B-52.3.1 Effects of global warming on dynamics and distribution of actual vegetation

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Abstract

The objective of our studies is to estimate the change of community dynamics and distribution of the present vegetation under changing climate. We drew the map of Japan presenting snow accumulation under present and warming climate. One analysis predicted a remarkable decrease of snow accumulation on the plains of the Sea of Japan side and inland provinces of Tohoku region. We estimated effects of snow cover and temperature on distribution and dynamics of snow-patch vegetation, subalpine Ericaceae scrub, *Pinus pumila* scrub, fir forests. We also estimated the past distributional change of snow-patch vegetation and fir forests by analyzing buried peat soil and pollen. We studied the effects of warming climate on leaf phenology of birch and species diversity of beech bearing forests. One study indicated that effects of warming climate on species diversity of beech bearing forests would be different between the Pacific and the Sea of Japan sides. The studies on snow-patch vegetation indicate that plant distribution is most sensitive to the date of snow disappearance and that amount of snow cover played a major role for the shrinkage of snow patch in spring and summer. The snow cover is one of the most important factors controlling vegetation dynamics on mountains in Japan, as well as the thermal factor.

Key Words climate change, snow cover, phenology, regeneration

1. Introduction

In general, global warming induces the shift of vegetational zonation under humid climate toward north and high elevation. It is not clear how existing vegetation will change through vegetation dynamics including replacement of species under warming climate. The main driving forces and vegetation processes are not yet clarified enough to predict changes of vegetation.

Since the actual vegetation is affected by both various environmental factors and human interference on different scales, it is not sufficient to predict the simple shift of vegetation toward colder regions under warming climate. The objective of this study is to estimate the effect of global warming on environmental conditions, especially snow cover, and on changes of actual vegetation on different scales.

2. Evaluating the influence of air temperature on distribution of snow amount using AMDAS data

In the Sea of Japan side in Japan, especially northern region in Honshu Island there are extensive heavy snow areas, where the precipitation in winter often exceeds 1000mm even in lowlands. But in many regions air temperature is comparatively high and snow melt by sensible heat flux often occurs even in mid-winter. Air temperature frequently influences the amount of snow cover than precipitation because snowfall often occurs in the temperature near the snow-rain boundary temperature. In this study we develop a method to estimate snow accumulation from precipitation and air temperature, and predict the change of snow accumulation under warming climate in Japan.

Data of precipitation and air temperature in each pixel were calculated from precipitation and air temperature data measured by Meteorological Agency as AMEDAS. Snow water equivalent was estimated using Degree Day method using functions as follows:

$$SWE=SWE+Pr \qquad Ta<Ts \qquad -(1)$$

$$SWE=SWE-K\times Ta \qquad Ta>=Ts \qquad -(2)$$

where SWE = snow water equivalent, Pr = precipitation, Ta = daily averaged air temperature, Ts = the snow-rain boundary temperature, and K = degree day factor. Ts used in each pixel was fixed on 1.3 degree that was obtained in Tohkamachi experiment station, FFPRI in Niigata. K was optimized in each AMEDAS point where snow depth was measured automatically. To estimate the change of snow accumulation due to change of air temperature, We used the substituted air temperature (Ta) to calculate the estimated SWE.

To verify our estimation method, we compared the estimated SWE and measured SWE in Tohkamachi Experiment Station. Estimated values showed the good agreement with observed values. This means that using suitable values of Ts and K, it is possible to estimate SWE by only precipitation and air temperature. We compared the maximum snow depth estimated along elevation and measured snow depth obtained in 20 points near the estimated site (Fig.1). Estimated values showed a good agreement with observed values.

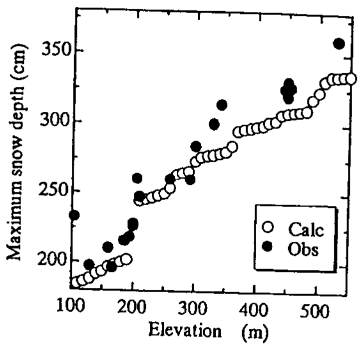

Fig.1. Calculated and observed elevation profile of maximum snow depth in Niigata.

Fig. 2 shows the distribution of the ratio of estimated maximum *SWE* using default air temperature (*Ta*) and air temperature of +2 degree (*Ta*+2℃) in 1995-1996. Decreasing ratio of maximum *SWE* is remarkable at plains of the Sea of Japan side and inland provinces of the Tohoku region in Honshu Island. The large decrease of maximum *SWE* by air temperature rise of 2 degree can be seen from Simane prefecture to the southern part of Hokkaido.

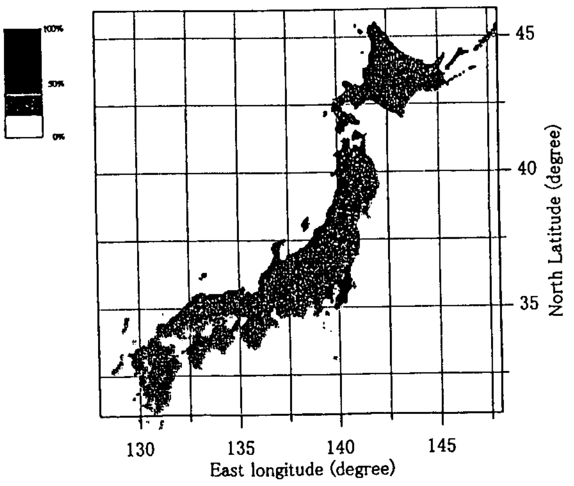

Fig.2. The distribution of the ratio of estimated maximum *SWE* using default air temperature (*Ta*) and air temperature of +2 degree (*Ta*+2℃) in 1995-1996.

3. Impact of global warming on snow patch grasslands in subalpine area of Japan

Snow patch grasslands in Japanese mountains are precious landscape because they contain many alpine plant species. Snow patch grasslands usually show concentric plant distribution controlled by summer snow patches[2]. Since summer snow patches reflect balance between snow accumulation and snowmelt [6], snow patch grasslands are very sensitive to climatic changes. Proxy data that record variation of past snow patch, such as meadow soil stratigraphy [3,8] and dated fossil ice[13] are important because they show how snow patches reflect past and future climate. This study aims to estimate an impact of global warming on snow patch grassland in snowy mountains in Japan analyzing present snowmelt and snow accumulation processes. Additionally, two series of fossil soil which suggest snow patch shrinkage in past warmer climate are studied and their paleoclimatic meanings are examined.

The buried peat layers found from Mt. Zarumori and the buried muck layers found from Mt. Chokai suggest that the snow patches have been smaller in the medieval warm period (ca.1ka yBP.) and hypsithermal period (ca. 6ka yBP.) than the present.

Snowmelt gradient is the principal environmental factor to control the distribution of snow patch grasslands. Its year-to-year variation principally depends upon the fluctuation of air temperature in melting season and snow accumulation in winter. The snowmelt rate is easily calculated from air temperature using Degree-Day Factor, which is a ratio of melted snow to cumulative air temperature (degree-day) as the following equation.

$$M = aI$$

where M = snowmelt (in snow thickness), I = degree day above -3°C, and a = Degree-Day Factor[9]. Degree-Day Factor from May to July was estimated as 11mm/°Cday from snowmelt observation in 1994 and 1995 around Mt. Zarumori[4].

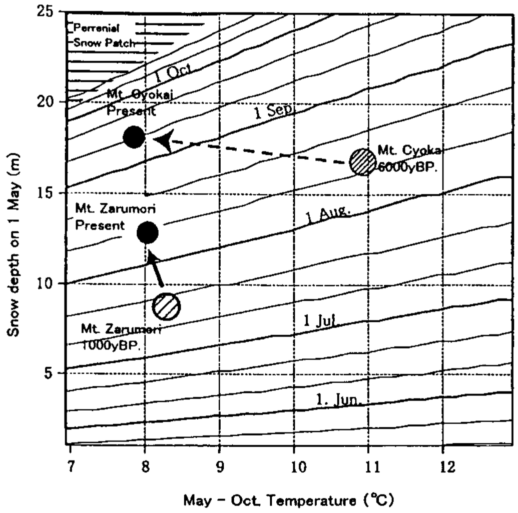

Fig.3. Charge of snow-disappearing date due to temperature (May-Dct.) change.

Using the degree-day snowmelt model, changes of snowmelt date caused by climatic changes were calculated (Fig.3). In snow patch grasslands, plants deeply covered by snow in winter must complete a vegetative life cycle quickly in summer. Figs.3 indicates that later snow line is more sensitive to increase in air temperature. This means that species which inhabit later snow released sites such as snow patch bare grounds, may seriously influenced or entirely disappear in some places due to 3°C warming in summer. At Mt. Chokai, the buried muck layers suggest that snowmelt was hastened by 10 days or more in the Hypsithermal Period. Since the snow depth of the site was almost fixed by the landform, the hastened snow release will mainly caused by increased air temperature in melting season.

4. Vegetation changes in the subalpine area of Mt. Yumori, Oou Mountais, during the last 2,000 years

In the subalpine zone of the Tohoku District, *Abies mariesii* is only the predominant conifer species. Deciduous broad-leaf scrubs and dwarf bamboo also occupy a large area in

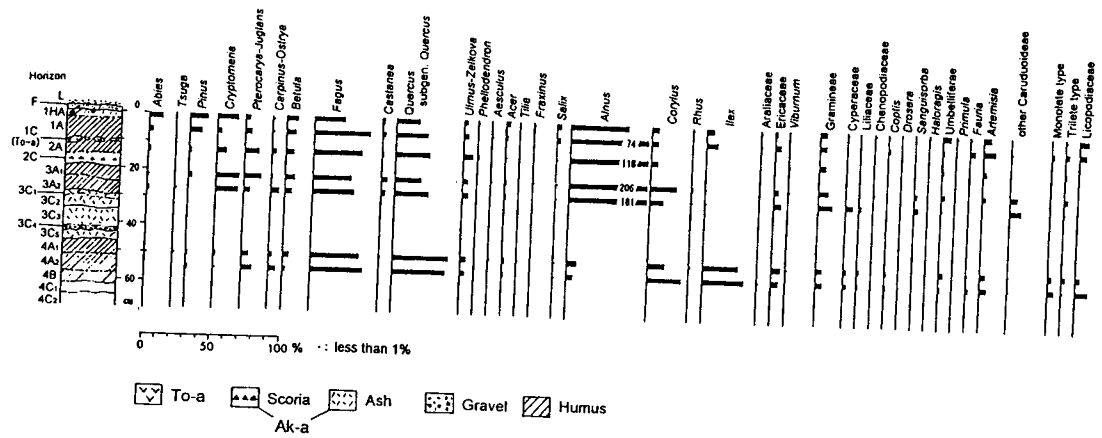

Fig.4. Pollen diagram of the soil section from the uppermost forest stand of *Abies mariesii* in Mt.Yumori, Oou Mountains.

this zone [12]. To predict the response to the global warming in such areas, we need to understand the vegetation history and the direction of the vegetation change. In this paper, we present the vegetation changes clarified from pollen analyses for the last 2000 years in the subalpine area of snowy region.

Samples for pollen analysis were taken from the soil profiles around Mt. Yumori

(1471m a.s.l.), Oou mountains, where *A. mariesii* forests are scattered. Fossil pollen grains and spores extracted from the samples were mounted on slides and identified at a magnification of ×400. At least 400 arboreal pollen grains were counted for each sample. The percentage values for each taxon in the pollen diagram was based on the total sum of the arboreal pollen.

Abies pollen began to increase after the To-a tephra fall in many places around Mt. Yumori (Fig. 4). In this area, two tephras are buried in soil profiles at a depth of about 1m. One is the To-a (erupted in 915 AD) and the other is the Ak-a(1900±85yBP). *Abies* pollen occurred with low frequencies in the whole profile except for the surface layer (1HA) showing more than 10%. This fact indicates that this uppermost forest stand of *A. mariesii* colonized in the recent age; a few hundreds years at most before the present. Before domination of the *Abies* forest, there were beech forests and scrubs of *Quercus*, *Alnus*, *Corylus* and *Ilex* species.

5. Crown development of *Abies mariesii* in snowy environment

Snow accumulation often alters crown development of trees in snowy environment. In Japan, the mechanical damage of snow on the crown is caused by heavy and sticky snow[7], whereas protection of trees by snow pack is generally known in boreal region[1,11]. Examining the effect of snow on the crown is necessary to understand the survival and reproduction of tree species growing in snowy environment in the contemporary climate regimes and to predict the dynamics of forest community during climate changes. The objective of the study is to examine (1) the effect of annual fluctuation of snow accumulation on the trunk and branches of *A. mariesii,* and (2) the effect of the mechanical damage by snow on the survival of individual trees.

The study site was located in a upper subalpine woodland-like community (1350 m a.s.l.) on the east-facing gentle slope of Mt. Yumori (39°45'N, 140°50'E) in the Oou Mountains in northern Honshu, Japan. Snow depth was measured for eight points three times from late April to late June in 1996 and four times from mid-March to late May in 1997 and 1998. In 1996 and 1997, mechanical damages on trunks and branches were examined for 153 trees with taller than 1.3 m in trunk height in 1995 by climbing up to the canopy, and the symptoms of the damages were recorded. In 1998, only trunk breaking and branch tearing were checked and recorded.

The value of snow depth in late April of 1996 was the highest in the measurements during the three years with a mean of 457 cm, being higher than the highest values in 1997 and 1998, with a mean of 384 cm and 259 cm, respectively. The latter two were recorded in mid-March in each year.

Breaking on the trunks larger than 5 cm in diameter at the broken position in 1996 and 1997 occurred on nine and six trees, respectively while such breaking did not occurred in 1998. One tree with the trunk broken in 1996 and three trees with such trunk in 1997 were dead in the spring of 1997 and 1998, respectively. This fact suggests that heavy snow accumulation affects the survival of some trees at least within two years after the snowfall.

6. Major environmental factors affecting subalpine vegetation dynamics in Oou Mountains, northern Japan

Tree-lines dynamics in subarctic and/or subalpine regions have been well examined in relation to past climate change. Long-term studies showed that positions of tree-lines generally declined after the Hypsithermal in response to fluctuation of air-temperature or precipitation[5]. Tree-line dynamics were also detected during the last few centuries, suggesting winter environments as main driving-force, e.g. maximum snow pack level[10]. Population dynamics in Japanese subalpine vegetation, especially at snowy regions in northern Honshu Island, might be affected by such regional-scale winter environments.

In this study, environment-subalpine vegetation interaction in northern Japan were examined, focusing on effects of snowfall patterns on regeneration success, for three major vegetation types; subalpine forest of *Abies mariesii*, dwarf scrub of *Pinus pumila* and shrub community dominated by *Ericaceae* species. Vegetation dynamics of each type under a scenario of future climate change was discussed.

The study site was located on Mt. Yumori (1472m a.s.l.) in Oou Mountains. Stand structure, tree ages and growth pattern were examined near upper forest-limit of *A.* mariesii on east-facing leeward slope. Growth pattern was analyzed using ring-width data of core samples to detect past disturbance events, especially snow damages. As for shrub community on wind-exposed site of the summit, phenological performance, e.g. seasons of flowering and fruiting, was compared among four major Ericaceae species; two evergreens (*Ledum palustre*, *Rhododendron brachycarpum*) and two deciduous (*Vaccinium ovalifolium*, V. *smallii*). Also, on the wind-exposed sites, regeneration processes of *P. pumila* were studied concerning interaction between nutcracker's behavior of seed caching and recruitment of pine seedlings. Air- and soil-temperatures, maximum snow depths, and duration of snow cover periods were measured at two contrasting sites, i.e. inside *A. mariesii* forest (leeward site) and on the summit (wind-exposed site), during the recent four years (1995-1998).

Winter environments contrasted between the two sites, leeward slope with *A. mariesii* forest and wind-exposed site where shrub community and *P. pumila* scrub occupied. Maximum snow depths were only 1 m or less and rather stable annually on the wind-exposed site. Year-to-year difference in snow-melting period was only two weeks in this site. On the other hand, maximum snow packs during the four years (1995-98) ranged between 2 and 5 m inside the *A. mariesii* forest, which resulted in a month or more annual fluctuation of snow-melting period. The comparisons indicated that snow-melting period at the wind-exposed site was mainly governed by air- and soil-temperature conditions in early spring while that on the leeward site was directly affected by extent of maximum snow packs in each winter.

This study demonstrates that local-scale environments, especially in winter or early spring, act important factors for reproduction or regeneration processes of subalpine vegetation in northern Japan. A future dynamics of *A. mariesii* on leeward site, e.g. altitudinal shift of upper forest-limit, might be not caused by only temperature increase due to global warming. At least, it requires any changes of snowfall patterns, e.g. intervals of much snowy winter. While, as for dwarf shrub community at wind-exposed site, a predicted condition, i.e. earlier snow-melting and prolonged snow-free period due to temperature increase, may be more suitable for survival of species which requires longer summer for reproduction performance. Thus, it is likely that species composition will change; probably species of warmer-climate origin dominate over colder-climate ones. However, such habitat competition in the wind-exposed site might be more complicated because of the presence of *P. pumila* of which regeneration success primarily depends on early summer water-conditions rather than temperature.

7. Leaf phenology of *Betula ermanii* on Mt. Ontake, Nagano Prefecture.

Studying phenological behavior of plants is important to detect the influence of global warming. However, a few studies have been made in high mountains because of the difficulty of observations. The objective of this study is to study the relationships between leaf phenology of *Betula ermanii*, a dominant deciduous broad-leaf tree species in the subalpine zone, and climatic environment, estimating the influence of warming climate on the phenoloy.

Phenological behavior of leaves of *B. ermanii* was observed along the southern slope of Mt. Ontake (3063m a.s.l) from 1986 to 1998. Phenological stages of leaves such as opening, development, yellow coloration and falling were recorded at elevational interval of 50m from 1600 to 2450 m. Air temperature was measured at 1700, 1950, 2120, 2400 m a.s.l.

The date of leaf opening was delayed with increase of elevation but there were short stops of leaf opening around 1900m in 1997 and around 2150 m in 1998. We compared accumulated temperature of leaf opening for all observation points, testing the different threshold temperature of physiological zero. The threshold temperature of 5℃ gave the best correspondence among the accumulated temperature for least opening at different elevations. Buds started to open at 100℃·day for every elevation and leaves completely opened at 190 ℃·day. The growing season (from complete open of leaf to yellow coloration) was 150 days at 1600 m a.s.l and 90 days at 2450 m. The results indicates that leaf phenology of *B. ermanii* is sensitive to change at thermal climate.

8. Relationships between thermal environment and species diversity of beech bearing forests in the Pacific and the Sea of Japan sides of Honshu

Beech (*Fagus crenata*) is a leading dominant in cool-temperate forests of Japan. The floristic composition and forest structure of beech bearing forests markedly vary between the Pacific side and the Sea of Japan side since winter climate characteristically expressed by snowfall are contrasting between the sides. The objective of this study is to analyze the species diversity of beech bearing forests of various locations and relationships between thermal factors and species diversity, predicting the effects of warming climate on the forests.

Collecting the releve data of published plant sociological studies in Tokyo Metropolitan, Yamanashi, Kanagawa and Niigata Prefecture, we established the database of beech bearing forest releves which include the information on climatic indices. The climatic indices were calculated for every releve from monthly lapse rate and the climatic data for every secondary mesh (c.a. 1km X 1km) which the Agro-environment Research Institute interpolated from a climate change scenario, MRI-OGCM.

The database included 169 releve in the Pacific side and 161 releve in the Sea of Japan side. The average number of species in releve was 34.3 in the Pacific side and 28.3 in the Sea of Japan side. The species number in releve varied more in the Pacific side.

The average species number in overstory (tree and sub-tree layers) was 8.5 in the Pacific side and 4.0 in the Sea of Japan side. The average species number both in shrub and herb layers was not significantly different between two sides but there was larger variation in the Pacific side. These results means that species diversity of a stand was more in overstory of the Pacific side than the Sea of Japan side but that that is not different for understory.

The analysis on the relationship between warmth index and species number in releve showed that there were releves of high species number even on lower WI on the Pacific side and that species number gradually decrease with decreasing WI in the Sea of Japan side (Fig.5). This suggests that warming climate induce the increase of species number in the Sea of Japan side and no change in the Pacific side.

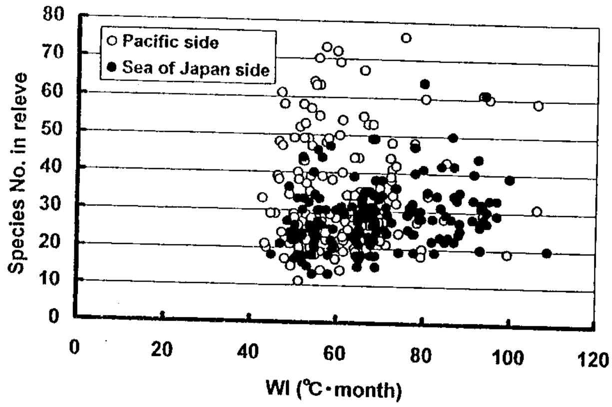

Fig.5. Relationship between WI and species number in releve of beech bearing forests on the Pacific side and the Sea of Japan side.

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