B－11 Assessment of Impacts, Adaptation and Vulnerability of Alpine-, Forest-, Agro-Ecosystems to Global Warming (Abstract of the Final Report)

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1. Introduction

IPCC pointed out that global warming due to human activity has proceeded and affected vulnerable snow/ice and flora and fauna, and it will cause serous damage to natural ecosystems and socio-economic systems[1)]. The extent and intensity of the impacts due to global warming is greatly dependent on sensitivity and adaptable capacity of ecosystems and socio-economic systems, but there has been little research so far. In recent years, many research reports identified the detected impacts of current going warming on natural flora and fauna as well as snow and ice.

2. Research Objective

This research project was originally designed to conduct impacts, adaptation, and vulnerability of various ecosystems in mainly Japan and partly Asian region, consisting the following 4 sub-research projects.

1) Comprehensive assessment of impacts, adaptation, and vulnerability of natural ecosystems
2) Assessment of global warming impacts on alpine ecosystems in Japan
3) Impacts, adaptation, and vulnerability of various forest ecosystems to global warming
-1 Sensitivity and future response of cold-temperate vegetation to snowfall fluctuation
-2 Sensitivity and future response of subtropical, warm-temperate and cool temperate forests to climate change
-3 Evaluation of the vulnerability of tropical ecosystems to global warming with the use of GIS-based forest-type categorization
-4 Estimation on vulnerability and adaptation of natural and man-made forests
4) Evaluation of vulnerability of agro-ecosystem to global warming

These 4 researches are closely linked through usage of common future climate scenarios as basic assumption of impacts and vulnerability evaluation, and the first

sub-project is designed to summarize the research results obtained by the other 3 research groups, and to integrate them into a series of impacts, adaptation, and vulnerability map of ecosystems.

3. Results and Discussion

3.1 Impacts, adaptation and vulnerability of natural ecosystem

In this research, we conducted the following 3 subtopics: (1) Development of spatially detailed climate scenarios for regional impacts assessment, (2) Development of adaptation for ecosystems to mitigate future serious impacts, and (3) Improvement of the natural ecosystem impacts models.

In terms of the first topics, a snowfall prediction model was developed and applied to Japanese weather observing site called AMeDAS. This model can predict daily snow fall event, and can be useful for evaluating global warming impacts on snow sensitive vegetation and adaptive capability of regional ecosystems. In addition to this, new regional climate prediction was available. The spatial resolution of this prediction is 20km in entire Japan.

In terms of second topics, we collected extensively papers and reports of adaptation, and summarized them and conceptualized an idea of adaptation of ecosystems to global warming.

In terms of third topics, we have revised the BIOME3/Japan model which was developed in the previous research project. This model is categorized into a geographical model and geochemical model, so we can use this model for prediction of vegetation impacts of global warming and its adaptation strategies.

3.2 Impacts on alpine Vegetation

The object of this subproject was to predict vulnerable sites or areas in Japanese alpine zone based on global warming local scenarios in Japan (mesh size; 10km×10km), and then to discuss adaptation options to global warming impacts. we conducted research on following themes; (1) disappearance of alpine vegetation establishing in Japanese national parks (**Figure 1**), (2) changes in warmth index at conservation area for *Callianthemum hondense,* which is a relic and endangered plant species, and climatic factor discriminating between short herbaceous fields where *C. hondense* are growing and tall herbaceous fields which is at lower position than that of short herbaceous field, (3) monthly mean temperatures at upper limits of ranges of *Plantago asiatica,* which is known to go up from low land to mountain areas by human movement, along 13 hiking roads in Hakusan National Park and at other Japanese mountains, and changes in height of upper limits of ranges of *P. asiatica*, (4) difference in vertical distributions of 3 animal species (short-tailed weasel, Japanese marten, red fox) along 2 hiking roads, between which there was a difference in number of hiker, in Hakusan National Park, (5) comparison of environmental tolerance traits and competitive traits between *Rhododendron brachycarpum* and *Rhododendron aureum.*, (6) annual change in area of

perennial snow patch "Senjagaike Sekkei" at Mt. Hakusanarea on early October, and relationships between the area of this snow patch and climatic date at Shiramine which is at foot of Mt. Hakusan, and then reduction of area of snow patch.

From these results, the alpine ecosystems in Japan are found to be very vulnerable to global warming. And the ecosystems will be influenced by direct human activity as well as by global warming. This means that entry of human into the alpine zone will increase effects of global warming on alpine ecosystems in Japan. Therefore, adaptation options in Japanese alpine zone will be need to be selected depend on utilization purpose of Japanese alpine zone.

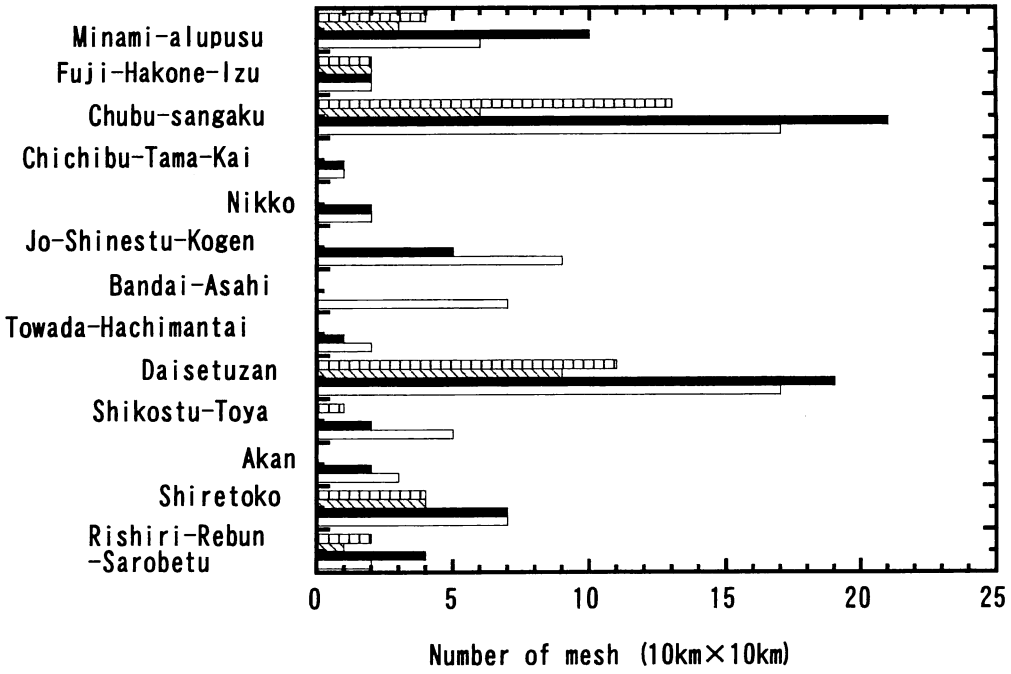

Figure 1 Changes in alpine vegetation establishing in Japanese national parks
Vertical axis shows name of national parks in Japan. Horizontal axis shows number of mesh classified as alpine vegetation (alpine-vegetation mesh). White columns shows alpine-vegetation mesh from a database "General reference system for natural environment (GREEN)" in the National Institute for Environmental Studies. Black columns show alpine-vegetation mesh calculated from present data in global warming local scenarios (GWLS). Columns in which oblique lines were shows alpine-vegetation mesh calculated from 2050's data in CCSR-GWLS. Columns in which vertical lines were shows alpine-vegetation mesh calculated from 2050's data in JP2-GWLS.

3.3 Estimation on vulnerability and adaptation of natural and man-made forests

(1) Impacts of global warming on cold-temperate vegetation: An evaluation of vulnerability to snow environment changes

The distribution of the cold-temperate vegetation in Honshu is seriously affected by winter snow cover. It is important to know the distribution of snow cover accurately in the mountain region. The objective of this study is to predict changes of snow environment in cold-temperate zone, and to evaluate the influence of changes in snow cover conditions on the cold-temperate vegetation under global warming.

To estimate snow water equivalent (SWE) from the precipitation and air temperature data, combined simple model using degree-day method and a threshold temperature for distinguishing between snow and rain was adopted. Estimated changes in SWE and snow cover duration that would accompany a rise in temperature of 2 °C were large on the coastal plains along the Sea of Japan in Honshu. The snow cover duration was estimated to decrease in these areas by about 70%.

The differences in initial regeneration traits between *Tsuga diversifolia* and *Abies mariesii* at 3 plots in Mt. Fuji (less snowy), Mt. Hayachine (intermediate) and Mt. Hachimantai (heavily snowy) were investigated with special reference to inhibition of seedling establishment. Disappearance of seedlings was generally rapid on Mt. Hayachine than on Mt. Fuji. On Mt. Hayachine, a *T. diversifolia* seedling cohort was almost extinguished in 1-year-old stage, while it was maintained on buttresses and fallen logs.

The relationship between present winter maximum snow depth (MSD) and the distributions of *A. mariesii* forests and T. diversifolia forests were analyzed, using ca. 1km mesh vegetation map and JMA mesh climate data. The A. mariesii forest presently occupies the sites with snow depth of 200-450cm, whereas the *T. diversifolia* forest favored less snowy sites with snow depth of 0-200cm. The changes of air temperature and winter maximum snow depth under the enhanced green house effect by increased CO_2 concentration (due to SRES Scenario A2), were estimated from Japanese Standard Climate Scenario (ver. 2). At the period of 2031-2050, subalpine areas may significantly decrease in northeastern Japan. At the latest period of this century (2081-2100), most subalpine sites in northeastern Japan may disappear, because mountains are not so high in this area. In this period, snowy subalpine sites where MSD exceeds 200cm will be restricted to a few mountains on the Japan Sea side (Mt. Gassan and Mt. Cyokai) in Honshu. Since under the warming climate snowy subalpine sites (over 200cm in MSD) will be located mainly in Hokkaido, many plant species in subalpine snowy mountains in the Honshu will be threatened to extinct.

(2) Evaluation of vulnerability and adaptation for subtropical, warm- and cool-temperate forests

Objectives of this study are to evaluate impacts of global warming on subtropical,

warm- and cool-temperate forests under climatic change scenarios, to identify vulnerable forests and areas, and to propose any means of adaptation.

Holdridge's life zone classification system, which is often used for world life zone classification, cannot incorporate limiting factors for vegetation distributions in the temperate zone, where seasonal temperature fluctuations dominate. This is because the classification system was originally developed for tropics. Alternative life zone classification system for humid climate was developed, by using accumulated temperature and minimum temperature conditions. This is suitable for East Asian humid forest zones, which are mainly controlled by temperature. Japanese vegetation formations were then classified by the alternative system and their future distributions were predicted. Results showed that the reduction of the areas with WI>85 and CMT<-1, so called the intermediate temperate zone, was the largest. This suggests that many relict plant species growing in this zone will be in danger of extinction.

Generalised Linear Models, Generalised Additive Models, Tree-Based Models, which are often used for predictive distribution modeling for plant species, were compared in terms of their model performance for buna (*Fagus crenata*) forest distributions in Japan. Results showed that Tree-Based Model performed the best, followed by Genralised Additive Models and Generalised Linear Models.

Potential distribution shift and forest vulnerability at the end of the 21st century under the two climate change scenarios, CCSR/NIES and SRES-A2, were studied by Tree-Based Model for buna forests, a representative forest type for the cool-temperate forest. Areas with distribution probability over 0.5 will be decreased in the 2090s by 90% (CCSR/NIES scenario) or by 60% (SRES-A2 scenario). Western Japan and the Pacific Ocean side of Honshu showed extensive decrease. Vulnerable buna forests were often found on the Pacific Ocean side of western Japan and the Central or inland part of Honshu (**Figure 2**).

Phytosociological Relevé Data-Base (PRDB) was constructed for the central to northern Honshu district. Twenty tree species commonly grown in the cool-temperate zone were selected from PRDB for constructing distribution models for each species, and potential shift in their distribution was predicted. Results showed that tree species shift their potential distribution individualistically under a climate change scenario.

(3)Investigation of the vulnerability of Asian tropical rainforest ecosystems to global climate change, and future prediction

The most areas of the current landscapes in Southeast Asia are characterized by the intermixture of various land-use types. The magnitude and types of land use can interact with the effects of global climate changes. The aims of this study were to predict the interactions of global climate changes (particularly effects of droughts) and land use in tropical rain forest areas in Borneo, which is in the midst of land conversions. We also used remotely sensed data to categorize land-use types as a base map for the entire area

of Borneo.

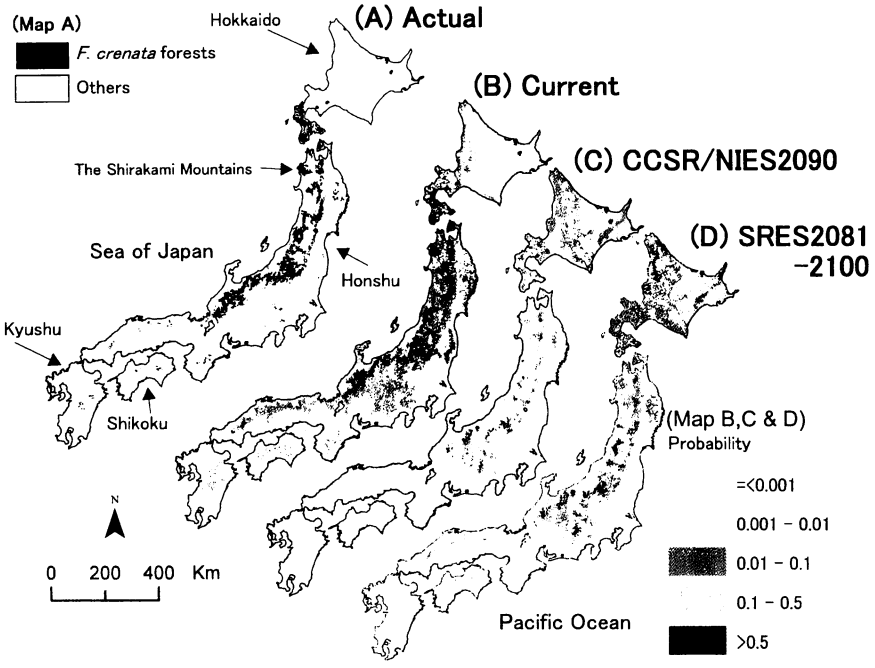

Figure 2 Predicted potential distribution of Buna forest (A) Current distribution, (B) Predicted current distribution (1990) by the model, (C) future distribution (2090s) based on CCSR/NIES, (D) future distribution (2080-2100) calculated based on the regional climate scenario (RCM20).

We parameterized CENTURY Model using the soil and tree physiology data collected from the research plots of Mt. Kinabalu. The scenarios used in the model runs are 1) a baseline scenario with gradual annual increase of monthly mean temperature by 0.043℃/yr without drought from 2000 to 2050, 2) a drought scenario with an El Nino event per 10 yrs equivalent to that of 1998 in magnitude, 3) a logging scenario that removes 49% tree biomass in the 1st year. We used SPOT VEGETATION data from Jan to Dec. 2002 to categorize land-use types.

Our model run indicates that the net primary productivity and biomass of the tropical rain forest will gradually increase and soil organic carbon will decrease according to the baseline scenario, with the net balance of null change in total ecosystem carbon. However, according to the drought scenario, forest biomass will gradually decline. Furthermore, if a severe logging is added to drought, the rate of decline of forest biomass will much surpass the rate of vegetation recovery. We conclude that the combination of drought and logging will reduce the area and biomass of tropical rain forests.

Land use of Borneo Island was mapped by remote sensing image analysis using SPOT VEGETATION data. This map and hot spot data derived from NOAA AVHRR data show that almost forest fires in 1997/1998 were occurred in or near plantation and

agricultural area. Therefore, adequate management and regulations of industrial activities around the forest which should be protected are required to avoid a loss of forest biomass by large scale forest fire due to severe drought caused by El Niño phenomenon.

(4) Evaluation of vulnerability and adaptation for plantation forests

Cryptomeria japonica D. Don (sugi) is the most important tree species in Japanese forestry practices, and sugi plantations cover approximately 4.5×106 ha in Japan, corresponding to about 45 % of the total afforested area. This species is known to be sensitive to water stress. Transpiration is strongly affected by temperature, thus increases in temperature caused by global warming would accelerate plant water consumption and exacerbate the water environment for plant growth, especially under low water availability. The objectives of this study were (1) to evaluate the potential changes of transpiration in sugi plantations as a result of rising temperatures, and (2) to indicate the vulnerable areas where drought stress may cause the decline of sugi plantations.

For each grid cell at 5'N×7.5'E resolution (about 100 km^2) in Japan, the amounts of transpiration in hypothetical sugi stands were calculated from mesh climatic data based on needle gas exchange characteristics. Annual transpiration, which ranged from 400 to 800 mm, was almost linearly related to mean annual temperature. The ratio of transpiration to precipitation (Tr/P ratio) was higher in the lowlands of the Setouchi and Kanto districts, where a decline in sugi trees has been observed.

We could categorize the key parameters for the soil water retention curves into four types of soils from the analysis of many reported data. We made a predicting model (a tank model) for soil water changes. The model under the conditions of the same rainfall and evapo-transpiration indicated that drought stress occurred more easily on brown forest soils of dry and wet types than on that of moderate moisture type and black soil. Potential soil water retention map was illustrated according to the digital national land information associated with the model outputs.

Overlay analysis of maps of the ratio of transpiration to precipitation and soil water retention showed the followings: Water stress for sugi forests happens in southwest Japan and Kanto district. Both Tr/P ratio and soil water retention can be contributory causes of water stress for sugi in southwest Japan. However, high Tr/P ratio resulted from low precipitation is a main reason for water stress in Kanto district. Our models using a future climate scenario indicate that global warming will have a serious effect on sugi plantations in Kanto district.

3.4 Vulnerability Assessment of Agro-Ecosystem to Global Warming and its Risk Modeling

Global warming and the associated climate variability are very likely to have major impacts on the hydrological cycle and consequently on the available water resources for agriculture and agricultural productivity. Then, the present research will focus the discussion on risks in agricultural production relating temperature and CO_2 rises and

water resource changes in China, which is one of the major food production areas in East Asia. Our objectives are: 1) to evaluate the impacts of climate change and variation on the environment and production of major crops in China for specifying the most vulnerable regions and proposing its mitigation strategy, focusing on precipitation change projected by GCM-derived downscaling method, and on soil moisture condition in crop root zone estimated from a water budget model, and 2) to understand distribution and variability of snow water resource and the contribution to the formation of spring river discharge in Heilongjiang Province, China and to evaluate the effects of global warming on soil N mineralization for major types of Japanese paddy soils.

Future precipitation change over China is projected using the statistical downscaling method which is consistent of multiple regression equations to explain precipitation change by sea level pressure (SLP) change. Statistical values that represent seasonal and annual variation of precipitation are calculated from a gridded historical monthly precipitation dataset covering Heilongjiang Province. The dataset is provided by extracting from that by Climatic Research Unit, University of East Anglia, UK (CRU). Seasonal and annual variations are calculated form is historical monthly climate dataset. The statistical values of river discharge at Harbin on Songhua River are calculated using dataset provided by GRDC (The Global Runoff Data Center). In order to evaluate the vulnerability in cereal production in China in terms of changes in soil water condition, we developed a soil water balance model for estimating the soil moisture in crop root zone. The model requires the information on phonology for individual crop species as well as weather variables such as temperature, solar radiation and precipitation to calculate soil moisture content resulted from the balance of crop evapotranspiration and precipitation. Focusing only on rain fed cultivation, we run the model under the past and the projected future climate conditions. In the past years for 1946-1995, dividing the period into two durations, i.e. 1946-1975 and 1976-1995, we compared the spatio-temporal patterns of soil water condition in agricultural field in China. In addition, we also compared the future changes in 2031-2065 with the past in 1961-1995. For the climate change scenario, we used the output from the atmospheric and ocean coupled general circulation model (AOGCM) developed in Hadley Centre UK.

The present status of the snow melt water, i.e. the amount, melting rate and the date of onset, are retrieved using the Index of Snow Melt (ISM)[2], which indicates the occurrence of snow melting by using the radiance of 37 and 19 GHz observed by SSM/I, a space bone radiometer. The sum of ISM value over the period of melting season can be considered to represent the total amount of deposited snow water in winter. In addition, we incubated top soils of major types of paddy soils and determined the parameters which control the N mineralization rate. We then analyzed the relationship between these parameters and soil total nitrogen content and compared the amount of mineralized N under present and +3°C conditions.

Important projections that the decreasing of precipitation over the Yangtze River region is associated with westward extension of the North Pacific High are conducted.

Also, it is projected that sever drought will be occur over the Yangtze River region. The soil moisture condition tends to become drier in the North-east part of China as well as the North China Plain. Agricultural water demand in south China is projected to decrease generally, and the cropland soil-moisture deficit would decrease due to climate change. However, in north China, agricultural water demand is expected to increase, and the soil-moisture deficit would increase generally. The changes in the water resources would have consequent impacts on the yield index. Cropland surface runoff during the growing period is expected to increase on some sloping croplands in the southwest mountain areas and in some areas along the south coast. These changes would have important implications for agricultural production. Particularly the rain-fed crops in the North China Plain and northeast China would face water-related challenges in coming decades due to the expected increases in water demands and soil-moisture deficit, and decreases in precipitation. What should be concerned is that the rain-fed crops in the North China Plain and northeast China would face water-related challenges in coming decades due to the expected increases in water demands and soil-moisture deficit, and decreases in precipitation. The effective adaptation options should include adjusting the inharmonious proportion between plantation, forestry and stockbreeding, improving greatly the water use efficiency in agriculture and increasing water supply to north China.

The coefficient of the year-to-year variation of ISM is calculated from ISM maps and found that there is a tendency where the more snow is deposited, the less relative variation of deposited snow amount. It is also found that east slope of Daxinganling region has higher value of the coefficient comparing with other regions. Year-to-year variation of the snow water resource is estimated as about 15 % in the watersheds where included in or adjoined to Heiliongjian Province. We found a clear relationship between the amount of spring flood of Songhua River and the sum of ISM. We also found that the amount of mineralized N from organic N could be estimated by soil types and soil total N content. The amount of mineralized N under 3°C higher temperature condition was estimated to be higher than appropriate amount of N uptake by rice in some soil types (e.g. Wet Andosols). This indicates the possibility of deterioration of rice yield or quality in future under global warming condition.

4. Concluding Remark

Based on the previous three year project (FY. 1999-2001), we started a new research project which focuses on impacts, adaptation and vulnerability assessment of natural and man-made ecosystems due to global warming. In this project, 4 sub groups conducted improvement of impact assessment models, gathering data and information via filed survey and experiments, and development of an idea of adaptation of natural and man-made ecosystems. In addition to the research, common climate scenarios such as regional climate scenarios and snow oriented climate scenarios are improved and utilized. Especially regional climate scenarios which was obtained from a method of nesting methodology is highly profitable for impacts study. A spatially detailed climate

scenario of which resolution is about 20km is now available which was developed and distributed by the National Meteorological Agency and the Meteorological Research Institute (MRI) in mid of this year of the project.

One of the main purpose of this project to create impacts or vulnerability map of various vegetation in Japan. For example, the following vulnerability maps were obtained, and these will be of great use for further research on regional and local assessment of vegetation impacts and for detection and monitoring global warming impact. The maps are the final results of the research. On the way of research, preparation of data and information, and calculation of impacts, we devised various types map information. These provisional maps information will be also of useful for future research.

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