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GROWTH RESPONSES OF TWO ALPINE PLANTS TO ARTIFICIALLY GENERATED WARMED ENVIRONMENT IN TATEYAMA RANGE, TOYAMA, JAPAN

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Abstract: Two mini-open top chambers (OTCs) were installed at a high elevation site of 2850 m above sea level on the Tateyama Range, Toyama Prefecture, Japan, to generate an artificially warmed environment and to assess growth responses of two alpine plants, *Empetrum nigrum* L. and *Loiseleuria procumbens* DESV. to the warmed environment. A total of 80 twigs of the said species, ten each from inside and outside of the two OTCs, were randomly chosen. They were tagged and periodically measured for their current year shoot elongations. Data loggers were set inside and outside one of the chambers (OTC 1) to record ground surface temperatures at every one-hour interval for 76 consecutive days from July 15th to September 30th, 1995. Mean daily temperature was 2.1°C higher on average inside the OTC 1 than outside. The OTC especially elevated daily maximum temperatures to result in a considerable larger diurnal temperature ranges inside the chamber. The OTCs substantially stimulated plant growth by increasing temperature inside the chambers. In both of the OTCs, shoot elongation was significantly greater inside for both species, presumably reflecting the ameliorated environment.

1. Introduction

There is a growing concern about effects of man-induced climate warming on arctic and alpine ecosystems. According to IPCC (HOUGHTON *et al.*, 1990), if the current trend of greenhouse gas increase, notably of CO_2, continues, global climate warming will likely take place. Then, global surface air temperature may increase on the order of 0.3°C per decade on average during the 21st century. If such a climate warming really takes place, upward advancement of vegetation may occur in mountain regions, which will create serious disorder in species composition and biodiversity of alpine plant communities (GRABHERR *et al.*, 1994; OZENDA and BOREL, 1995).

In recent years, a number of experiments have been conducted to assess the effects of climate warming on terrestrial ecosystems in frigid environments, especially in the Arctic. An international effort has been initiated to correlate such research activities by various organizations and individuals of different countries. As a result, ITEX (International Tundra Experiment) was established in 1990. In order to standardize and correlate their research designs and outcomes, an ITEX manual was compiled and distributed to research groups and individuals interested in tundra ecosystems (MOLAU, 1992, 1993). Considerable development has occurred since (ITEX Update No.7, 1995). Lately, the ITEX activities have been extended to alpine ecosystems (ITEX Update No.6, 1994). Some research sites have been established in the Alps and Fennoscandian mountains (GUISEN *et al.*, 1995).

Recently in Japan, some new development in this aspect included an initiation of research effort to evaluate effects of climate warming on vegetation at high elevations and to link their research with the ITEX activities for its world-wide research network. At least three research sites have been established at high elevation in Japan (KOJIMA, 1995). As to the actual field experiment, a more compact open-top chamber (mini-open top chamber) than those specified in the ITEX manual was designed by KUDO and used at high elevations in Hokkaido and other sites.

The present study attempts to assess the effects of the mini-open top chamber and responses of two alpine plants (*Empetrum nigrum* L. and *Loiseleuria procumbens* DESV.) to an artificially generated warmed environment by the chamber, with a hypothesis that the mini-open top chamber would increase inner temperatures and stimulate plant growth inside the chamber.

2. Study Area

The study area is located at high elevations above 2800 m asl in the Tateyama Range, Hida Mountains (also known as Northern Japan Alps), Toyama Prefecture, Japan (Fig. 1). Its latitude is 36°33′42″N, longitude 137°36′29″E, and elevation from 2800 to 2900 m above sea level. Physiography is mountainous and very complex. Topography is steep and rugged with various aspects and slope inclinations, which provides a wide range of habitat conditions. Vegetation of the area is generally represented by *Pinus pumila* thicket on gentle mid-slopes where snow stays moderately long. Treeless tundra and heath vegetation develop in wind-exposed and snow-patch habitats. The wind-swept vegetation consists mainly of *Diapensia lapponica* L., *Dryas octopetala* L., *Loiseleuria procumbens* DESV., *Minuartia hondoensis* OHWI and *Potentilla matsumurae* T. WOLF. The snow-patch vegetation may be represented by *Empetrum nigrum* L., *Geum pentapetalum* MAKINO, *Phyllodoce aleutica* A. HELLER and *Anaphalis alpicola* MAKINO.

The research site was situated on a gentle saddle-crest between two summits (Mt. Ryuoh and Mt. Johdo), where an alpine heath vegetation develops covering a gently undulating relief of the saddle-crest. Such vegetation consists of dense mats of *Empetrum nigrum, Vaccinium vitis-idaea, Phyllodoce aleutica* and *Deschampsia flexuosa.*

3. Methods and Procedures

A mini-open top chamber (OTC) designed by G. KUDO of Hokkaido University was employed to simulate a warmed climate (Fig. 2). It is a pentagonal cone, 49 cm across and 33 cm tall, with a truncated open top, made of 3 mm thick transparent plastic board. Its size is much smaller than the open top chamber designed for and widely used in the ITEX experiments in the Arctic (MOLAU, 1992). The one used in the ITEX research is an open-top ortho-hexagonal cone with a basal diameter of 208 cm and 50 cm tall.

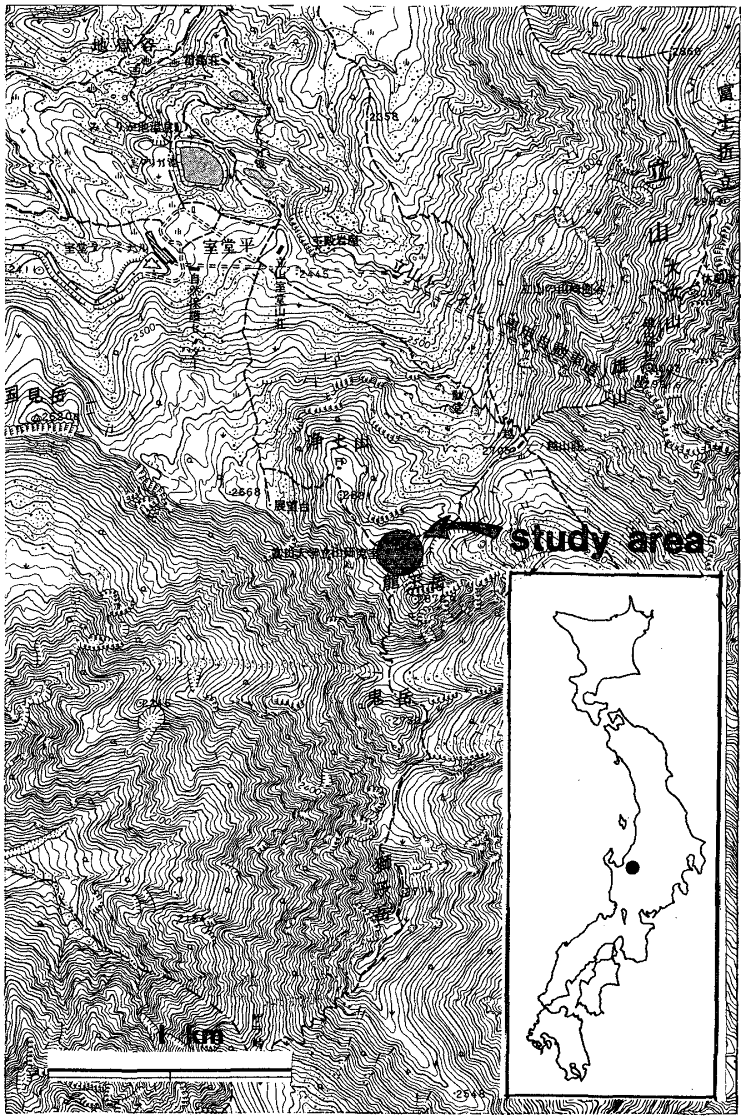

Fig. 1. *Study area. It is located in the heart of the Tateyama Range, Hida Mountains of central Japan. Its elevation ranges from 2800 m to 2900 m above sea level.*

At the study site, two OTCs were installed in the heath community. One is set on a gentle slope facing south and another was on an east-facing slope. They were firmly fixed to the ground with pegs and strings at each of five corners. To one of the OTCs (OTC 1), two data loggers (Kadec-U II) with thermister temperature probes were installed to record ground surface temperatures inside and outside the OTC during the experiment. One temperature probe was set on the ground surface inside the OTC 1 and the other outside. Both probes were loosely wrapped with aluminum foil so as to avoid effects of direct sunlight, and were laid on the vegetation at a height roughly 5 cm above the soil surface. Temperatures were regularly recorded every one-hour interval for 76 consecutive days during the experiment from July 15th to September 30th, 1995.

Ten twigs each of *Empetrum nigrum* and *Loiseleuria procumbens* were randomly

Fig. 2. An open-top chamber installed in an alpine heath community at an elevation of 2850 m above sea level.

chosen in each of the two OTCs. Another ten twigs each of the same species were also chosen nearby and outside each of the OTCs. A total of 80 twigs were subjected to this experiment. They were all tagged with very thin red strings. Current year new shoot elongation of the twigs was periodically measured by a digital micro-caliber. The measurements were averaged for each species and every measurement time. Statistical analysis was applied to detect significant differences between species and between treatments (*i.e.*, inside and outside).

The experiment was initiated on July 15th, 1995, and terminated on September 30th, 1995.

4. Results and Discussions

4.1. Temperature measurements

Figure 3 shows the ground surface temperature oscillations of the inside and outside of the OTC 1 recorded by Kadec-U II data loggers. Table 1 presents a summary of the temperature statistics. Evidently the OTC 1 ameliorated the thermal conditions at high elevation. The average ground surface temperature was 2.1°C higher inside the OTC than outside. The OTC enhanced considerably the daily maximum temperatures as the average maximum temperature was 6.2°C higher inside than the outside, whereas that of the minimum temperatures remained only 0.4°C higher inside. The former was statistically significant at $p<0.001$ while the latter was not significant at $p<0.05$. The OTC considerably exaggerated the daily maximum temperatures but not the daily minima. This indeed expanded the magnitudes of daily temperature amplitudes as averages of the daily temperature amplitudes inside and outside were 23.6°C and 17.8°C, respectively, which were significantly different at

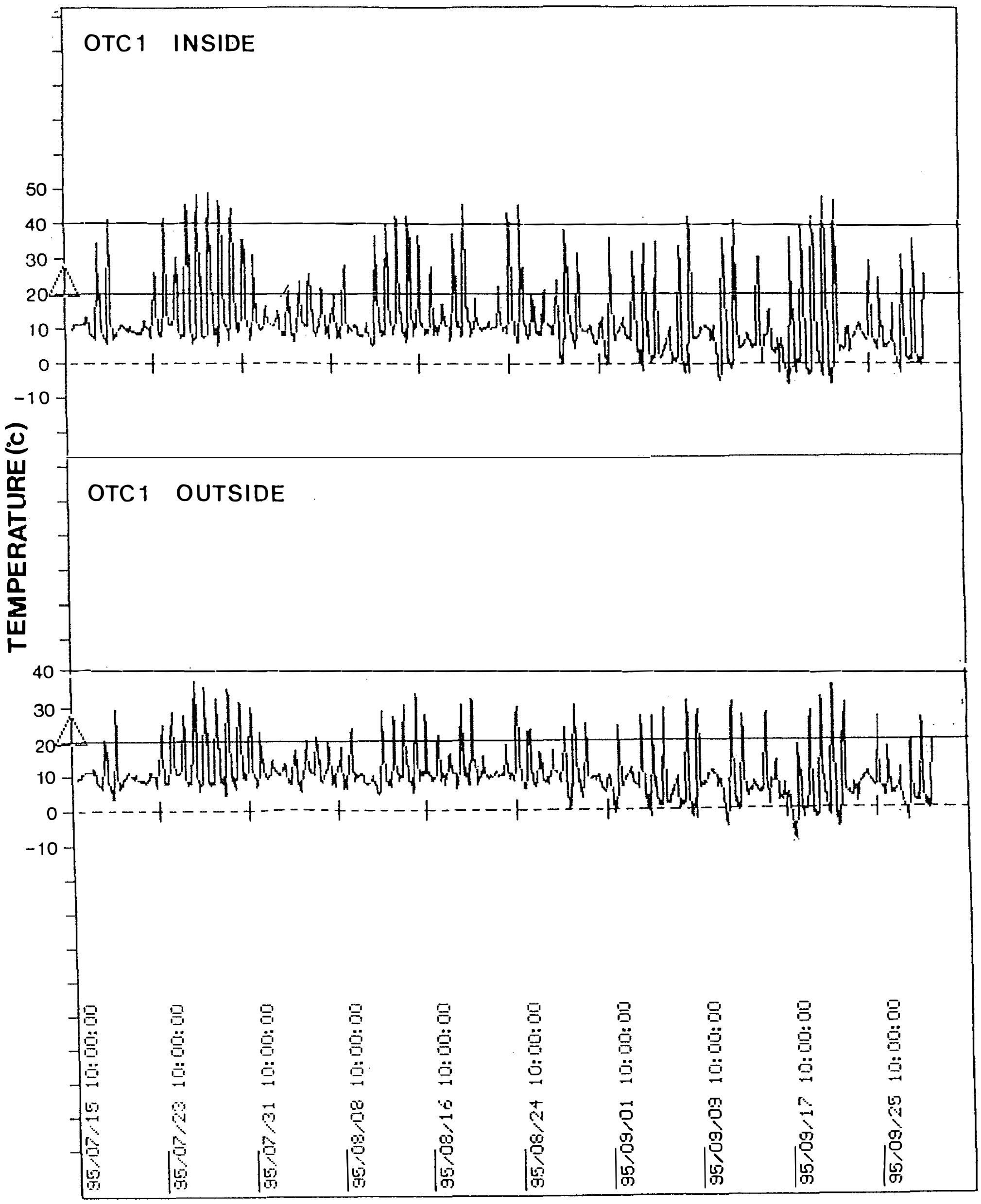

Fig. 3. Fluctuations of ground surface temperature recorded by data loggers (Kadec-U II) during the experiment. Temperature was generally high in late July to mid-August and become lowered in late August and September. Daily maximum temperature often exceed 40°C inside but not outside the OTC. The magnitude of diurnal oscillation was greater inside than outside.

$p<0.01$. The extreme maximum temperature throughout all the measurements was 48.4°C, which was recorded on July 28th inside the OTC. The extreme maximum temperature outside was 37.6°C recorded on July 26th. The OTC greatly elevated daily maximum temperatures as the extreme maximum temperature inside the OTC was 10.8°C higher than outside. The extreme minimum temperature throughout all the measurements was −9.9°C, which was recorded on September 22nd outside the

Table 1. A summary table of ground surface temperature characteristics inside and outside OTC 1 (temperature in °C).

Temperature items	Inside	Outside	Level of significance
Mean maximum	27.3	21.1	**
Mean daily	12.0	9.9	**
Mean minimum	4.1	3.7	ns
Extreme maximum	48.4	37.6	
(Date of occurrence)	(July 28)	(July 26)	
Extreme minimum	−6.6	−9.9	
(Date of occurrence)	(Sep. 18, 22)	(Sep. 18)	

**$p<0.01$, ns: not significant.

OTC. The extreme minimum inside the OTC was −6.6°C, recorded twice on September 18th and 22nd. Daily minimum temperatures often dropped below the freezing point in September.

4.2. *Growth responses of the plants*

Plants obviously responded to the artificially warmed environment. Figure 4 illustrates the growth responses of the plants for the OTC 1 and 2. For both OTCs, plants inside the OTCs showed better growth than outside. The maximum growth (15.26 mm) was observed in *Loiseleuria procumbens* inside the OTC1. The minimum growth (7.46 mm) was noted for *Empetrum nigrum* outside the OTC 2. Table 2

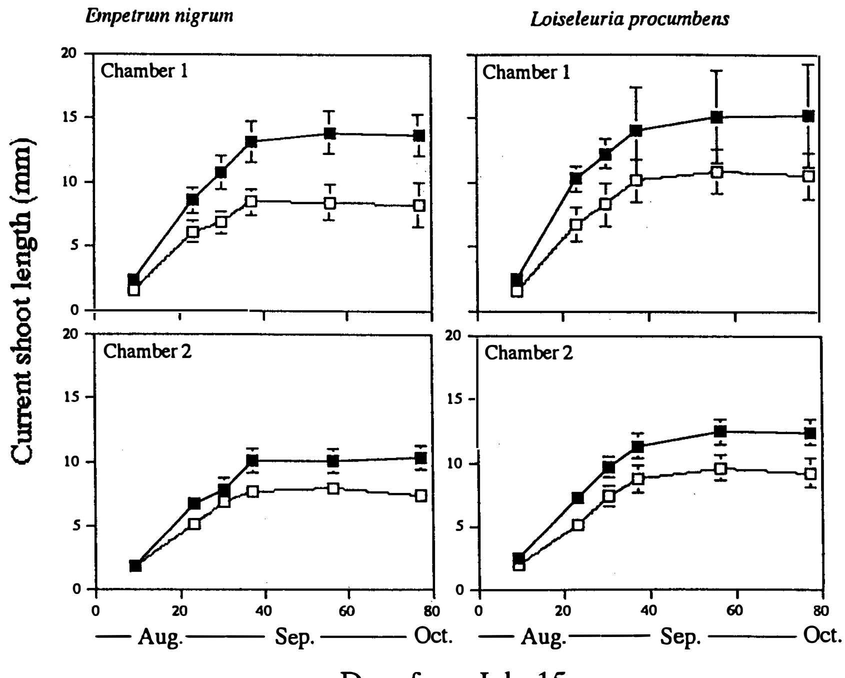

Fig. 4. Growth pattern of current shoots of the two alpine plants inside (solid squares) and outside (open squares) the OTCs. Vertical bars show standard errors.

Table 2. Effects of OTC on the current shoot elongation in Empetrum nigrum *and* Loiseleuria procumbens. *Average current shoot length (mm) at the end of the growing season (late September) is shown here with standard errors (n=8–10).*

	OTC 1		OTC 2	
	Inside	Outside	Inside	Outside
Empetrum nigrum	13.64±1.62	8.22±1.71	10.38±0.93	7.46±0.59
Loiseleuria procumbens	15.26±3.98	10.55±1.81	12.36±0.98	9.19±1.10

Table 3. An analysis of variance table showing level of significance of species, position relative to the OTC and interaction.

Item	d.f.	Mean square	F-value	p: level of significance
Species: A	1	82.347	5.942	0.0174
Position relative to OTC: B	1	293.627	21.187	0.0000
Interaction A×B	1	0.400	0.003	0.9572
Error	68	13.859		

presents the results of the experiment. Table 3 shows a two-way analysis of variance which showed much more significant differences existing between inside and outside the OTCs than the species difference. This indicated that the OTCs significantly affected the plant growth. The species difference was also significant at $p<0.05$.

At the study site, plants started their current-year growth in early to mid-July and ceased to grow in late August to the beginning of September, when the minimum temperature fell below the freezing point. In Fig. 4, the outside measurements appeared to show some decrease toward the end of the experiment. This is, however, merely a reflection of measurement errors.

4.3. *Implications*

OTC 1 elevated mean inside temperatures by 2.1°C on average. This was similar to the result of an experiment conducted in the Arctic using a hexagonal OTC designed specifically in the ITEX manual. An approximately 3°C temperature increase was noted in the Arctic experiment (Molau, 1993).

In this study, the OTCs obviously stimulated plant growth to result in a considerably better shoot elongations of both species inside the OTCs. This is presumably an outcome of the elevated temperatures inside the chamber. The inside temperature of OTC 1 was, indeed, 2.1°C higher on a daily average. A similar circumstance may be expected in OTC 2 though actual measurement was not made. There is a possibility that an extension of the growing season may have occurred inside the OTCs, which may have resulted in better growth of the plants. Nevertheless, there was no significant difference in the mean minimum temperatures between the inside and outside, and both inside and outside temperatures fell below 0°C simultaneously. This implied that there was no difference in the length of growing season. However, the OTCs might have reduced strong wind effects which should be common at high elevations, to result in better shoot elongation inside the OTCs.

It is known that high temperature above 30°C is rather harmful to most of the plants, especially to those that grow at such high elevations. In fact, the inside temperature frequently rose to more than 40°C during the experiment. However, such an extremely high temperature did not last long. It occurred for a short time during day and then the temperature dropped soon to a more or less normal range.

Plants both inside and outside OTC 1 showed slightly better growth than those in OTC 2. This may be attributed to micro-topographical conditions. OTC 1 was set up on a slope facing southwest (S60°W, 12°) whereas OTC 2 was facing due east (S90°E, 15°). Better insolation in the OTC 1 elevated temperatures more than in the OTC 2 both inside and outside the chamber to result in better plant growth in the OTC1 .

It is predicted that the global average of annual temperature may increase on the order of *ca.* 2–4°C when the atmospheric concentration of CO_2 becomes doubled (HOUGHTON *et al.*, 1990). The OTCs could simulate the warmed environment by elevating the inside temperature by 2.1°C, which is close to the predicted global atmospheric temperature increase. Nevertheless, the ground surface temperature may be even higher than this when air temperature increases by 2°C. The warmed environment would stimulate growth of alpine plants, as exemplified by *Empetrum nigrum* and *Loiseleuria procumbens* in the present study, but rates of growth increase may differ from species to species. This may create new competitive interactions in the alpine plant communities. New invasion and colonization of plants from lower elevations may also generate additional complications as to species composition of the communities. This subject needs further study in the alpine environment.

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