| Phyton (Austria) Special issue: "APGC 2004" | Vol. 45 | Fasc. 4 | (253)-(260) | 1.10.2005 |
|---|---|---|---|---|

# Climate Change and Shoot Elongation of Alpine Dwarf Pine (*Pinus pumila* Regel): Comparisons between Six Japanese Mountains

By

N. WADA[1], K. WATANUKI[2], K. NARITA[3], S. SUZUKI[4], G. KUDO[5] & A. KUME[2]

Key words: Alpine, climate change, *Pinus pumila*, shoot elongation.

Summary

WADA N., WATANUKI K., NARITA K., SUZUKI S., KUDO G. & KUME A. 2005. Climate change and shoot elongation of alpine dwarf pine (*Pinus pumila* Regel): comparisons between six Japanese mountains. – Phyton (Horn, Austria) 45 (4): (253)-(260).

In northern to central Japan, alpine dwarf pine (*Pinus pumila* Regel) is a principal component of vegetation in the alpine life zone above the timberline. In this study, we examined interannual variations in the shoot elongation of *P. pumila* growing on the summits of six Japanese mountains and analysed the relationships between climatic factors and shoot growth during the period from 1980 to 2003.

A significant increment of annual shoot elongation over the last 24 years was detected in three populations studied in central Japan, showing synchronization between the populations. However, such a trend was not found in the populations in northern Japan. In central Japan, interannual increasing trends in summer temperatures during the period were observed at meteorological stations near the populations. In the three populations of northern Japan, however, similar trends were not obvious, but a significant decreasing trend in summer sunshine duration was observed at a meteorological station located near the northernmost population. Summer sunshine duration, as well as summer temperature, was significantly positively correlated with shoot elongation of *P. pumila* in four out of six populations. We discuss these geographical variations in interannual shoot elongation of *P. pumila* between the six populations in relation to climate change in Japan.

[1] Center for Far Eastern Studies, Toyama University, 3190 Gofuku, Toyama 930-8555, Japan. Fax: +81-76-445-6549, e-mail: wada@sci.toyama-u.ac.jp

[2] Faculty of Science, Toyama University, Toyama 930-8555, Japan.

[3] Faculty of Education and Human Studies, Akita University, Akita 010-8502, Japan.

[4] Institute for Environmental Sciences, Aomori 039-3212, Japan.

[5] Graduate School of Environmental Earth Science, Hokkaido University, Sapporo 060-0810, Japan.

## Introduction

High mountain ecosystems where low temperature limits plant life are considered sensitive to climate change (KÖRNER 1994, GRABHERR & al. 1995). Because the impact of human land use has been scarce in high mountains, alpine life zones, such the summit of a mountain, provide a unique opportunity for comparative climate impact research (GRABHERR & al. 2000).

Alpine dwarf pine *Pinus pumila* Regel is distributed throughout north-eastern Asia in east Siberia, Ussuri, north-eastern China, Kamchatka, the Kuril Islands, and northern to central Japan (SHIMIZU 1982). In Japan, *P. pumila* is commonly found in high mountains and is a principal component of vegetation in the alpine life zone above the timberline (YOSHINO 1978). The pine begins to elongate its terminal bud in early June and terminates in late July (KAJIMOTO 1993). The shoot does not elongate further in the following years. Taking this feature into account, annual elongations of the past two to three decades are measurable (SANO & al. 1977, OKITSU 1988, TAKAHASHI 2003). It has been reported that annual shoot elongation of this species is positively correlated with summer temperatures (SANO & al. 1977, TAKAHASHI 2003) and sunshine durations (SANO & al. 1977) of the previous year. SANO & al. 1977 also observed a synchronization of interannual shoot growth of *P. pumila* between populations distributed over a wide region of Japan during the period from the early 1950s to the early 1970s. If recent climate change has raised summer temperatures even at high altitudes (WADA & al. 2004), interannual increases of shoot elongation are expected for *P. pumila*, showing a synchronization between populations in central to northern Japan. If this is the case, mountain biota and alpine biodiversity might be considerably affected by enhanced shoot growth of *P. pumila*, mostly because its high productivity and dense foliage (KAJIMOTO 1995) suppress the growth of other alpine plants. Thus, it is important to assess the interannual growth of the pine to help conserve alpine biodiversity.

In this study, we examined interannual variations in the shoot elongation of *P. pumila* growing on the summits of six Japanese mountains, and analysed the relationships between climatic factors and shoot growth of the alpine dwarf pine. The aims of this study were to 1) clarify whether interannual increasing trends in shoot elongation are observed in *P. pumila* in each population studied, 2) clarify interannual variations in air temperature, sunshine duration, and precipitation, that might affect interannual variations in shoot elongation, and 3) determine which factors (temperature, sunshine duration, and/or precipitation) significantly affect the annual shoot elongation of this pine species.

## Material and Methods

### Study sites and field methods

This study was carried out on six Japanese mountains: Mt. Kaun (Taisetsu Mountains), Mt. Oo (Hakkoda Mountains), and Mt. Chokai in northern Japan; and Mt. Johdo, Mt. Jii, and Mt. Norikura (Hida Mountains) in central Japan. At each study site, from late August to mid-September, 2003, we measured the annual shoot length over the last two to three decades of the main stems of *P. pumila* from different patches of the scrubs growing at the upper altitudinal limit on or near the summit (Table 1).

Data analysis

According to SANO & al. 1977, we calculated the shoot length chronology of *P. pumila* at each site by averaging the shoot length among the *P. pumila* scrubs in each year. The shoot length chronology at each site was determined from 1980 to 2003 (n = 24 years). A linear regression analysis was used to detect any interannual trend in the shoot elongation of each population of *P. pumila*. A simple correlation test was used to clarify any synchronization of interannual variations in shoot elongation between the six populations.

There was no available meteorological data set for each population of *P. pumila* studied. We chose five meteorological stations managed by the Japan Meteorological Agency (JMA) for our analysis of regional climate change near each study site (Table 1): Asahikawa station (N43°45.4' in latitude, E142°22.3' in longitude, and 120 m above sea level in altitude) located near Mt. Kaun, Aomori station (N40°49.3', E140°46.1', and 3 m a.s.l.) near Mt. Oo, Sakata station (N38°54.5', E 139°50.6', and 3 m a.s.l.) near Mt. Chokai, Toyama station (N36°42.5', E137°12.1', and 9 m a.s.l.) near Mt. Johdo, and Takayama station (N36°09.3', E137°15.2', and 560 m a.s.l.) near Mt. Jii and Mt. Norikura. Because the JMA replaced the sunshine recorders in 1986 or 1987, the sunshine duration data from each station were calibrated using a formula according to KATSUYAMA 1987. Monthly mean air temperature, monthly sum of sunshine duration after calibration, and monthly sum of precipitation for June, July, August, and September, were used for our analysis, taking the growing season for *P. pumila* in the alpine life zone into account. A linear regression analysis was used to detect any interannual increasing or decreasing trends in the air temperature, sunshine duration, or precipitation recorded by each meteorological station during the period from 1979 to 2003 (http://www.data.kisho.go.jp/index.htm). The slope of the regression line was shown as a trend in the interannual variation of each climatic variable. A simple correlation test was used to determine which climatic factors significantly affected shoot elongation of *P. pumila* in each population studied. The shoot elongation in each population was compared with the meteorological data of the previous growth period (June, July, August, and September in the previous year) and of the current growth period (June, July, and August in the current year).

Table 1. Location of study sites for *Pinus pumila* and the Japan Meteorological Agency (JMA) stations whose data were used to analyze the relationships between climatic factors and *P. pumila* shoot growth. The numbers in parentheses in the "Altitude" column show the number of *P. pumila* samples. "Distance" means the horizontal distance between each study site and the corresponding JMA meteorological station.

| | Latitude | Longitude | Altitude | Summit | JMA station | Distance |
|---|---|---|---|---|---|---|
| Mt. Kaun | N43°33.4' | E142°52.0' | 1910 m (24) | 1954 m | Asahikawa | 48 km |
| Mt. Oo | N40°39.5' | E140°52.5' | 1550 m (19) | 1585 m | Aomori | 25 km |
| Mt. Chokai | N39°05.7' | E139°02.6' | 2110 m (29) | 2236 m | Sakata | 38 km |
| Mt. Johdo | N36°33.8' | E137°36.5' | 2830 m (39) | 2831 m | Toyama | 40 km |
| Mt. Jii | N36°24.5' | E137°35.7' | 2820 m (10) | 2825 m | Takayama | 42 km |
| Mt. Norikura | N36°06.7' | E137°33.3' | 2820 m (19) | 3026 m | Takayama | 28 km |

## Results and Discussion

Annual shoot elongation of *P. pumila* growing in northern Japan (Mt. Kaun, Mt. Oo, and Mt. Chokai) showed little synchronization with that of any other population, while that in central Japan (Mt. Johdo, Mt. Jii, and Mt. Norikura) was significantly synchronized between the three populations (Table 2 and Fig. 1).

A significant interannual increase of the shoot elongation was detected in populations on Mt. Johdo (0.020 cm $yr^{-1}$ (= slope of the regression line), $F = 5.64$, $r^2 = 0.17$, $p = 0.027$), Mt. Jii (0.052 cm $yr^{-1}$, $F = 20.96$, $r^2 = 0.47$, $p < 0.0001$), and Mt. Norikura (0.036 cm $yr^{-1}$, $F = 7.72$, $r^2 = 0.23$, $p = 0.011$). The other three populations distributed in northern Japan showed no significant trends in the linear regression analysis ($r^2 < 0.10$, $p > 0.05$). However, it appears that annual shoot elongation decreased after 1995 for a population on Mt. Kaun, and after 1989 on Mt. Chokai (Fig. 1).

Table 2. Correlation coefficients between populations of annual shoot elongation of *Pinus pumila* over the last 24 years (1980-2003). Asterisks denote statistical significance: $^{**}$, $p < 0.01$; $^{***}$, $p < 0.0001$ (by the Pearson correlation test).

| | Mt. Kaun | Mt. Oo | Mt. Chokai | Mt. Johdo | Mt. Jii |
|---|---|---|---|---|---|
| Mt. Oo | -0.09 | - | - | - | - |
| Mt. Chokai | 0.04 | 0.38 | - | - | - |
| Mt. Johdo | -0.38 | 0.10 | 0.19 | - | - |
| Mt. Jii | -0.24 | -0.21 | -0.14 | $0.61^{**}$ | - |
| Mt. Norikura | -0.19 | -0.09 | 0.12 | $0.71^{***}$ | $0.68^{**}$ |

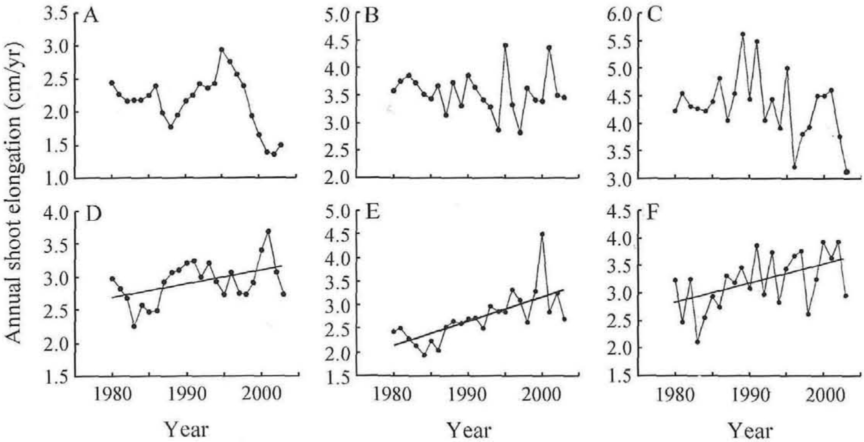


Fig. 1. Interannual variation in *Pinus pumila* shoot elongation (average value) from 1980 to 2003 (n = 24 years). A, Mt. Kaun (N = 24 shoots); B, Mt. Oo (N = 19 shoots); C, Mt. Chokai (N = 29 shoots); D, Mt. Johdo (N = 39 shoots); E, Mt. Jii (N = 10 shoots); F, Mt. Norikura (N = 19 shoots). Regression lines are shown when significant ($p < 0.05$).

We analysed the increasing or decreasing trends in interannual variations in air temperature, sunshine duration, and precipitation in June, July, August, and September, at the JMA meteorological station located near each study site (Fig. 2).

Monthly mean air temperature in both July and September increased significantly over the last 25 years in Toyama and Takayama, both located in central Japan. This suggests that increased temperatures may have caused increased annual shoot elongation in the *P. pumila* populations growing on Mt. Johdo, Mt. Jii, and Mt. Norikura during this period (Fig. 1). In northern Japan, the monthly mean air temperatures in mid-summer did not increase significantly, but those for September did in Aomori and Sakata. No significant trend was found in any month in Asahikawa. In contrast, the sunshine duration in July and August decreased significantly over the last 25 years in Asahikawa. A significant decreasing trend was also found in September in Aomori and in June in Toyama.

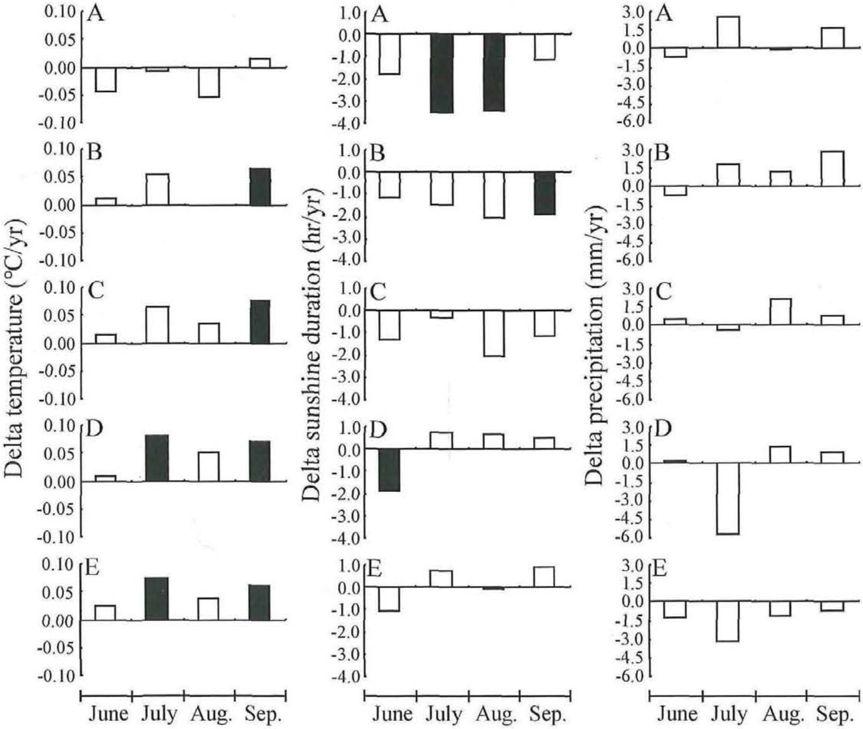


Fig. 2. Trends in interannual variation in temperature (delta temperature), sunshine duration (delta sunshine duration), and precipitation (delta precipitation) from 1979 to 2003 (n = 25 years) analyzed by the linear regression model. The slopes of the regression lines reflect trends in climate change in June, July, August, and September. Shaded bars: significant slopes of the regression between climatic variables and year according to the linear regression model ($p < 0.05$). Open bars: non-significant slopes ($p > 0.05$). A, Asahikawa meteorological station; B, Aomori station; C, Sakata station; D, Toyama station; E, Takayama station. Data from the Japan Meteorological Agency (http://www.data.kisho.go.jp/index.htm).

There was no clear trend in summer precipitation at each meteorological station. Thus, it appears that a rising trend in mid-summer temperatures was notable in parts of central Japan, while a decreasing trend in sunshine duration was conspicuous in northernmost Japan.

In northern Japan, the annual shoot elongation of *P. pumila* was significantly positively correlated with summer temperatures (June and July) of the previous year for the population on Mt. Oo, but the other two populations did not show any significant correlation between annual shoot elongation and summer temperatures (Fig. 3). However, the shoot elongation was significantly positively correlated with sunshine duration in July or August of the previous year in each of these three populations (Fig. 3). In contrast, all three populations studied in central Japan showed significantly positive correlations between annual shoot elongation and summer temperatures (Fig. 3). However, the populations on Mt. Johdo and Mt. Jii showed a pattern of correlations that differed from that of the population on Mt. Norikura: in these two populations, temperatures in both September of the previous year and July of the current year were significantly positively correlated with annual shoot elongation. Sunshine duration was not significantly correlated with the annual shoot elongation, except for the population on Mt. Norikura (Fig. 3). Significant negative correlations between annual shoot elongation and precipitation were found for the populations on Mt. Kaun, Mt. Johdo, and Mt. Norikura (Fig. 3). This was probably because higher precipitation would be accompanied by shorter sunshine duration and lower solar radiation, which will decrease the rate of photosynthesis in *P. pumila*, resulting in lower shoot growth. Significant negative correlations between precipitation and sunshine duration in July were found in Asahikawa ($r = -0.54$, $p = 0.004$, $n = 25$), Toyama ($r = -0.43$, $p = 0.031$, $n = 25$), and Takayama ($r = -0.61$, $p = 0.0008$, $n = 25$).

It is well known that shoot growth of *P. pumila* depends on climatic conditions of the previous year, because bud formation occured in the previous year. Our study reconfirmed this in the six populations studied. However, two populations showed that not only summer climatic conditions in the previous year but also those in the current year were significantly correlated with the annual shoot elongation. Our stepwise regression analysis showed that both temperature in September of the previous year ($t_{SP}$) and that in July of the current year ($t_{JC}$) contributed to the annual shoot elongation (standardized partial correlation coefficient r ($t_{SP}$) = 0.43 ($p = 0.03$) and r ($t_{JC}$) = 0.36 ($p = 0.05$) for the population on Mt. Johdo; r ($t_{SP}$) = 0.40 ($p = 0.04$) and r ($t_{JC}$) = 0.37 ($p = 0.05$) for the population on Mt. Jii). The reason and the mechanism for this are uncertain from the present study; however, it seems reasonable that the combination of climatic conditions in the previous year with those in the current year would affect the shoot growth. In the region where the two populations on Mt. Johdo and Mt. Jii were distributed, temperatures in both July and September showed significant interannual increases over the last 25 years (Fig. 2). This suggests that increasing temperatures in September may enhance the photosynthetic production and then bud formation in the prolonged growing season length and those in July may improve directly the limits of low temperature for the growth of *P. pumila*. However, further studies, based on physiological measurements such as photosynthetic carbon gains and temporal resource allocations, are necessary to clarify the temporal and the geographical variations in the shoot growth of the pine.

In central Japan, *P. pumila* showed significant interannual increases in shoot elongation and the growth was correlated significantly with temperatures in July or both July and September, which had increased during the 25-year periods.

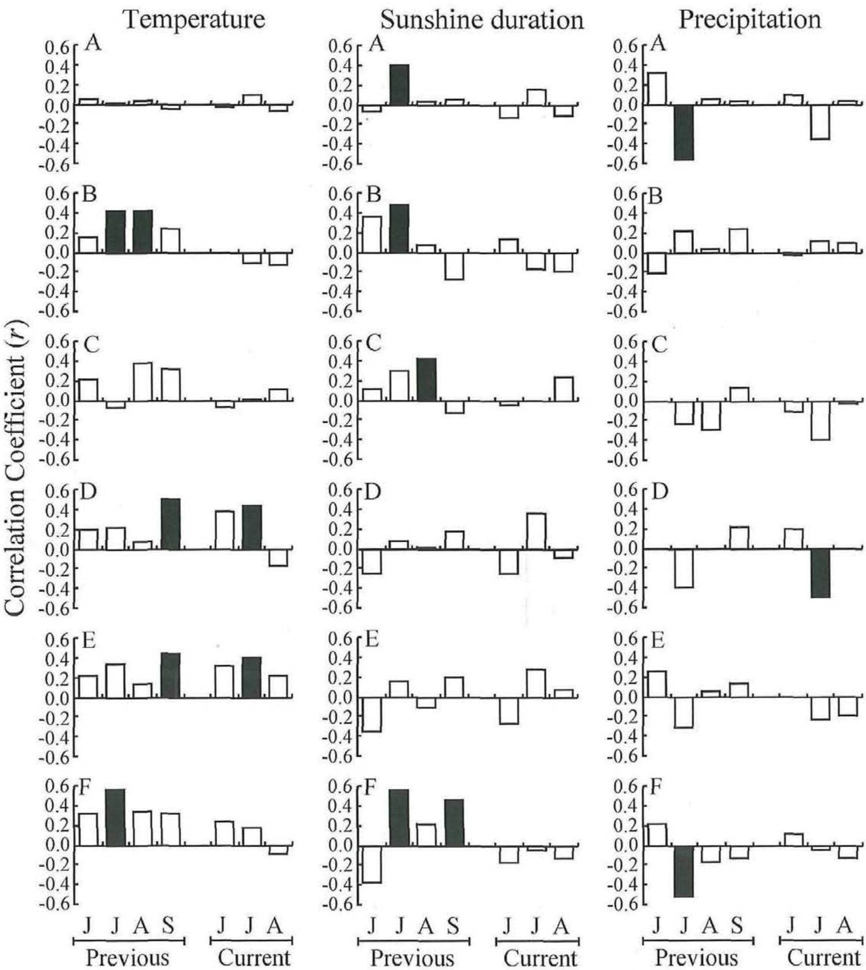


Fig. 3. Correlation coefficients between the annual shoot elongation of *Pinus pumila* and the monthly climatic conditions (monthly mean temperature, monthly sum of sunshine duration, and monthly sum of precipitation) of the previous year and the current year. A, Mt. Kaun; B, Mt. Oo; C, Mt. Chokai; D, Mt. Johdo; E. Mt. Jii; F, Mt. Norikura. Shaded bars indicate significant correlations ($p < 0.05$ by the Pearson correlation test).

In northern Japan, however, *P. pumila* showed no significant interannual increases in shoot elongation and the growth was significantly correlated with sunshine duration in July or August rather than with temperatures in two out of the three populations studied. Sunshine duration in July and August decreased significantly during the period in the region where the northernmost population was distributed. Thus, geographical variations in the annual shoot elongation of *P. pumila* may be caused by different changes in recent climate regimes (ASANUMA & al. 2004), associated with the atmospheric circulation of air masses in northern to central Japan (e.g., SATO & TAKAHASHI 2001).

## Acknowledgements

We would like to thank T. KASAGI, N. IMAMURA , T. KAWAMORITA and R. MATSUZATO for their assistance on field surveys. This study was in part supported by a grant from the Ministry of Education, Science, Sports, Culture and Technology of Japan (Nos. 13440226 and 16370007) .

## References

ASANUMA J., KAMIMERA H. & LU M. 2004. Pan evaporation trends in Japan and its relevance to the variability of the hydrological cycle. – Tenki 51: 667-678 (in Japanese).

GRABHERR G., GOTTFRIED M. & PAULI H. 2000. GLORIA: a global observation research initiative in alpine environments. – Mountain Res. Develop. 20: 190-191.

— , GOTTFRIED M., GRUBER A. & PAULI H. 1995. Patterns and current changes in alpine plant diversity. – In: CHAPIN III F. S. & KÖRNER CH. (Eds.), Arctic and alpine biodiversity, pp. 167-181. – Springer-Velag, Berlin, Heidelberg.

KAJIMOTO T. 1993. Shoot dynamics of *Pinus pumila* in relation to altitudinal and wind exposure gradients on the Kiso mountain range, central Japan. – Tree Physiol. 13: 41-53.

— 1995. Ecological characteristics of *Pinus pumila* with special reference to dry matter production and regeneration. – Jpn. J. Ecol. 45: 57-72 (in Japanese with English summary).

KATSUYAMA M. 1987. On comparison between rotating mirror sunshine recorders and Jordan sunshine recorders. – Weather Service Bulletin 54: 169-183 (in Japanese).

KÖRNER CH. 1994. Impact of atmospheric changes on high mountain vegetation. – In: BENISTON M. (Ed.), Mountain environments in changing climates, pp. 155-166. – Routledge, London.

OKITSU S. 1988. Geographical variations of annual fluctuations in stem elongation of *Pinus pumila* Regel on high mountains of Japan. – Jpn. J. Ecol. 38: 177-183 (in Japanese with English summary).

SANO Y., MATANO T. & UJIHARA A. 1977. Growth of *Pinus pumila* and climate fluctuation in Japan. - Nature 266: 159-161.

SATO N. & TAKAHASHI M. 2001. Long-term variations of the Baiu Frontal zone and midsummer weather in Japan. - J. Meteor. Soc. Japan 79: 759-770.

SHIMIZU T. 1982. The new alpine flora of Japan in color. Vol. I. - Hoikusha Publishing, Tokyo (in Japanese).

TAKAHASHI K. 2003. Effects of climatic conditions on shoot elongation of alpine dwarf pine (*Pinus pumila*) at its upper and lower altitudinal limits in central Japan. - Arc. Antarc. Alp. Res. 35: 1-7.

WADA N., KAWADA K., KAWAMURA R., AOKI K. & KUME A. 2004. Increasing winter runoff in a middle-latitude mountain area of central Japan. - J. Meteor. Soc. Japan 82: 1589-1597.

YOSHINO M. M. 1978. Altitudinal vegetation belts of Japan with special reference to climatic conditions. - Arc. Alp. Res. 10: 449-456.

Zeitschrift/Journal: Phyton, Annales Rei Botanicae, Horn

Jahr/Year: 2005

Band/Volume: 45_4

Autor(en)/Author(s): Wada N., Watanuki K., Kume A., Narita K., Suzuki S., Kudo G.

Artikel/Article: Climata Change and Shoot Elongation of Alpine Dwarf Pine (Pinus pumila Regel): Comparisons between Six Japanese Mountains. 253-260