B-12.1 Prediction of the Effects of Global Warming on Ecosystem

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Abstract

The effects of global warming on plants and ecosystems were investigated by following studies. a)The potential vegetation distribution shift in Japan and China caused by global climatic change was predicted by the direct transfer function approach. b) The probable effects of climate changes on geographical distribution of net primary productivity (NPP) of natural vegetation in East Asia were estimated. c) The maps of effects on phenology (the date of blooming, budding, leaf-color change, leaf-falling) in Japan were made. The strong correlations were found between phenological dates and latitude, longitude and height. d) Impacts of ENSO on plant phenology, agricultural production and natural hazard in East Asia were studied. e) Flora in the Nansei-shoto Islands was investigated to estimate the responses to climate change. f) The combined water temperature-ecological (WT-ECO)model was developed. The ECO model was used to estimate the effect of global warming on a lake's ecological dynamics.

Key Words phenology, distributional shift, lake ecosystem, Net Primary Productivity

1. Introduction

The concentration of greenhouse gases in the atmosphere is increasing at a surprising rate mainly due to the massive consumption of fossil fuels and large-scale deforestation. This increase in greenhouse gas concentration has been considered likely to lead to a warming of the atmosphere near the Earth's surface. The first assessment of Working Group I of the International Panel on Climate Change (IPCC) presented in 1990 a report indicating a probable increase in global mean surface temperature of about 1℃ by 2025 and of about 3℃ by the end of the next century. Climate change may also affect natural vegetation and the productivity of agriculture. We have investigated the effects of climate change on plants in East Asia, which is one of the most important regions in relation to global environmental problems because of rapid populationgrowth and active indusstrialization. The probale changes in climate and the modeling and prediction of plant production, vegetation distribution, phenological events, and lake ecosystems.

2. Research Object

There is current concern about changes in the distribution of vegetation and possible extinction of plant species caused by global warming. Therefore, it is necessary to condust studies on prediction of changes and clarification of effect. The objectives were to promote fundamental studies on the relation between phytophysiology and climate, and to predict global warming effects on the plants.

3. Research Method

(1) Prediction of Japanese potential vegetation distribution in response to climatic change

Potential shift of natural vegetation in Japan caused by global climatic change was predicted by the direct transfer function approach. Two types of vegetation distribution model, fuzzy model and multinomial logit model, were applied to explain the relationship between vegetation classification of remaining natural vegetation and climatic conditions. The logit model indicated a more successful result than the fuzzy model. Then, the effects of increase in mean annual temperature were predicted using the logit model.

(2) Climatic change and its impacts on the vegetation distribution in China

The potential vegetation distribution shift in China caused by global climatic change was predicted by the direct transfer function approach. Two types of statistical model, the discriminant analysis model and the multinomial logit model, were applied to explain the relationship between vegetation classification and climatic conditions. The logit model resulted in a more successful result than the discriminant analysis model.

(3) Climatic change scenarios for Monsoon Asia based on $2\times CO_2$-GCM experiments

This investigation is made of the possible climatic change scenarios due to a doubling of carbon dioxide concentration in the atmosphere. The three global climate or general circulation models (GCM) have been used to produce the climatic change scenarios for Monsoon Asia. Using These scenarios, the information was obtained on the possible distribution of annual air temperature, annual precipitation, annual global solar radiation, annual net radiation, and annual average of radiative dryness index on the Monsoon Asia. Regional averages of relative changes in climatic elements under $2\times CO_2$ induced warm climates were calculated for the four sub-areas corrsponding to the ice and desert climate area (I), cool and /or warm temperate climate area (II), subtropical and/or tropical climate area (III), and humid tropical area(IV).

(4) Probable effects of climatic changes on plant production of Monsoon Asia

The probable effects of climate changes on plant production of East Asia attempts to estimate the geographical distribution of net primary productivity (NPP, t dry matter/(ha・yr)) of natural vegetation of East Asia, in which about 45% of the world population is living at present. Estimates have also been made of probable effects of climatic changes induced by CO_2-doubling and of human land use on the total net primary production (TNP, t dry matter /yr) of this area. The Chikugo Model based on a relationship between climatic factor and dry matter production was used to calculate NPP-values of natural vegetation of this area. The Chikugo Model based on a relationship between climatic factor and dry matter production was used to calculate NPP-values of natural vegetation of this area. Normal climate data and climate scenarios generated by three GCMs were used to estimate the influence of climate warming on the potential total net production.

(5) Effects of global warming on the phenological observation in Japan

Strong correlation were found between blooming dates and meteorological factors. On the basis of on these correlations, predictive maps of blooming dates in the Japanese Islands were proposed for each case 1℃, 2℃ and 3℃of monthly mean temperature warming. The correlation was tested for the blooming dates of *Prunus yedoensis, Prunus Mume, Camellia japonica, Traxacum* sp., *Rhododendron Kaempferi, Wistaria floribunda, Lespedeza bicolor, Hydrangea macrophylla, Lagerstroemia indica, Miscanthus sinensis,* etc., using the data on monthly mean temperatures from 102 meteorological stations in Japan for the period 1953-1990. Simple and multiple regression analyses were used for the correlation. Among meteorological factors, the strongest correlation was shown for monthly mean temperatures. Notably, the strongest was obtained for the case of *Prunus yedoensis*. In these species, there was a delay of 2-7 days with a 1 degree increase in mean temperature. The 30-year 1 km^2 temperature -climate mesh-file developed by the Japan Meteorological Agency was used for the phenological estimation and predictive maps of phenological dates. Each observatory station was classified according to its annual mean temperature. Phenological dates for each mesh were estimated trough monthly mean temperatures and regression equations of corresponding stations. Then, distribution maps of predictive phenological dates distinguished by 5-day division were made.

(6) Variations in the plant phenology affects by global warming

Impacts of El Niño events (ENSO) and La Niña events (Anti-ENSO) on (i) the flowering date of cherry blossoms (*Prunus yedoensis*) in Japan, (ii) harvesting amount of paddy rice affected by drought in Indonesia, (iii) positive/negative correlation of sugar cane production affected by drought in Minamidaito-jima, SW-Japan, and (iv) natural hazard in Japan (a: flood and wind damage during the Bai-u season in early summer and the typhoon season in autumn and b: snow damage in winter) were tested by collecting data for the respective typical years. It was indicated that the contrast between the El Niño events and La Niña events are striking. But, it should be noted that the impacts of El Niño events were quite clear in the case of strong El Niño, such as in the case of 1982 and 1987, and were not clear in the weak cases. Generally speaking, impacts La Niña are weaker than those of El Niño. It is of importanted (acting as reverse effects) in the following seasons in the case of paddy rice production in Indonesia, when we analyze the relationships by three reasons.

(7) The temperate elements of the flora of the Nansei-shoto and the global climatic change

In the Nansei-Shoto the phytogeography is complicated and present an interesting problem in studies related to climatic fluctuation in the past and also to climatic changes induced by increasing atmospheric CO_2. In the Nansei-Shoto from sea level to peaks of mountains at 979m, varied floras show different origins and affinities. The Islands share the flora of the lowlands with Taiwan, southern China, and Malaysia.

(8) Development a water temperature-ecological model to simulate global warming effects on a lake ecosystem

The development of water temperature-ecological model to simulate global warming effects on a lake ecosystem describes a newly developed combined water temperature-ecological (WT-ECO) model which is employed to simulate the effects of global warming on lake and reservoir ecosystems. The WT model includes (i) variations in the eddy diffusion coefficient based on the degree of thermal stratification and the velocity of wind, and (ii) a sub-model for simulating the freezing and thawing processes of surface water, water temperatures, and the mixing rates between two adjacent layers of water. The ECO model then uses these results to calculate the resultant effect on a lake's ecological dynamics, e.g., composition of phytoplankton species, their respective concentrations, and nutrient concentrations.

4. Results and Discussion

(1) Prediction of Japanese potential vegetation distribution in response to climatic change

From the results of the analysis, it is indicated that even only a 1 degree increase in annual mean temperature might cause potential shift to another vegetation classification for approx. 23% of the total grid-cells (approximately 1km x 1km) in Japan. What does the potential shift indicated by the study mean? First, as for the accuracy, since the hit ratio of the model is approx. 76%, it must be noted that a corresponding error may be included. Next, as for the ecological meaning of the potential shift, as many ecologists have pointed out, the shifting speed of plant species may be slower than that of a habitat by global warming. Besides, it differs depending on each species. Therefore, it cannot be considered that all plant communities shift to habitats with the same species composition and the same forest structure. In the regions where shifting of plant species cannot catch up with that of the habitat, some change might be caused in the ecosystem. However, the methodology used in the study has limitations in predicting whether the change might be "competitive displacement" or "catastrophic decline"[1]. Moreover, the model doesn't include all environmental changes in the future. Especially, fertilization effects caused directly by an increase of atmospheric CO_2 might change plant response to temperature, precipitation, and other climatic conditions.

(2) Climatic change and its impacts on the vegetation distribution in China

As we described in the introduction, our final goal is to answer the question 'How does global climatic change affect the vegetation distribution in China?' through compilations of maps of vegetation type distribution. In this study, we were able to identify regions where climatic change might have a serious impact on the actual vegetation. We can summarize the results of the study as follows. 1) There is a possibility that the ecosystem in China may change in the next century when the temperature increase of 3 °C is estimated more than that in the this century. 2) As a result of comparison between the discriminant analysis model and the multinomial logit model to explain the actual vegetation distribution in China by annual mean temperature and annual precipitation, the logit model proved superior to the discriminant analysis model in terms of the hit ratios and geographical distribution of estimated actual vegetation. 3) The total hit ratio for the logit model was 68.7%, which indicates that for nine classes of Chinese vegetation, around 70% of it can be explained by annual mean temperature and annual precipitation. The residuals are thought to be caused by the spatial accuracy of the climatic data used in the study, and the vegetation distribution is considered to depend partially on other environmental factors such as solar radiation, wind, snow, soil properties, and slope gradient. 4) The potential vegetation under the climatic change was estimated using the logit model. Two scenarios proposed by Robock et al.[2] were applied: Scenario A, a 2-degree increase in temperature and a 20% increase in precipitation, and Scenario B, a 4-degree increase in temperature and a 20% increase in precipitation. As a result, it was predicted under the climatic change scenarios that (i) the conifer forest distributed in northeast China at the present time may be deprived of its habitat within the boundary of China, (ii) the broadleaved forest distributed in east China may shift northward by around 3 degrees of latitude for Scenario A and 5 degrees for Scenario B, and (iii) the desert region may expand its area, and steppe and savanna may decrease, especially in the case of Scenario B (Fig. 1).

If we summarize the impact of climatic change on Chinese vegetation, the habitat for forests might shift rapidly toward the north in east China, and steppe and meadow might be replaced by desert through drying up in west China. Therefore, future research should take into account these results and place priority on the following two points. 1) In east China, the forest zone might shift in a northerly direction. However, because of the very large population concentration in this region and the predominant use of land in this region for paddy or wheat fields, the majority of forests are isolated geographically. For the forest's smooth shift, flexible dispersal of plant seeds is necessary. However, geographical isolation may prevent the forest from shifting smoothly. Therefore it is urgent priority to develop a 'landscape transition model' based on spatial rules or neighborhood interactions, which can examine the potential for shifting in the face of changing landscape patterns for the purpose of appropriate forest management[3]. 2) In west China, especially the areas surrounding deserts, the change in moisture conditions due to increasing temperature and drying-up may cause 'desertification' of steppe and savanna. Then desertification accompanied by reduction of vegetation may accelerate the climatic change through an increase in albedo, reduction in soil moisture and evapotranspiration, and decrease in surface roughness, i.e., a positive feedback of climatic change. Therefore it is necessary to develop a 'grassland model' that can simulate the regional patterns of ecosystem properties including plant production and soil properties, taking account of fertilization effects by increased CO_2, extreme events such as drought and severe heat, and livestock management for appropriate grassland management so as not to cause desertification[4]. The CENTURY model[5] or EPIC model[6] may be instructive for development of such a model.

(3) Climatic change scenarios for Monsoon Asia based on $2 \times CO_2$-GCM experiments

The normal climate data and the climate data projected by three 2 x CO_2-GCM experiments were processed to provide future climate scenarios for Monsoon Asia under 2 x CO_2 conditions. Climate values at each grid point on the study area were used to provide grid mesh maps of annual mean or annual total of five climate elements (air temperature, precipitation, global solar radiation, net radiation, and radiative dryness index). The grid mesh maps presented here can be used as a first order future climate scenario for Monsoon Asia under 2 x CO_2 conditions. Plant growth and consequent biomass production are strongly affected by seasonal changes in climate. Particularly soil moisture affecting yield of summer crops is known to be influenced significantly by regional and seasonal changes in precipitation and evaporation. As regards precipitation, however, there is less agreement and it is pointed out that precipitation scenario obtained from GCM of the first generation is not meaningfull. Although there is such an uncertainty in precipitation scenarios, it is reasonable to assume that the grid mesh maps of climate elements presented here could be used as a first approximation of a future climate for impact assessment studies. In order to improve our knowledge of possible regional patterns of climatic change, it is needed to study the future climate scenarios for Monsoon Asia using results of high resolution GCM experiments.

(4) Probable effects of climatic changes on plant production of Monsoon Asia

The aim of this paper has been to calculate the biomass production of natural vegetation in the Monsoon Asia and to estimate probable effects of CO_2 induced climate changes on the biomass production. Calculations were also made of effects of human land use on the total net production of the Republic of Indonesia (Table 1). The results obtained in the study can be summarized as follows: 1) The potential total net production (TNP_0) of this study area (10°S to 50°N in latitude and 70°E to 150°E in longitude) was calculated to be 23.26×10^9 t dry matter/yr by the Chikugo model, assuming that whole land area is completely clothed in natural vegetation such as grass and forests. Sub-areas III and IV, on which subtropical and tropical rain forests are well grown, were expected to account for about 80% of the whole total net production. 2) Although the sub-area I accounts for about 22% of the whole land area of this study area, its contribution to the whole total net production is remarkably lower and about 2%. This is evidently because the natural conditions in this area are quite unfavorable to plant growth due to cold and dry climate. 3) Climate scenarios generated by three GCMs (GISS, GFDL, and UKMO) for doubled CO_2-level were used to estimate probable effects of climate changes on the total net production. If natural vegetation could adapt to rapid shift of climatically suitable habitats for each species through the fast migration of plant species, it was expected that the total net production of this study area would increase by about 10 % due to climatic changes under doubled CO_2-level. 4) To estimate probable effects of environmental degradation due to human land use on the total net production, calculations were made of the Republic of Indonesia using the land use data of this country. It was found that at present the total net production of this country accounts for about 88% of its potential total net production. Although this percentage value is higher than those values for Japan (75%) and for the world (60%), it is expected that this higher percentage would decrease rapidly in the near future because of considerable population growth and so rapid economical development of this country.

(5) Effects of global warming on the phenological observation in Japan

The results indicate that a high correlation was observed during the relatively low-temperature months of March to April, and that the cold indices have high correlation with the blooming date of *P. Mume, Camellia japonica* and *Taraxacum* sp. The blooming dates of these three plants are earlier than that of *P. yedoensis*. The magnitudes of the shifts are 7.2 days for *C. japonica*, 6.8 days for *P. Mume* in the case of 1°C rise in monthly mean temperature in January; 4.1 days for *Taraxacum* sp. under 1°C rise in monthly mean temperature in March. These magnitudes of shift are larger than that of P. yedoensis. For the plants with blooming dates after March, 3.0 days in shift were found for Rhododendron Kaempferi and Wistaria floribunda under 1°C rise in monthly mean temperature of April. The accuracy of estimation is the same with both plants[7]. Monthly mean temperatures for three months were effective on blooming dates of plants from late April; these include *Hydrangea macrophilla, Lagerstroemia indica*, and *Miscanthus sinensis*. On Lagerstroemia indica, the highest correlated month is June; 1°C rise in temperature makes the blooming days 6.4 days earlier. On *Ginkgo biloba L.* and *Acer palmatum*, high correlation was found in September to November, and the leaf-color change dates and the leaf-falling dates shift about 4 days later under 1°C temperature rise.

(6) Variations in the plant phenology affected by global warming

Phenology in the case of warming in the coming century was studied first by reviewing the previous studies and secondly by the data obtained from various sources. They are summarized as follows: 1) The flowering seasons of various plants, that is, the period from earlier to later flowering dates, will become longer in spring in the case of warming. 2) The effect of urbanization on the flowering dates of cherry blossom becomes earlier with a rate of about 3-4 days per 1°C warming. But, it shows relatively large, local differences: large in North Japan and small in South Japan. 3) The phenological date of cherry blossom becomes earlier under the influence of urban warming with a rate of 4-6 days per 100 years in Beijing, China, which is also found in Japanese big cities. 4) Flowering date of cherry blossom relates closely to March air temperature, but it depends upon also winter temperature. Cold winter and warm spring are the most effective to quicken the flowering. 5) Climatic fluctuations reconstructed by the phenological date in China coincides roughly with that in the Northern Hemisphere. 6) In the time scale of centuries, the warm periods are from the second half of 12th to the end of 14th century and from the second half of 16th to the first half of 17th century. Little Ice Age from the second half of 17th to the end of 19th century can be seen. 7) Such cycles were occurred in parallel with those in the regions in East Asia. 8) Based on the facts in the El Niño event year, it can be estimated that the flowering dates in the case of warming become earlier than the present. 9) Deviation of sugar cane harvesting area of summer planting in the El Niño event year is negative, but that of spring planting sugar cane is positive, in Minamidaito-jima, a small island in the sub-tropical zone in the North Pacific(Table 2). 10) On the contrary, it is completely opposite in the La Niña event years. 11) Roughly speaking, 10-15% of negative/positive deviation occurs in the harvesting area of summer planting sugar cane in the El Niño/La Niña events years. 12) Negative deviation of sugar cane harvesting area of summer planting and also grown from stumps, whose amout becomes to about 80% of total area, occurs in the case of El Niño event, associated with higher temperature and drought conditions. Similar phenomena can be estimated in the global warming.

(7) The temperate elements of the flora of the Nansei-shoto and the global climatic change

The Intergovernmental Panel on Climate Change (IPCC) has discussed the shifting of vegetational zones and floristic compositions under several scenarios of drastic climate change induced by a global increase in atmospheric CO_2[8-9]. The effect of climate change due to CO_2 doubling on the natural vegetation of Japan was estimated[10-11]. Ohba[9] suggested that small sized plant communities, which are often restricted in their ranges, would have difficulty surviving drastic climate changes because of their narrow range, discontinuous distribution, and special isolation. In relation to communities endemic to Amami-Oshima, the *Quercus amamiana* and the *Arisaema heterocephalum-Castanopsis sieboldii* communities would be seriously threatened. These communities contain a considerable number of endemic species with narrow ranges. These species might disappear because of climate change and deformation or extinction of the communities in which they occur. Furthermore, most temperate elements in the Nansei-Shoto would be seriously threatened. They may have narrowly escaped extinction after migrating to the islands after the last glacial period. At present many endemic species with temperate origins, such as *Vaccinium amamianum* and *Oxalis amamiana*, are difficult to locate because of their rarity. A large number of them may have gone extinct during the last two decades. To estimate responses to the scenarios for global climate change induced by increasing atmospheric CO_2 the need to make clear the detailed distribution of each species is still urgently needed and taxonomic data about the flora is a vital necessity. These data should also include geography and habitat, life history, and interactions with abiotic factors and with other organisms.

(8) Use of a water temperature-ecological model to simulate global warming effects on a lake ecosystem

A newly developed combined water temperature-ecological (WT-ECO) model is employed to simulate the effects of global warming on lake and reservoir ecosystems. The WT model simulates water temperatures and the mixing rates between two adjacent layers of water. The ECO model then uses these results to calculate the resultant effect on a lake's ecological dynamics. When the model was benchmarked against Lake Yunoko, a dimictic lake, fairly good agreement was obtained over a 4-yr period; thereby indicating it is suitably calibrated. In addition, to assess the effects of global warming on a lake ecosystem, changes in Lake Yunoko's water temperature/quality were simulated in response to an increase in air temperature of 2-4°C. Results indicate that such an increase will (i) increase thermal stratification in summer, which increases the nutrient concentrations in bottom water due to nutrient release from bottom sediment, (ii) increase the concentration of phytoplankton at the beginning of the autumn circulation period, and (iii) change the composition of phytoplankton species. Further research will be directed at simulating rainfall/snowfall patterns as a result of global warming, and also obtaining more detailed data on the temperature-dependent characteristics of phytoplankton growth.

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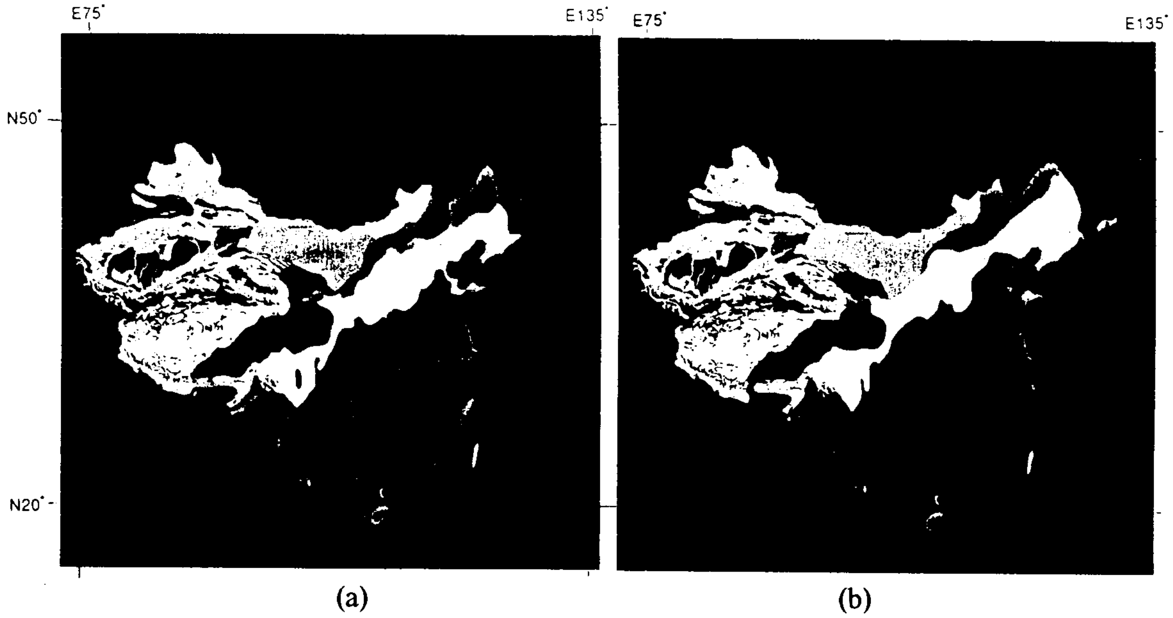

Fig. 1 Potential vegetation distribution predicted by the logit model under Scenario-A and Scenario-B.

Table 1 Potential net production (TNP_0)and actual net production (TNP_a) of major islands of the Republic of Indonesia

	percent area (%)		TNP_0	TNP_a	RTNP
	Forests	Non-forests	10^9 t dry matter/yr		
Sumatra	43	57	1.210	1.000	0.833
Kalimantan	63	37	1.590	1.410	0.887
Sulawesi	52	48	0.456	0.405	0.888
Maluku islands	70	30	0.070	0.064	0.914
Irian Jaya	82	18	1.270	1.200	0.945
Bali	23	77	0.012	0.010	0.833
Java	7	93	0.036	0.026	0.722
Other small islands	60	40	0.155	0.137	0.884
Total or Average			4.798	4.251	0.886

Table 2 Air temperature and rainfall conditions and deviation of harvest area of sugar cane in Minakidaito-jima in the case of El Niño and La Niña events

Event	Average of mean ann. temperature deviation	Maximum deviation of mean ann. temperature	Annual rainfall deviation observed	Deviation of harvested area[3]		
				Summer planting	Spring planting	Growth from stumps
El Niño[1]	+0.3°C	+0.9°C	-0.56~-457mm	negative	positive	negative
La Niña[2]	-0.1°C	-0.3°C	+246~+337mm (with one excep. year)	positive	negative	positive

Notes: 1) Average of 1972, 1977, 1982,1987, 1991.
2) Average of 1971, 1973, 1976.
3) Average deviation is shown in Table 4.