Council on Climate and Air Quality was established by Presidential Decree (No. 29713) in April 2019 to address the problem of particulate matter. It is being operated with the goal of preparing the basis for implementing particulate matter policies through the direct participation of citizens. Since it is difficult to solve or mitigate this problem simply by publicizing the practical method of refraining from going out during forecasts of harmful levels of particulate matter, international forums have been enabled along with announcements of national policy proposals with the goal of forming a network with various countries in northeast Asia to solving this problem. The aim is to obtain advice from experts and domestic/foreign erudite scholars in how to enable science/technology and international cooperation to reduce particulate matter generation and prevent damage from its effects.

9. Human Settlements and Welfare

9.1 Introduction

As the frequency and intensity of abnormal weather conditions such as heat waves, tropical nights, heavy rainfall, and cold waves have increased, damage related to human settlements and welfare due to climate change have also increased. This issue of urban dwelling and vulnerable populations involves severe problems in Korea due to its aging society, growing inequality, and urbanization.

Because of the impact of climate change, vulnerabilities and risks vary depending on individual, geographical, and social characteristics; thus, policies and studies considering these factors are necessary, and vulnerable groups with low adaptation capacity need to be considered.

While the plan to cope with climate change at the city level can be classified into reduction and adaptation, these two classifications are highly correlated. Rather than an assessment through classification, studies and policies have arranged adaptation factors, and measures related to the reduction have been derived.

9.2 Observed Impact

Human settlements can be classified into urban and rural areas. Although urban areas are directly impacted by climate change through the use of energy, they also make the greatest contribution to climate change (substantial agreement). Rural villages exhibit a high possibility of suffering from huge damage due to climate change because of the impending decrease in population, increase in aged population, decrease in income, and low standard of infrastructures (substantial agreement). In the welfare sector, Korea is promoting the policies to consolidate the management of specific vulnerable groups and areas (substantial agreement).

Although Korea's urban area is merely 15.9% of the national territory as of 2018, urbanization, which indicates the ratio of the population living in urban areas to the total population, has reached 91.8%. Owing to the increase in direct energy consumption in urban areas, total air pollutants have increased by 6.4% from 1999 to 2007. The energy consumption (2.34 billion toe, nationwide), which is deeply related to carbon emission, was shown to be high, following the order of Jeollanam-do (18.15%), Gyeonggi-do (12.54%), Ulsan (12.17%), Gyeongsanguk-do (9%) and Seoul (6.41%) based on the 2017 results.

The number of farmhouses and their population in Korea is gradually decreasing, and the proportion of the population aged 70 or older is 38.4%, representing an increase of 6.7% from 2010. This has an impact on the average farmhouse income because of the increased percentage of farmhouses containing elderly persons with relatively low income. Owing to the various types of farming policies for young people and the recent increase in multicultural families, the birth rate has increased in some areas. This is affected by the high probability of moving to the city during the growth process of a child in the family. In most other rural areas, population outflow, aging, and economic decline are simultaneously exhibited, owing to the hollowing-out phenomenon, and vacant sites and vacant houses of rural villages are increasing. Based on 2017 results, 36.6% of all administrative rural village (Ri) districts cannot obtain the water supplied through the ordinary water supply. This area is expected to be vulnerable to climate change, as 51.2% of the area does not have a sewage treatment facility and 99% does not have city gas installed. While a national policy has been promoted to improve the living environment of deteriorated rural areas, the result of this has been inadequate. Although a policy toward consolidating management on specific vulnerable groups and regions was presented in the Second National Climate Change Adaptation Policy, unlike other living infrastructure targeting the entire nation, the drastically increased welfare demand in the public sector cannot be satisfied because of the sudden increase in the aged population and the weakened functions of the family.

9.3 Outlook of Impact

In urban areas, population decrease in some areas is expected. To mitigate the impact of climate change of urban areas, a smart city and urban regeneration new deal project is introduced (moderate agreement). Although the population of some rural villages can be increased, the population in the Guns (counties) is expected to decrease, with a population of less than 60,000 (moderate agreement). Although the standard infrastructure is under investigation, the impact of climate change was demonstrated to be high owing to the increased deterioration level and the lack of infrastructure (substantial agreement). The damage due to climate change are also closely related to social factors, such as space, income, and age group (substantial agreement).

The population living in urban areas is expected to gradually increase. While the population of special self-governing districts in 2030 will decrease by 11.8%, compared with that in 2010, the population is expected to increase by approximately 1.6%, 22.5%, and 2.7% in other urban areas. As the deterioration of urban areas has progressed, the Special Act on the Revitalization and Support of Urban Regeneration was legislated, and the urban regeneration new deal project has been underway since 2017. In addition, the development of the smart city is in progress to solve urban problems. Since deteriorated buildings in urban areas have low energy efficiency and can be greatly affected by climate change, it is expected that the impact of climate change can be reduced through policy-based projects, such as regeneration projects or smart cities.

In the case of rural villages, the population of urban-rural complex cities in 2030 will increase by 59.6% compared with 2010. Although an increase of 26.7% was predicted even in Guns (counties) with a population of more than 60,000, the population will decrease by approximately 33.3% in these areas. In relation to the infrastructure directly exposed to the impact of climate change, the government is investigating the status of housing infrastructure in rural and fishing villages. Decreased efficiency of heating/cooling in homes, inadequate water/sewage facilities, deterioration of homes, and lack of public transportation were shown as vulnerable factors.

Damage due to climate change is also closely related to social factors such as space, income, and age group. Since there is vulnerability to the accessibility of low-priced energy in the case of rural and fishing villages, vulnerabilities due to climate change can become higher than in urban areas. Even in the capital area, the frequency of damage in the low-income group was shown to be high. In addition, elderly people in the age group, children, low-income residents, and cardiovascular disorder patients were shown to be vulnerable.

9.4 Primary Causes of Vulnerability

In urban areas, the risk of climate change exhibits an increasing trend due to flood, lack of water resources, and the heat island phenomenon. To assess the vulnerability level quantitatively, an index-based assessment method is widely used (substantial agreement). In the rural villages, the vulnerability from climate change is increasing due to the deteriorated housing and infrastructures, and the government is conducting various surveys to identify such conditions (substantial agreement). The groups vulnerable to climate change can be classified as biologically/socioeconomically vulnerable, residents of a vulnerable area, and residents in the vicinity of a vulnerable area (moderate agreement). For these people, the vulnerability increases owing to deteriorated housing facilities and low energy efficiency (moderate agreement).

While the risk of climate change in urban areas varies depending on the region, the causes can be classified as flood, lack of water resources, and heat island phenomenon. To analyze such risks, methods such as vulnerability assessment of urban air pollution or vulnerability assessment of high temperature due to the components of the dwelling area are performed.

The housing facilities left unattended in deteriorated rural villages with low accessibility increased. To manage these facilities, the Rural Development Administration conducts a rural life index survey to identify and analyze the conditions of rural life. The proportion of households that fell short of the minimum living standard was found to be high in rural and fishing villages, with such conditions serving as the primary cause of vulnerability to climate change.

Table 9.1 Status of residential infrastructure in rural areas in 2015 (Agricultural Forestry and Fisheries Census, Statistics Korea), (Jung et al., 2018).

Types		Administrative repairs (% of total administrative repairs, %)
waterworks	Waterworks	23,342 (63.4%)
	Small-scale water-supply system	12,174 (33.1%)
	Private waterworks	881 (0.2%)
	None	395 (0.1%)
Waste water treatment	Public Sewage treatment	13,974 (38.0%)
	Village sewage treatment	3,982 (10.8%)
	None	18,836 (51.2%)
Gas	Installed	3,601 (1.0%)
	Uninstalled	33,191 (99.0%)
Total administrative account		36,792

The groups vulnerable to climate change can be classified as biologically/socioeconomically vulnerable, residents of vulnerable areas, and residents in the vicinity of vulnerable areas. The damage due to climate change is shown to be high in the vulnerable group, and there is a high possibility of increases in repair costs and health problems due to deteriorated housing facilities and low energy efficiency. In addition, an effort is necessary to diagnose and improve the indoor environment for households that are vulnerable to climate change.

9.5 Adaptation Options

For climate change adaptation, smart green cities and the formation of infrastructure has been attempted in urban areas using technical aspects (moderate agreement); meanwhile, climate change adaptation in rural villages is promoted through the introduction of welfare policies targeting old petty farmhouses (moderate agreement). In addition, programs to improve the ability to adapt to climate change are promoted, targeting groups vulnerable to climate change (moderate agreement).

To improve the urban climate change adaptation and climate elasticity, the characteristics and potential impacts of major meteorological disasters are analyzed. In addition, spatial planning and design, such as that of smart green cities or the formation of green infrastructure, are implemented. In rural villages, reduction of the tax burden and various welfare systems are introduced targeting old petty farmhouses to increase the income of small old farms in an effort to improve income inequality caused by the aging of the society.

For groups that are vulnerable to climate change, various programs have been presented in the Second National Climate Change Adaptation Policy. Improvements in the housing environment, winter snow-removing operations, improvement projects in vulnerable areas, and maintenance projects in risky areas are included in these programs. Since vulnerable groups can be more sensitive to the impact of climate change than ordinary people, it is necessary to introduce factors to mitigate the impact of climate when planning the outdoor space.

10. Adaptation Measures and Plans

10.1 Introduction

The climate change adaptation policy is a five-year unit action plan established by the nation and the local government to reduce the damages and impacts caused by climate change as well as to take advantage of an opportunity to improve adaptation ability. In 2010, the first legal plan called the National Climate Change Adaptation Policy (2011-2015) was set up under the supervision of the Ministry of Environment. In December 2012, the legal basis for the establishment and enforcement of adaptation measures for local governments was prepared starting in 2015. This report contains research details that provide scientific information on the national level required for establishing national and local government adaptation policies. This involves providing training programs and services for decision-making, conducting a climate change impact assessment and awareness survey, and governance.

10.2 Setup of Climate Change Adaptation Policy

In accordance with Article 48 of the Framework Act on Low Carbon and Green Growth and Article 38 of the Enforcement Decree of the Act, the nation, metropolitan cities, and lower-level governments are set to improve the implementation ability of policies by checking/assessing the implementation each year after the climate change adaptation policies have been arranged (substantial agreement).

In the Second National Climate Change Adaptation Policy, the performance and limitations of existing policies were evaluated by each sector. Mid/long-term and short-term visions and objectives were presented through differentiation, and the policy considering the co-benefit effect was included in the consideration of the reduction of and adaptation to climate change. In addition, the execution ability of the policy was secured by preparing inspection/feedback systems for adaptation policy assessment and climate change impact monitoring through the consolidation of the execution/inspection system. The Second Adaptation Plan attempted to accomplish the goal of "reducing the risks due to climate change and the realization of opportunities" through a vision of "building a society where people are happy and safe through the climate change adaptation." Adaptation principles were aligned with sustainable development principles in the consideration of vulnerable groups, use of scientific evidence and technology as a basis for decision-making, securing of the connection with existing policies to create an integrated synergy, and encouragement of the participation of interested parties.

There were differences in the types of scientific material related to climate change used by each local government, and the differences were evident in the process and methods of prioritizing important sectors through data and gathering opinions from interested parties. In the detailed implementation plan on the climate change adaptation measures of most local governments, meteorological data related to climate change provided by the Korea Meteorological Administration were used, and the RCP scenario was applied to the climate change outlook section. Most local governments have performed a vulnerability assessment using the vulnerability assessment tool provided by the Ministry of Environment.

However, each local government exhibits limitations in providing sufficient adaptation measures: 1) inadequate execution assessment system for securing consistency with the upper plan and promoting a detailed implementation plan, 2) lack of customized climate environment data for each region, 3) weak systematic base of ordinance or budget, 4) inadequate system for the exchange of information such as sharing duties between cities/provinces and systematic performance management, 5) difficulty in managing the program due to the similarity between detailed programs, 6) and

Table 10.1 Comprehensive Analysis Method for Selecting Priority by Each Lower Level Local Governments (Hyun, Jung Hee, et al. 2019).

Local Government	Vulnerability Assessment	Citizen Perception Survey	Civil Servant Perception Survey	Past Impact Assessment	Expert's Assessment	Other
Gwanak-gu (Seoul)	80%		20%			
Dalseong-gun (Daegu)	50%	30%	20%			
Namdong-gu (Incheon)	√*	√	√	√		
Dong-gu (Daegu)	√				√	√
Seo-gu (Daejeon)	√			√	√	√
Dong-gu (Ulsan)	√	√	√	√	√	
Pocheon-si (Gyeonggi-do)	20%	30%	30%	20%		
Taebaek-si (Gangwon-do)	√	√	√	√	√	√
Hwacheon-gun (Gangwon-do)	√	√	√	√	√	
Cheongju-si (Chungcheongbuk-do)	√	√	√	√		
Goesan-gun (Chungcheongbuk-do)	20%	25%	25%	10%		20%
Asan-si (Chungcheongnam-do)	√	√	√			
Yesan-gun (Chungcheongnam-do)	20%	30%	30%	20%		
Gwangyang-si (Jeollabuk-do)	20%	30%	30%	20%		
Hwasun-gun (Jeollanam-do)	√	√	√	√		
Pohang-si (Gyeongsangbuk-do)	√	√	√	√	√	√
Yeongyang-gun (Gyeongsangbuk-do)	√	√			√	√
Gimhae-si (Gyeongsangnam-do)	√	√	√			
Sancheong-gun (Gyeongsangnam-do)	√			√		

* If there is a number, it is the weighted value of evaluation item. √ was used as an evaluation item but the weighted value was not given.

absence of an execution evaluation system, such as the execution management assessment index. It is difficult to interpret the results due to the absence of a standardized methodology. In addition, the analysis is not connected to the selection of actually implemented projects (Table 10.1). Accordingly, the Ministry of Environment provides guidance for the successful setup and implementation of plans through support programs such as those training and consulting a targeted wide area and lower-level local governments through the Korea Adaptation Center for Climate Change since 2011.

10.3 Research on the Methodology to Set Up Climate Change Adaptation Policy

Through scientific methods that support adaptation policies, studies have contributed to the advancement of impact and vulnerability assessment, implementation of an adaptation perception survey, setup of a governance panel, assessment of policy, and establishment of priority. In addition, a feedback process was enabled through a performance inspection (substantial agreement).

For the advancement of climate change impact assessment, which is the most basic scientific data used to set up the adaptation policy, studies must be performed on the uncertainty of the outlook on the climate change impact, using various types of General Circulation Models (GCM) results and impact assessment methods along with standardized climate change scenario data processing. For the climate change impact and vulnerability assessment, a web-based vulnerability assessment tool to build a climate change adaptation plan, defined as functions of adaptation ability, has been available since 2014, such that lower-level local governments and other municipalities could utilize the vulnerability results on the RCP scenario to formulate the adaptation plan. In addition, since the existing scenario-based impact assessment is being changed to a risk assessment system, starting with the IPCC Fifth Assessment Report, it is necessary to construct a coping strategy by referring to this change.

In research on surveys of citizen perceptions of climate change, the general public and all interested parties are shown to consider adaptation and mitigation as more important in coping with climate change. In addition, since increasing the level of perception of the risks of climate change and their impact at the individual level influences actions related to adaptation/mitigation and voluntary actions, the perception and actions of various adaptation subjects must be considered for the successful implementation of the adaptation plan.

Along with minimizing the negative impact of climate change, adaptation to increase the coping ability of society is also important. Since the government is not the sole performer in exploring and solving major social problems, approaches and participation through governance, where various performers participate in the decision-making process, are necessary. When the adaptation plan of the region is arranged based on the mutual consent of various interested parties, including local residents, the acceptability of such an adaptation plan becomes higher, and the effectiveness of implementation also improves.

The first step in the effective implementation of climate change adaptation is to establish the priority of the adaptation policy and a decision of low-regret based on proactive principles. Although the qualitative evaluation method is used to derive priority within and between sections, research to derive the priority of implemented projects through quantitative analysis/assessment is also being performed.

To check the actual effects and derive performance over the mandatory period of the adaptation plan, revision/supplementation is performed through the inspection/assessment of implementation based on the detailed implementation plan and the feedback of policies on the assessment results. The examination of the implementation evaluation results of key projects verifies satisfactory implementation if more than 90% of the projects are evaluated as "excellent." In the case of projects whose implementation has been evaluated as "unsatisfactory", "lack of appropriateness on the plans related to climate change" or "low execution rate of budget" have been pointed out as the main reasons.

10.4 Considerations During the Setup of Climate Change Adaptation Policy

At the time of setting up the climate change adaptation policy, studies on the consideration of vulnerable groups, spatial planning with an emphasis on regional characteristics, and correlation between adaptation and reduction were performed, and the strategies to set up/develop the adaptation policy were also presented (moderate agreement).

Since the climate change impact for each region has the potential to cause greater damage to vulnerable groups with low physical and socioeconomic adaptation ability, preparation of policies considering the socioeconomic and environmental characteristics of the region is emphasized for the adaptation of the vulnerable group. In the climate change adaptation policies of local governments, services such as consolidating support systems in disaster prevention, direct damage management, or support of goods are included. However, greater consideration of more fundamental and mid/long-term adaptation is necessary.

Regionally customized adaptation policies are known to have high executability and impact. For the preparation of adaptation policies considering the types and status of the region, research based on spatial plans, such as the preparation of adaptation-type space management and evaluation of urban climate elasticity is implemented. In addition, since the energy consumption adaptation policy can reduce the effect of reduction policy, it is necessary to construct adaptation strategies and policies that consider common benefits through the connection between adaptation and reduction, such as building urban green infrastructure.

For the active execution of adaptation, concerns and opinions of local community stakeholders are crucial. It is necessary to secure the validity of various stakeholders through opinion gathering processes and participation opportunities. In addition, the active concern of the local government head is essential in the process of arranging adaptation policies for effective region-based responses. The ability to execute adaptation was improved through the organization of consulting bodies to supervise/manage the government-initiated operation of governance and execution of policies and reflect on the feedback system through the process of consultation and coordination between the central government, wide-area local government, and lower-level local government.

Finally, considering the international adaptation trend of the IPCC, research on decision-making for sustainable development would have to be actively promoted, considering the sustainability and impartiality of adaptation options or diagnosis of the scientific risks based on the regional characteristics.

Summary for Policymakers

Korean Climate Change Assessment Report 2020
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Published by Minister of Environment

Edited by Yoen Jin Bae, Hyun Joon Lee, Bong Woo Jung (MOE)
Hui-Cheul Jung (KEI)

Publication Date July, 2020

Government Complex-Sejong, 11, Doum 6-Ro, Sejong-si, 30103, Republic of Korea
T. +82-1577-8866 F. +82-44-201-6386 W. http://me.go.kr

ISBN 978-89-93652-60-4, 978-89-93652-57-4 (세트)
Registration Number 11-1480000-001692-01

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ISBN 978-89-93652-60-4
978-89-93652-57-4 (세트)