Proc. NIPR Symp. Polar Biol., **11**, 147–158, 1998

SHORT-TERM EFFECTS OF WIND SHIELD ON PHENOLOGY AND GROWTH OF ALPINE PLANTS IN MOUNT KISO-KOMAGATAKE, CENTRAL JAPAN

Satoshi FUKUYO[1], Midori KURIHARA[2], Ikuko NAKASHINDEN[3], Keiji KIMURA[3], Yoshihiro IIJIMA[4], Yoichiro KOBAYASHI[5], Tadashi MASUZAWA[1], Satoko YAMAMOTO[1], Maki MORIMOTO[3], Tetsuya KOUYAMA[2], Shingo KOBAYASHI[6], Takahito YAMAMOTO[6], Kazuharu MIZUNO[7] and Hiroyuki MACHIDA[8]

[1] *Department of Agriculture, University of Tokyo Agricultural and Technology, 5–8, Saiwaicho 3-chome, Fuchu-shi, Tokyo 183-0054*
[2] *Department of Geography, Kokushikan University, 28–1, Setagaya 4-chome, Setagaya-ku, Tokyo 154-8515*
[3] *Department of Geography, Graduate School of Science, the University of Tokyo, 3–1, Hongo 7-chome, Bunkyo-ku, Tokyo 113-0033*
[4] *Department of Geography, Faculty of Science, Tokyo Metropolitan University, 1–1, Minami Ohsawa, Hachioji-shi, Tokyo 192–0364*
[5] *Department of Geography, Housei University, 17–1, Fujimi 2-chome, Chiyoda-ku, Tokyo 102-0071*
[6] *Ehime Prefectural Science Museum, 2133-2 Daishoin, Niihama 792-0060*
[7] *Center for African Area Studies, Kyoto University, 46 Shimoadachi-cho, Yoshida, Sakyo-ku, Kyoto 606–8304*
[8] *Sano Junior High School of Nihon University, 2555 Ishizuka-cho, Sano 327–0103*

Abstract: To determine the effect of wind on alpine plants, we set up five wind-shields (called WS) on a wind-blown alpine dwarf shrub community on Mount Kiso-komagatake (2956 m), in the Central Japanese Alps, in June 1996. Air temperature at vegetation height, soil temperature, and relative humidity on the windward side of the WS plots and control plots were recorded. Phenological observations and growth measurements of five species, *Diapensia lapponica* var. *obovata*, *Empetrum nigrum* var. *japonicum*, *Loiseleuria procumbens*, *Arctous alpinus* var. *japonicus* and *Vaccinium uliginosum*, were conducted from June to October. By setting up the WSs, the daily mean temperature did not change significantly in comparison with the control plots. Growth periods of four species, except for *D. lapponica* var. *obovata*, were extended at the WS plots, and *E. nigrum* var. *japonicum*, *L. procumbens* and *V. uliginosum* bloomed earlier at the WS plots. Annual shoot length of *E. nigrum* var. *japonicum*, *L. procumbens* and *V. uliginosum* was longer at the WS plots. These results suggest that one of the important effects of wind on the alpine plants was the restriction of shoot growth, probably due to decreasing leaf temperature. The effect of the wind shield was not significant for *D. lapponica* var. *obovata*, which has a mat-shaped growth form.

key words: alpine plant, phenology, shoot elongation, climatic change, wind

Introduction

Distribution and growth of arctic and alpine plants are mainly determined by temperature, water and nutrient availability. Some experimental studies have shown the effects of these factors on plant growth in alpine and arctic regions (WOOKEY *et al.*, 1993; PARSONS *et al.*, 1994; NAKASHINDEN *et al.*, 1997). However, distribution and growth of alpine plants are also determined by wind, snow depth, and geological features. In the Japanese high mountains, a strong west wind prevails year round. In winter, strong wind affects the distribution of snow accumulation which directly determines the time of snow melt and length of the growing season. Therefore, wind is one of the potential factors affecting the growth and distribution of alpine plants.

There are some studies indicating the effects of wind on the distribution of alpine plants (KOIZUMI, 1974; TAKAHASHI and SATO, 1994), but few studies of the direct effects of wind on plant growth (WILSON, 1959). To assess the effect of prevailing wind on the growth and phenology of alpine plants on Mount Kiso-komagatake (2956 m a.s.l.), in early June of 1996, we selected an experimental site on a wind-blown alpine fellfield, and set up five wind-shields (called WS) windward of an alpine plant community. The phenology and shoot growth of five alpine plants were recorded at the WS plots and the control plots. In this paper, we introduce the results of this experiment in the first year.

Study Site

Mount Kiso-komagatake (2956 m a.s.l.) is located in the central mountain area of Honshu (35°47′N, 137°49′E) (Fig. 1). Above timberline (*ca.* 2600 m a.s.l.), glacial and periglacial landforms such as cirques, moraines, block fields, and fellfields with patterned grounds were formed during 10000–80000 BP (YANAGIMACHI, 1983). Alpine heath, alpine dwarf-shrub and *Pinus pumila* communities are distributed in a mosaic pattern. On 8th June 1996, an experimental site was set up on a slope with turf-banked terraces at about 2850 m a. s. l. where an alpine heath community dominated. Major component species of this community were *Diapensia lapponica* var. *obovata*, *Potentilla matsumurae*, *Stellaria nipponica*, *Leontopodium shinanense* and *Vaccinium uliginosum* (KOIZUMI, 1980). Mean monthly temperatures near the experimental site (*ca.* 2650 m a.s.l.) ranged from −12.1°C (January) to 11.9°C (August), with mean annual temperature at 0.8°C (1990 to 1992; measured by Mr. T. KINOSHITA, Chuo Alps Kanko Co., Ltd.). Snow usually covers a large part of the mountain from early November to early May. There is sparse snow cover around this experimental site due to strong westerly wind during winter. Snow depth in January 1997 was about 20 cm.

Methods

To reduce the wind effects, five wind-shields (Fig. 2) were set up on the experimental site on 8th June, 1996. Each wind-shield (WS) was made of two transparent acrylic resin boards and an aluminum corner connecting the two boards at an angle of 108 degrees (Fig. 3). A pentagonal plot with 40 cm sides was set up at the leeward of each

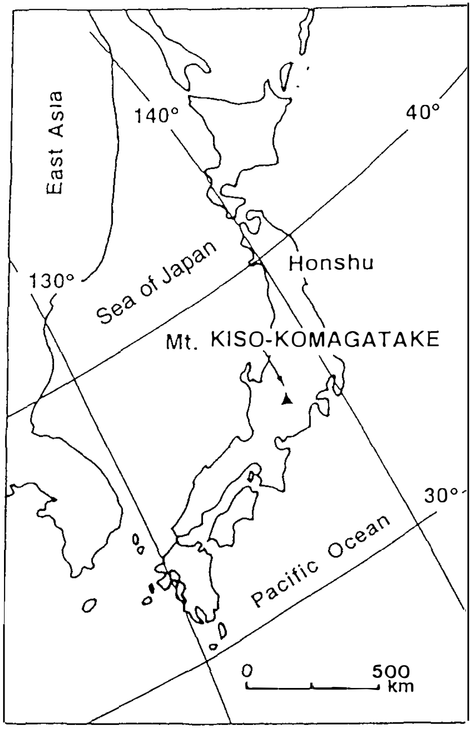

Fig. 1. The study site on Mt. Kiso-komagatake (2956 m), in the Kiso Mountains of central Japan (from NAKASHINDEN *et al.*, 1997).

Fig. 2. The experimental site including five WS plots was set at an elevation of 2850 m above sea level (July, 1996).

WS (WS-A to E). Two sides of the pentagon were parallel to the WS. Six square plots (50 cm × 50 cm) were selected as controls (called CTRL-1 to 6) near the WSs. Experimental surveys of plant phenology and shoot growth were carried out at these eleven plots. Two thermistor sensors (Kona-System Co., Ltd., Sapporo, Japan) were set inside

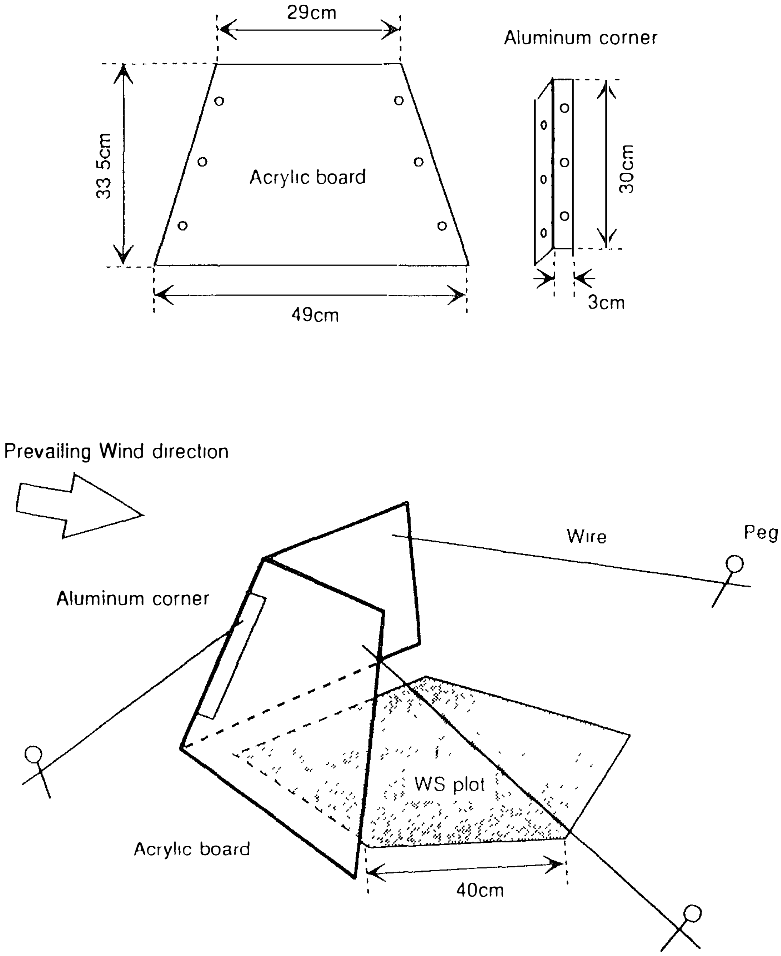

Fig 3. Structure of wind-shield. Each WS was made of acrylic boards and an aluminum corner, and was set against the prevailing wind direction (WSW)

WS-A and CTRL-2 to measure temperature. One sensor shielded from direct sunlight was set at vegetation height (5 cm above the ground) for measurement of air temperature, and the other was set at 3 cm below the ground surface for measurement of soil temperature. Temperatures were recorded once per hour by an automatic recorder (Kadec U2, Kona-System Co., Ltd., Sapporo, Japan) from 17th July to 30th August. An automatic recorder with sensor was set at height 10 cm for measurement of relative humidity inside WS-B and CTRL-3 (StowAway, Onset Computer Co., Ltd., USA.). Relative humidity was recorded once per hour from 8th August to 30th August. Within the experimental site, near the WS and the CTRL plots, air temperature at height 1.2 m was recorded once per hour from 8th June to 12th October. Wind direction and velocity (*ca.* 3 m high) were measured and recorded once per hour from 17th July to 30th August.

We observed the percentage cover of each plant species in the WS and CTRL plots (Table 1). Three evergreen dwarf shrub species, *Diapensia lapponica* var. *obovata*, *Empetrum nigrum* var. *japonicum* and *Loiseleuria procumbens*, and two deciduous dwarf shrub species, *Arctous alpinus* var. *japonicus* and *Vaccinium uliginosum* were selected for phenological observation and growth measurements.

Phenological events of *D. lapponica* var. *obovata* was observed at four plots (two

Table 1. Plant cover (%) of each species at the study site.

Plot	Wind shields					Controls					
	A	B	C	D	E	1	2	3	4	5	6
Plant cover (%)	90	70	85	75	80	70	85	85	60	85	80
Species											
Carex vanheurckii	10	5	5	5	5	5	10	3	5	3	10
Vaccinium uliginosum	15	5	30	15	20	5	40	15	15	20	3
Arcterica nana	5	3		10	5	1	10	3	5		1
Potentilla matsumurae		+	5	5	3		3		5	5	5
Arctous alpinus var. *japonicus*	10	10		3	3		5	+	+		20
Gentiana algida	+	+	3		3		1		1	1	1
Empetrum nigrum var. *japonicum*	20	20		35		40		25	25		3
Oxytropis japonica			3		1					5	3
Diapensia lapponica var. *obovata*			35		30		20			40	
Minuartia hondonensis			1		+						1
Calamagrostis sp.					10					10	
Loiseleuria procumbens	30	25	5	+		20	+	40	3		30
Euphrasia matsumurae			+							+	
Pinus pumila								+			
Leontopodium shinanense										+	
Agrostis flaccida						+					

Surveyed on July 27, 1996. +Means < 1%. Modified Braun-Blanquet (1964).

WS plots and two CTRL plots) and those of *E. nigrum* var. *japonicum*, *L. procumbens*, *A. alpinus* var. *japonicus* and *V. uliginosum* at six plots (three WS plots and three CTRL plots ; except for *L. procumbens* which existed at only two WS plots). The most frequent phenological stage was recorded for the five species at each plot at six- to eight-days intervals from 8th June to 12th October. For *D. lapponica* var. *obovata*, we observed the leaf phenology irrespective of leaf age as follows: (1) more than 10% of leaves are green in early season, (2) more than 50% in early season, (3) more than 10% were colored in late season, and (4) more than 50% were colored in late season. For *E. nigrum* var. *japonicum* and *L. procumbens*, the stages were (1) bud, (2) bud-break, (3) leaf expansion, and (4) full leaves. For *A. alpinus* var. *japonicus* and *V. uliginosum*, the stages were (1) bud, (2) bud-break, (3) leaf expansion, (4) full leaves, (5) more than 10% of leaves coloring, (6) more than 50%, (7) more than 10% were wilting, and (8) more than 50%. To analyze the phenological results, we took the date of an observed phenological change to be halfway between the dates before and after the change. The mean date of each phenological change for the two or three WS plots was compared with that of the CTRL plots. The flowering period of each species was recorded and analyzed similarly.

Growth measurement was conducted for 10 to 15 current shoots in each species (except for *D. lapponica* var. *obovata*) at more than three plots from late August to early September. We selected the current shoots beyond the tops of previous shoots. The shoot elongation, number of leaves and number of branches (shoots growing from the previous year's shoot) of *E. nigrum* var. *japonicum* and *L. procumbens* were measured on 30th and 31st August and 7th September in 1996. The shoot elongation, number of leaves and number of branches of *A. alpinus* var. *japonicus* and *V. uliginosum* were measured on 17th, 30th and 31st August in 1996.

The differences of meteorological and biological data recorded between the WS plots and the CTRL plots were statistically analyzed by the Mann-Whitney *U*-test.

Results

Microclimate

Mean air temperature at the site during the observation period (8th June to 12th October) was 8.0°C. Temperature increased gradually from June to July, remained high and then decreased gradually from late August to October (Fig. 4). Mean temperature from late July to late August was 10.8°C (Table 2).

Frequencies of west-southwest wind, southwest and east wind were high, 23.6%, 21.6% and 16.0%, respectively, from 17th July to 30th August (Fig. 5A, B). The velocity of west-southwest wind, southwest wind and east wind were 7.5 m/s, 7.1 m/s and 5.2 m/s, respectively. Westerly winds were more frequent and stronger than easterly wind.

Mean temperature at vegetation-height from 17th July to 30th August was 14.4°C at WS-A, and 0.1°C lower at CTRL-2 (Table 2): there was no significant difference between them ($p > 0.05$) except at 1900. At night, the temperatures at both plots were around 8°C. The temperature increased at 0600 and reached around 25°C at 1100, then decreased from 1500 and was under 10°C before 2000 (Fig. 6A).

Mean soil temperature was 14.0°C at WS-A and 14.5°C at CTRL-2 (Table 2), and there was no significant difference between them ($p > 0.05$). At night, the temperature at WS-A was about 2°C lower than that at CTRL-2, and the difference was significant ($p < 0.05$). But the temperature at WS-A was the same as that at CTRL-2 around 1000 and reached more than 20°C at 1200, then decreased from 1600 (Fig. 6B).

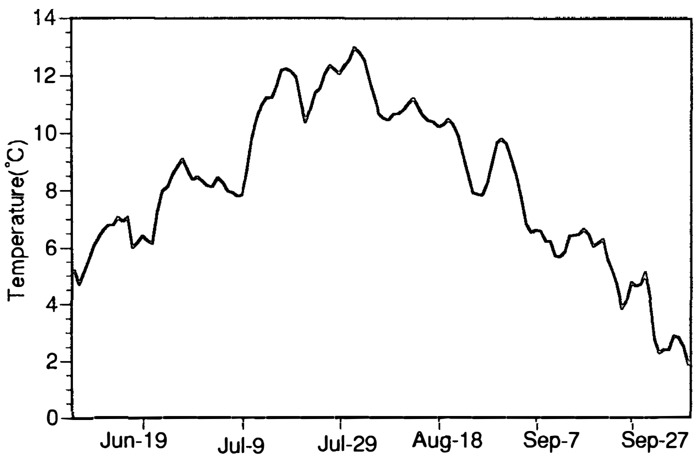

Fig 4 Mean daily air temperature at 1 2m height above the ground surface Air temperature was recorded once each hour from June-2 to October-13, 1996 The temperature was more than 10°C in mid-July to mid-August, the highest daily temperature was 14°C in on July 17

Table 2. Mean, maximum and minimum values of microclimate at the study site in July and August 1996.

	Air temperature (°C)	Wind velocity (m/s)	Vegetation height (°C)		Ground (°C)		Relative humidity (%)	
			WS-A	CTRL-2	WS-A	CTRL-2	WS-B	CTRL-3
Mean	10.8	7.7	14.4	14.3	14.1	14.5	72.8	75.8
(SD)	(2.6)	(4.9)	(8.5)	(7.7)	(5.5)	(4.8)	(26.8)	(28.9)
Max	20.2	33.9	46.1	39.9	30	29	100	100
Min.	5	1.1	2.6	2.2	5	6	13.9	9.7
Period	July 17 to Aug. 30	July 17 to Aug. 30	July 17 to Aug. 30	July 17 to Aug. 30	July 17 to Aug 30	July 17 to Aug. 30	Aug. 8 to Aug. 30	Aug 8 to Aug 30

Mean, Max. and Min. are mean, the highest and lowest hourly value during recording period, respectively.

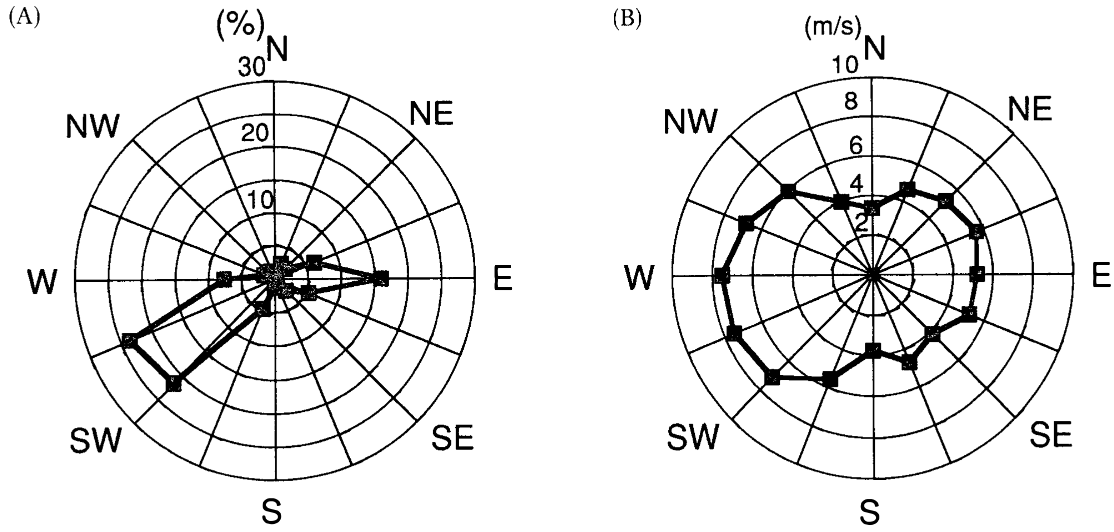

Fig. 5. (A) Frequency and (B) mean velocity of wind direction at the study site. They were recorded once each hour from July 17 to August 30, 1996. West-southwest, southwest and east winds were frequent at the site. Westerly winds were stronger than easterly winds.

Mean hourly relative humidity was 72.8% at WS-B and 75.8% at CTRL-3 (Table 2). There was no difference between them ($p > 0.05$). The values at both WS-B and CTRL-3 were almost the same during the daytime. At night, the value at WS-B was around 90%, but it was 2.7% to 4.4% higher at CTRL-3 and the difference was significant ($p < 0.05$).

These results indicate that the microclimate other than wind condition during the day time was not so changed by the WSs.

Phenology of five species

Times of each phenological events of five species were observed in the CTRL plots (Fig. 7). More than 50% of *D. lapponica* var. *obovata* leaves turned to green by mid-June, and bud-break of *A. alpinus* var. *japonicus* and *V. uliginosum* occurred at the same time. In early July, bud-break of *E. nigrum* var. *japonicum* and *L. procumbens* occurred, and

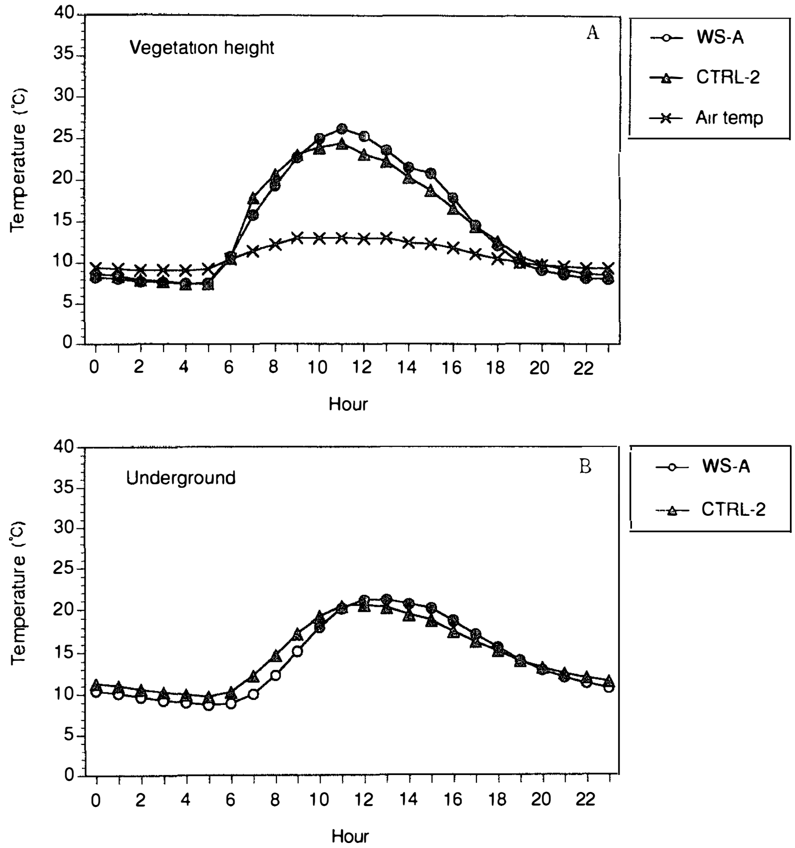

Fig. 6. (A) Mean hourly temperature at vegetation-height (about 5 cm height above the ground) (B) Mean hourly soil temperature (3 cm below the ground surface) at WS-A and CTRL-2 The temperatures were recorded once each hour from July 17 to August 30, 1996. Open circles show that the data at the WS plots were significantly different from those at CTRL-2 ($p<0.05$) There were no significant differences between temperatures at WS-A and at CTRL-2 during the daytime

leaf expansion of *A. alpinus* var. *japonicus* and *V. uliginosum* started, after which it continued for 10 to 15 days. After that, *E. nigrum* var. *japonicum* and *L. procumbens* began leaf expansion and shoot growth. The leaves of *A. alpinus* var. *japonicus* and *V. uliginosum* turned to red by late August, and began to wilt in early September. The leaves of *D. lapponica* var. *obovata* began to change color to purple for low temperature acclimation in mid-September.

Flowering of *E. nigrum* var. *japonicum* occurred in mid-June and lasted for 9 days. Then, *L. procumbens* and *D. lapponica* var. *obovata* began to bloom in late June, continuing for 15 and 19 days, respectively. After that *V. uliginosum* began to bloom in late July, the flowering lasted for 8 days.

The major differences in phenological events between the WS and the CTRL plots were as follows: leaf expansion of *L. procumbens* occurred 8 days earlier at the WS plots than at the CTRL plots; leaf coloring and wilting of *A. alpinus* var. *japonicus* were delayed at the WS plots for 10 days and 12 days, respectively; leaf wilting of *V. uliginosum* was delayed at the WS plots for 13 days. Except for *D. lapponica* var. *obovata*, the growth period (the period of leaf expansion and full leaves) of each species was extended.

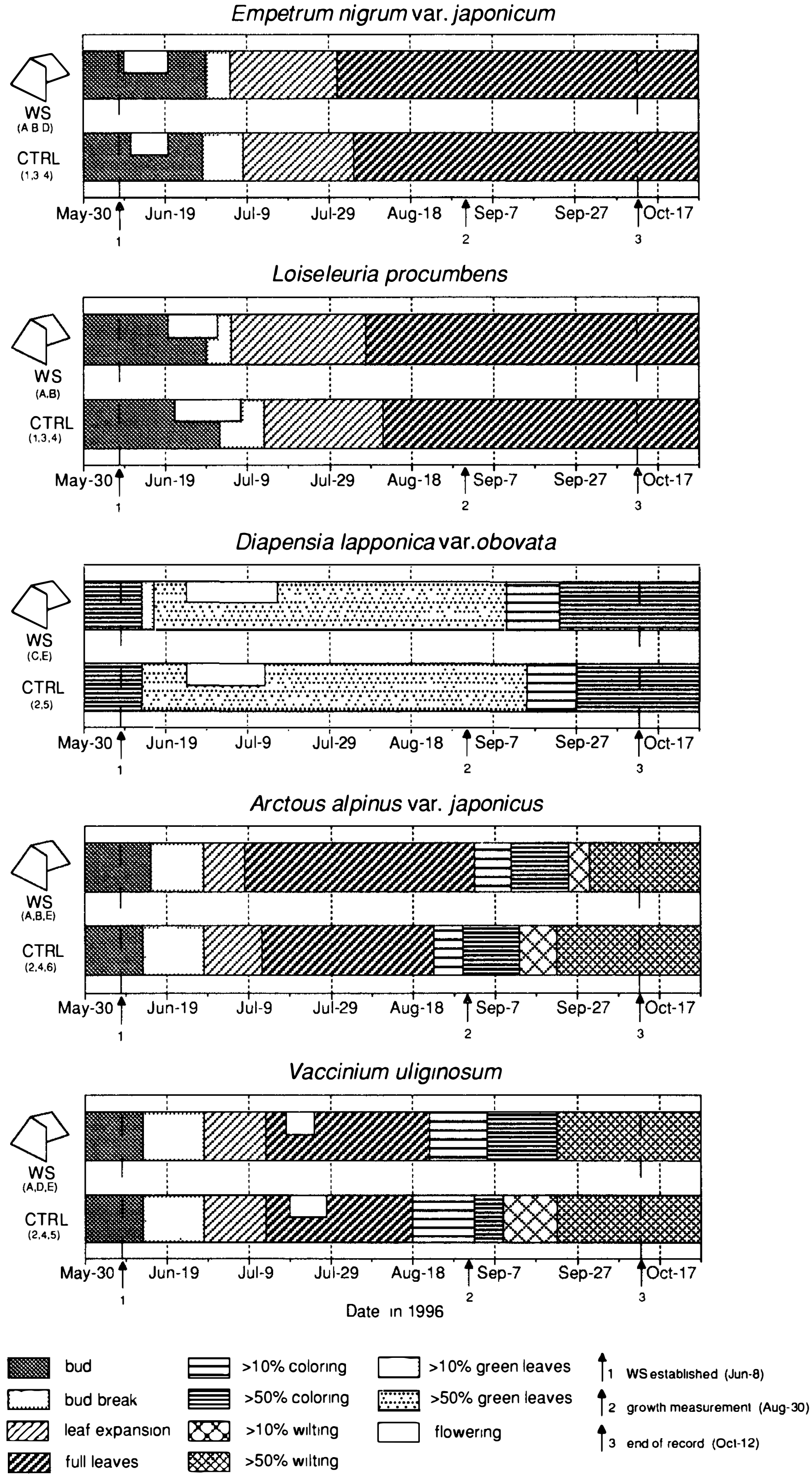

Fig. 7. Leaf and flower phenology of the five species in 1996. The days of each leaf phenological stage is the average of two or three plots shown in parentheses. The flowering period is an average period over two or three plots.

Table 3. Growth characteristics of 1996 shoots of four species.

Number of measurement shoots were as follows, *E. nigrum* var. *japonicum*, *L. procumbens*, *A. alpinus* var. *japonicus*, and *V. uliginosum* were 16, 25, 15, and 29, respectively at the WSs and 26, 27, 15, and 30, respectively at the CTRLs.

	Wind shields		Controls	
	Average	SD	Average	SD
Empetrum nigrum var. *japonicum*				
Shoot length (mm)	9.8**	3.2	7.1	3.0
Leaf number	33.1	6.5	32.6	8.0
Branch number	3.1	2.8	2.5	2.7
Loiseleuria procumbens				
Shoot length (mm)	7.8***	2.9	5.4	2.7
Leaf number	5.8	1.4	6.2	1.2
Branch number	1.2	1.5	1.2	1.4
Arctous alpinus var. *japonicus*				
Shoot length (mm)	4.4	1.8	4.3	1.4
Leaf number	7.3*	1.2	8.0	1.3
Branch number	1.0	0.0	1.0	0.0
Vaccinium uliginosum				
Shoot length (mm)	6.4*	2.7	4.7	2.2
Leaf number	7.0	1.1	5.9	1.2
Branch number	2.2	1.6	2.4	1.8

* $p < 0.05$, ** $p < 0.01$; *** $p < 0.001$.

First flowering of *E. nigrum* var. *japonicum*, *L. procumbens* and *V. uliginosum* at the WS plots occurred 2 days earlier than at the CTRL plots. There was no difference in the first flowering date of *D. lapponica* var. *obovata* between the plots. There were no flowers of *A. alpinus* var. *japonicus* in either the WS or the CTRL plots.

Shoot growth of four species

Although we measured shoot growth over two different periods (late August and early September), the growth of the four species was already stopped by late August, and the differences in values between the two periods were not significant ($p > 0.05$), so the values from both periods were analyzed together (Table 3). The current shoots of *E. nigrum* var. *japonicum*, *L. procumbens* and *V. uliginosum* were significantly longer at the WS plots than those at the CTRL plots ($p < 0.01$, $p < 0.001$ and $p < 0.05$, respectively). The number of leaves of *A. alpinus* var. *japonicus* was lower at the WS plots than at the CTRL plots ($p < 0.05$), but there were no significant differences in the number of leaves for the other three species. In all species, there were no differences in the branching number between the WS and the CTRL plots.

Discussion

By setting up the WSs, the mean hourly temperature at vegetation-height and soil temperature, and the mean hourly relative humidity were not changed during the daytime in July and August. However, some phenological responses and growth responses were observed. It is known that wind affects plant growth by decreasing leaf temperature and increasing leaf transpiration rate (HAMLYN, 1992). Therefore, some species extended the photosynthetic period (observed in three species), and increased the annual shoot growth (observed in three species) in the WS plots.

There was no difference in the date of bud-break in any of the five species between the WS and the CTRL plots. Because the WSs were set at least one week after the snow disappeared at the site, timing of the bud-break might not have been affected by the WSs in the first season. The date of bud-break may occur earlier at the WS plots in the next year.

The dates of leaf coloring and wilting in *A. alpinus* var. *japonicus* and *V. uliginosum* were delayed, indicating that the growth periods were extended by the WSs. However, the coloring date in autumn in *D. lapponica* var. *obovata* was not delayed by the WSs. This may be due to the growth form of *D. lapponica* var. *obovata*, which spreads its shoots covering the ground surface like a mat where wind is much weaker than at the vegetation height of the other four species. For *D. lapponica* var. *obovata*, the wind condition was little changed by the WSs.

Among the growth characteristics, shoot lengths of three species were significantly increased by the WSs, but the number of leaves and branches (except for the number of leaves of *A. alpinus* var. *japonicus*) were unchanged in the first year. This is because primordias of leaves are formed in the previous year. Previous studies suggest that growth characteristics will change in the second year after the environmental modifications. On Mt. Tateyama, the number of leaves of *E. nigrum* var. *japonicum* increased in the second year within the open-top-chambers (MIYAMOTO personal communication). PARSONS *et al.* (1994) showed that various changes in growth characteristics such as leaf area, leaf weight and shoot weight were observed in the second year after the beginning of the experimental manipulations in a subarctic tundra, in which temperature conditions were changed by means of open-top polythene tents. In our study, the growth periods of both *A. alpinus* var. *japonicus* and *V. uliginosum* were extended by the WSs, but growth characteristics showed little change in the first year. To elucidate the effects of the WSs, measurements of other growth characteristics (leaf size, leaf thickness and specific leaf area) will be needed.

Although we focused on the effects of wind during the growing season in this study, the results showed that alpine plants are influenced by wind in various ways. Of course, the direct effects of wind during winter and the indirect effects of wind such as snow accumulation are also important. More than 30 cm depth of snow was observed windward of the WSs on 31st December 1996, whereas there was less than 15 cm depth of snow around the site. Such snow conditions may affect the survival of winter buds, and also plant growth and phenological events in the next year. These will be examined next year and the wind effects on alpine plants will be assessed by season.

Acknowledgments

We wish to thank the following people: Prof. OHMORI and Prof. MATSUMOTO of the University of Tokyo for much help and many suggestions; Prof. HUKUSHIMA of Tokyo University of Agriculture and Technology for important advice; Prof. KANDA of the National Institute of Polar Research and Prof. MASUZAWA of Shizuoka University for much support in this study; Mr. T. KINOSHITA for providing meteorological data; the Nagano Prefectural Park Office, the Forestry Bureau of Komagane, Mr. S. YOSHIKAWA and T. ARUGA for permission and for cooperation with the experiment within the natural reserve area; and members of the Laboratory of Vegetation Management of Tokyo University of Agriculture and Technology and graduate students of Geography of the University of Tokyo for their assistance in the field and for their comments.

References

BRAUN-BLANQUET, J (1964). Pflanzensoziologie. Berlin, Springer, 359 p

HAMLYN, G. J (1992). Plants and microclimate Cambridge, Cambridge Univ. Press, 428 p.

KOIZUMI, T. (1974). Landschaftsokologische untersuchungen in der alpinen stufe des Kisokomagatake in den Japanischen zentralalpen-Mit besonderer berucksichtigung der vegetation und des strukturbodens Jpn J. Ecol., **24**, 78–90 (in Japanese with German summary)

KOIZUMI, T (1980) Periglacial processes and alpine plant communities on the high mountains in Japan, in relation to lithology, IV Wind-blown vegetation on the present and fossil periglacial slopes in the vicinity of Mt. Hinokiodake, Central Japan Alps. Jpn J Ecol , **30**, 245–249 (in Japanese with English summary).

NAKASHINDEN, I., MASUZAWA, T., FUKUYO, S., KIMURA, K., YAMAMOTO, S., IIJIMA, Y., MIZUNO, K , KOBAYASHI, S., YAMAMOTO, T , MACHIDA, H and TAKAOKA, S. (1997): A preliminary report on phenological monitoring using experimental chambers in Mt Kisokomagatake, central Japan Proc. NIPR Symp Polar Biol , **10**, 196-204

PARSONS, A. N., WELKER, J. M., WOOKEY, P. A , PRESS, M. C., CALLAGHAN, T. V. and LEE, J A. (1994). Growth responses of four sub-Arctic dwarf shrubs to simulated environmental change. J. Ecol., **82**, 307–318.

TAKAHASHI, N. and SATO, K. (1994) Tail-shaped vegetation patch as an indicator to estimate the winter prevailing wind in the alpine bare ground Q J. Geogr., **46**, 136–146 (in Japanese with English summary).

WILSON, J. W. (1959). Notes on wind and its effects in arctic-alpine vegetation J. Ecol , **47**, 415–427

WOOKEY, P. A , PARSONS, A N , WELKER, J. M., POTTER, J A., CALLAGHAN, T V , LEE, J A. and PRESS, M. C. (1993): Comparative responses of phenology and reproductive development to simulated environmental change in sub-arctic and high arctic plants. Oikos, **67**, 490–502.

YANAGIMACHI, O. (1983): Glacial fluctuations and chronology during the Last glacial age in the northern part of the Kiso Mountain Range, Central Japan Chigaku Zasshi (J. Geogr), **92**, 12–32 (in Japanese with English summary)

(Received February 28, 1997, Revised manuscript accepted December 3, 1997)