B-12.2.1 Global warming effects on the distribution pattern of natural vegetation in Japan

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Abstract The following studies on climatic, edaphic biological conditions, and their influences were carried out in northern and middle Japan as: estimation of snowfall by ground air temperature, modeling of melting process of snowpatch, phenological change of snowpatch vegetation, growth and distribution of *Pinus pumila* scrub, effects on litter decomposition rate in different forest types. We have tried to reconstruct past climatic conditions by means of alpine-subalpine meadow soil stratigraphy, which records past snow disappearance time in nivation hollows. Buried peat found on Mt. Zarumori indicates that the date of snow cover disappearance in approximately 1000 y.B.P., was earlier than in recent times. Calculations of the past snowmelt rate by the degree-day method, indicate that warming in summer and lower winter snowfall accumulation, hastened snowmelt and enabled the peat to deposit. This warmer climatic condition in north Japan corresponds to the so-called "Medieval Warm Period" of Europe and North America. It is suggested that subalpine conifers never expand into the alpine vegetation zone which *P. pumila* has already occupied, even under the higher temperature conditions.

Key Words climate change, alpine and subalpine vegetation, phenology, snow cover

1. Introduction

The most simple and distinct effect of global warming on plants is the shift of vegetation zones toward higher latitude and altitude. The effects on the ecosystems of alpine and subalpine zones may be the most conspicuous since the areas of high altitude into which the plants can immigrate are usually very limited.

2. Research Objective

The objective of our studies is to predict the effects of the global climate change on local ecosystems through the investigation of habitat conditions of representative plant communities. The target vegetation includes subalpine coniferous forest, alpine scrubs, alpine meadows and high moor. The relationship between these vegetation types and the climatic (snow, wind, rainfall, mist, temperature, etc.) or edaphic (topography, geology, soil, etc.) conditions are investigated.

3. Research Areas and Methods

Ou Mountain Range which traverses the central part of northeastern Japan is chosen to investigate the relationships between snow conditions and vegetation. Studies on the snowpatch and vegetation are made in the alpine meadow on southeast slope of Mt. Zarumori (1541m). Mt. Zarumori is an old volcano and consists of basic andesite lava, and has a steep slope on its northwest side, and a gentle slope with shallow depressions on its southeast side. The summit of Mt. Zarumori is not so high, it is located in the subalpine temperature zone. However it has severe snowstorms in winter, so the mountain top lacks trees. The severe snowstorms form thick snow deposits (about 12 m) in the nivation hollow of this study.

The second study area includes the upper part of the Kitakami Mountains. It is located on a lifted peneplane, and most of the mountains here have gentle slopes. In this study, locations of sample pits were chosen from the mountains of higher than 1200 m in elevation, and sampled at the stable place from pedoturbation, and these are higher than 1100 m

The study of *Pinus pumila* scrub was carried out on Mt. Kinpu (2595 m) in the Okuchichibu mountain range of central Japan. The uppermost part of Mt. Kinpu (above ca. 2450 m) was dominated by a dwarf scrub of *P. pumila*, below which (above ca. 1700 m) was represented by subalpine conifer forests consisting mainly of *Abies mariesii*, *A. veitchii* and *Tsuga diversifolia*. Six research plots (1-2 m^2 in area) were established in the pine scrub; three plots were on the north-facing slope at different elevations (N1: 2575 m, N2: 2560 m, N3: 2540 m) and the other three plots were on the south-facing slope (S1: 2580 m, S2: 2560 m, S3: 2550 m).

In the Akaishi Mountains from Sawarajima to Fujimitaira in Shizuoka Prefecture, edaphic conditions are studied. The elevation of study sites ranges between 1120 m (Sawarajima) and 2725 m (Fujimitaira) above sea level. The Akaishi Mountains mainly consist of Mesozoic sedimentary rocks which were modified by Shimanto activity. Temperature varies depending on topography and elevation with an annual mean of 4ºC-5ºC at 2000 ml. Annual precipitation is about 2600 mm at the same elevation. Seven fixed quadrates were set at each elevation, i.e., plot No. 1 at 1120 m, plot No. 2 at 1560 m, plot No. 3 at 1840 m, plot No. 4 at 2130 m, plot No. 5 at 2470 m, plot No. 6 at 2560 m and plot No. 7 at 2725 m. Landforms are classified into five types, i.e., alluvial toeslope, convex creepslope, transportational midslope, seepageslope and interfluve. Soil types which appeared in these experimental plots are B_D, BC (PDIII), BA (PDIII), P_DII, P_DI. Forest types are classified into *Larix kaempferi, Quercus crispula, Tsuga diversifolia, Abies veittchii, Abies mariesii* and *Pinus pumila* with understory vegetational types of macro herbs, *Dryopteris-Cacalia*, moss, and *Rhododendron*.

The relationships between change of snow rate and air temperature are studied in Tokamachi, Niigata Prefecture, based on climatic observation from 1963 to 1994.

4. Results

Changing snow environment and snow patch grassland

A series of buried peat layers were found in the Ou Mountains area, and the paleoenvironment which enabled their deposition was estimated, based on the understandings of relationships between air temperature, snowmelt rate, and vegetation and soil zonings. The simulation of snowmelt process estimated that snowfall change was more affective than changes of air temperature in summer. This suggests that snowfall in mountain area has changed due to Holocene climatic changes. The observations of micro landforms formed by snow griding and measurements by snow gride-meter showed that snow griding process occurs on the treeless slopes steeper than 20 degrees, and it affects distribution of mountain forests. Snow gride was seemed to affect the distribution and expansion of subalpine trees. *Abies mariesii,* the dominant species of subalpine forest in northeastern Japan, tends to distribute on slopes with less snow pressure. If the warming will be accompanied by decrease in snowfall, it will bring the more suitable environment for expansion of the *Abies mariesii*, which has continued since ca. 1000 y BP.

Distribution pattern of plant communities and phenology around snow patch

At the tops of Mt. Genta, Mt. Yumori and Mt. Chausu in subalpine area of the Ou Mountains, the relationship between soil freezing and distribution pattern of plant communities was studied in connection with snow depth. Under *Pinus pumila, Tsuga diversifolia*, and the windy site communities (ex. *Juniperus communis* var. *nipponica*), the surface soils froze deeply, while *Abies mariesii* little. The results of the survey at Mt. Yumori show that snow depth controls soil freezing. Therefore, in this study area, it is presumed that soil freezing corresponds to the distribution pattern of the plant communities.

The phenology of snow patch vegetation (*Primula nipponica, Fauria crista-galli* and *Hemerocallis dumortieri* var. *esculenta*), snowmelt and weather conditions were observed at Mt. Zarumori in Akita Prefecture, during the summer in 1993. Snowmelt and subsequent soil temperature were calculated by a micrometeorological model. They showed two growing patterns of snow patch vegetation, and an index of climate resource for snow patch vegetation.

Effects of external factors on growth and structure of Pinus pumila scrub

Site differences in microclimates and productivity due to slope aspect and elevation were assessed for the alpine dwarf pine (*Pinus pumila*) scrub on Mt. Kinpu, central Japan. Leaf area index, aboveground biomass and annual production rates were larger for the pine stands on the south-facing slope than those on the north-facing slope. For each slope, these parameters increased with decreasing elevation. With respect to environmental factors, the daily photon flux density during the summer months were almost the same between the N- and S-slopes, but the temperature conditions differed due to slope aspect, especially soil-temperature, which was 2-4°C higher on the S-slope. The positive correlation between temperature and productivity indicated that stand development of *P. pumila* scrub could be enhanced under higher temperatures. The effects of recent global warming on the Japanese alpine/subalpine vegetation dynamics were discussed by focusing on habitat competition between *P. pumila* and other subalpine conifers.

Effects of environmental conditions on the site dynamics of a subalpine forest

Data were collected and measured on microclimates, stand structure and growth, composition of understory vegetation, litter decomposition rate, soil properties and tree regeneration at seven fixed plots. Air temperature in November decreased linearly with increasing elevation because of adiabatic expansion of air with its ascent. Soil temperature showed a clear decrease when elevation increased, except in the highest plot (2725 m). The pH values in the topsoil indicated a negative correlation with elevation in which the pH values decreased as elevation increased. The total carbon content in the topsoil tended to increase with elevation, except in the highest plot. The relationship between elevation and the decomposition rate did not show a clear negative correlation due to that it is affected by landform and vegetation.

Relationships between change of snow rate and air temperature

Using Degree-day method and distinction of snowfall and rainfall by ground temperature, we estimate the change of snow water equivalent by ground air temperature and precipitation for 31 years from 1963 to 1994. Calculated ground air temperature for distinction was 1.4 degree. And calculated averaged snowmelt coefficient was 4.09, and had relationship with changing of snowmelt period. We compared snowmelt rate calculated by degree-day method and heat balance method with observed snowmelt obtained by lycimeter. Degree-day method can be used in warm snow area using averaged snowmelt coefficient except with very low snowfall years.

5. Discussion

Changing snow environment, snow patch, and vegetation

How much must average summer temperature and snowmelt rate change to affect zoning of soil types in nivation hollows? The degree-day method provides the best and simplest way to evaluate snowmelt rate by changing temperature. We measured air temperature at 1-hour intervals, and surface snowmelt to calculate a 'Degree Day Factor'. Effective cumulative temperature (E.C.T.) is the sum of daily average temperatures which exceed -3 degree plus 3 degrees. The relationship between surface snowmelt and E.C.T. is accurately represented by the linear equation, $Y=9.3X$, where Y is surface snow melt (mm), X is E.C.T. and the Degree Day Factor is 9.3. Using this equation, we can evaluate snow melt under changing temperature and snow depth.

The cumulative surface snowmelt curves in summer under the changing temperatures were drawn using the above equation. They are also simulation curves for snow disappearance when we regard the snow thickness axis (vertical axis) as snow depth in early summer (June 1st). The average summer temperature in 1993 was 2°C lower than the past 70 years at Akita. Therefore each curve shows the case of +2,0,-2 and -4 °C temperature changes from the past 70 years. If average summer temperature rises +4°C higher than 1993 (+2°C higher than the past 70 years), snow cover will disappear in latest July , almost the latest time at which peat can deposit. However a +2 °C rise will be too large a change, considering that a climatic change usually accompanies a change in snowfall. If the Medieval Period's warming was with decreased snowfall, a smaller temperature rise will be enough for peat deposition. Fig. 5 shows snow deposition in the Mt. Zarumori nivation hollow, in the summer of 1993 and 1994. The shape of snow deposition resemble a delta, and positions of front-end (forest) are very different from each other. So if the amount of snow fall decrease, the position of the front-end will retreat and snowdepth will change dynamically near the front-end. We should further consider changes in snowfall when we discuss the past and future vegetation of Japanese mountains.

There also existed many fine charcoals on most surfaces of the soil profiles. There were probably more effects from human activities, especially burn-off, than forest fire. This is because the Kitakami Mountains have been famous as a production center of horses, and in the last part of the Edo period, pastures and meadows were moved from the low lands to the upper part of the mountains. Therefore, the natural vegetation was probably burned off for pasturing.

Judging from changes of soil color in the profiles, it appears that the accumulation of humus began sometime around the To-Cu tephra fall. To confirm this hypothesis, carbon in each soil horizon was quantitatively analyzed. As the carbon content began to increase (more than 5-6%) simultaneously from about the To-Cu horizon in many profiles, it almost corresponds to the soil color. But there also is another type of profile, Aomatuba A had been more than 7% of carbon content from bottom of the profile. According to a study of soil pollen analysis on the same samples, even the warm period ca. 5500 y.B.P., there were only a few shrubs, herbs and ferns in most of the subalpine area, while at the tops of Sakudogamori and Aomatsuba A were deciduous broad-leaved forests.

From these results, we believe that the accumulation of humus in most of the study area began after the To-Cu tephra fall. The accumulation of humus began after the To-Cu tephra fall in most of the subalpine area of the Kitakami Mountains. However, in some stable places, it began before the To-Cu tephra fall, and it is believed that *Abies mariesii* had colonized these places.

Effects of external factors on *Pinus pumila* scrub

In the European Alps, the effects of microclimates on the photosynthesis of subalpine conifer trees have been well examined on two contrasting slopes (e.g., north- and east-facing) of the same elevation. Turner et al.[1] indicated that the annual net carbon gains of two pine trees (*Pinus montana*, *P. cembra*) were much less on the northern slope than on the eastern slope due to the limitations of soil-temperature and total photosynthesis period on the N-slope. Hasler[2] also showed that the average daily CO_2 uptake rates of *Larix decidua* seedlings on the northern slope were about half of those on the eastern slope irrespective of similar irradiance input, and suggested that the lower soil temperature level on the N-slope was the main limiting factor in photosynthesis. Similarly, the productivity of *P. pumila* stands was greater on the south-facing slope than on the northern slope. This might be due in large part to the higher summer temperatures in the S-slope, especially soil temperature, because the differences in microclimates due to slope aspect were more conspicuous in temperature than in irradiance regimes.

In subarctic regions, the upward shifts of tree-limits due to extensive seedling establishment in the warmer years of the 20th century have been observed for *Picea glauca* [3] and *P. abies* [4]. Temperature increase caused by recent global warming, which was noted[5] in the 1980s, may promote the migration of Japanese subalpine conifers (*A. veitchii*, *A. mariessii* and *Tsuga diversifolia*) into higher elevations. However, the positive correlation between temperature and productivity mentioned above indicates that stand development of the *P. pumila* scrub could be enhanced under higher temperatures. Thus, in the Japanese alpine regions, the regeneration success of subalpine conifers primarily depends on habitat competition with *P. pumila*.

Kimura[6] showed that the relative light intensities on the floors of subalpine fir (*A. veitchii*, *A. mariessii*) and hemlock (*T. diversifolia*) forests averaged 5.9-6.5% where seedlings of each species could survive. Kohyama[7] suggested that *A. veitchii* and *A. mariesii* seedlings required a relative light intensity of 5-8% for survival and 27-28% for maintaining normal growth-rates to reach the sapling stage. Generally, natural regeneration of the *Abies* and *Tsuga* can progress only in open sites after gap-formation. These results in relatively even-aged forests, such as "wave-regenerated *Abies forests*" and "mosaic-patch *Tsuga* forests" [8]. In the *P. pumila* stands at Mt. Kinpu, light conditions under the canopies, 15-39% in relative *PFD*, may allow the establishment of such conifer seedlings.

Kajimoto[9] showed that mature *P. pumila* stands (ca. 100 yrs-old in the aboveground age) in the Kiso Mountains had *LAI* values exceeding 5 m^2m^{-2}, in which the relative *PFD* values on the floors were below 10%. He also indicated that gap-formation due to individual mortality had rarely occurred within the mature *P. pumila* scrub because of its vegetative propagation by layering). Such canopy structure and reproduction habits in the well-developed pine scrub probably act defensively against invasion from other subalpine conifers. Thus, it is impossible to predict future vegetational changes in the Japanese alpine/subalpine areas, i.e., upward expansion of the subalpine conifer forests to succeed the *P. pumila* zone, based solely on temperature increases resulting from global warming.

Effects of environmental conditions on the site dynamics of a subalpine forest

The air and soil temperature conditions in alpine and subalpine zone have been discussed taking into account the freeze-thaw cycles and the formation process of microlandform. Although air temperature decreases nearly linearly at the lapse rate with the elevation, its decreasing tendence fluctuated depending on season in this study. Air and soil temperature conditions are affected by direct sun light, snow fall, vegetation, soil water condition, organic matter and landform. The results of this study showed the fact that soil temperature of plot 6 where is windy and has lower and sparse forests as lower than that of plot 7 with higher elevation.

Temperature and soil fauna and flora affect litter decomposition rate. Among of these factors, temperature is most important. As already described above, air and soil temperatures decreased with increasing the elevation. Therefore, litter decomposition rate decreased gradually with increasing the elevation. We found that pH in the topsoils decreases with the elevation, affecting the litter decomposition rate. Values of pH also decreased with the elevation in the alpine of the Beartooth Plateau of Wyoming and Montana, U.S.A.[10]. It is considered that air and soil temperatures decrease with elevation and litter decomposition rate also decreases according increasing elevation. According these facts, Organic matter accumulated at higher elevation and soil water and soil becomes acidic.

If the global warming occurs, litter decomposition rate will be accelerated at higher elevation in subalpine area. Therefore, the acidity of topsoil will become more neutral and then subalpine site condition (Akaishi mountains) will change, habitat of *Tsuga diversifolia* which distributes at the ridge of Podozolic soil will change and *Abies* and other species will invade this habitat. Vegetational changes around snowpatch may be little if the accumulation of snow was not decreased so much. Distribution of *Pinus pumila* scrub closely correlates with the distribution of frozen soil. Certain species of alpine meadow are affected by the effect of day length more than the increasing temperate.

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