A comparison of fine-scale species richness and climatic condition in alpine tundra communities between Mt. Changbai, China, and Mt. Tateyama, Japan

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A comparison of fine-scale species richness and climatic condition in alpine tundra communities between Mt. Changbai, China, and Mt. Tateyama, Japan

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Abstract

We compared the species richness of vascular plants in the alpine tundra community of Mt. Changbai in northeastern China and Mt. Tateyama in central Japan. The fine-scale species-area relationships in an area ranging from 0.0625 m^2 to 1.25 m^2 were investigated, and the number of species per given space and the increasing rate of species richness with area were compared between the two mountains. Dominant species were two deciduous shrubs (*Vaccinium uliginosum* var. *alpinum* and *Rhododendron redowskianum*) on Mt. Changbai and two evergreen shrubs (*Diapensia lapponica* var. *obovata* and *Arcterica nana*) on Mt. Tateyama. The coverage and frequencies were greater on Mt. Changbai than on Mt. Tateyama. The number of species per m^2 was greater and the increasing rate of species richness was slightly higher on Mt. Tateyama than on Mt. Changbai. We discussed the reasons from the view of dominant deciduous shrubs on Mt. Changbai.

Key words : Alpine tundra, Circumpolar plants, Species-area relationship, Species richness.

Introduction

In the alpine life zone of Mt. Changbai, a mid-latitude mountain in northeast China, alpine tundra communities composed of circumpolar plants, such as *Dryas octopetala* L. are well established (Zhu et al. 2003). The presence of these communities that migrated from the high latitude regions during the glacial period (cf. Qian et al. 1999) suggests that this mountain acted as the southernmost refuge on the Eurasian continent for arctic and alpine plants during warm interglacial periods. In contrast, such alpine tundra communities are very small and occupy little space on Mt. Tateyama in central Japan, located ca. twenty thousands km southeast from Mt. Changbai, putting the Sea of Japan between these mountains. Differences in historical factors, such as migration processes and floristic richness of a territory, and recent ecological factors may affect species richness of the alpine communities (Onipchenko and Semenova 1995 ; Qian et al. 1999 ; Kammer and Möhl 2002). However, identifying which factors influence the floristic composition of a particular community is difficult, only comparative studies of communities may help to clarify which factors strongly affect species richness (Onipchenko and Semenova 1995 ; Qian et al. 1999).

In this study, we compared the fine-scale species richness of vascular plants found in the alpine tundra communities of Mt. Changbai in northeast China and Mt. Tateyama in central Japan. Because of the tininess of individual alpine plants, a large number of species can be nested even in a small space (Körner 2002). By comparing species richness, we focused on species-area relationships in wind-blown heath communities growing under similar ecological conditions, and the number of species per unit area and increasing rate of species within the area are discussed.

Study sites

The alpine tundra communities of Mt. Changbai in northeast China are well established and are found above the timberline at ca. 2,000 m above sea level（Zhu et al. 2003）. In the alpine life zone, snowbed communities composed of graminoids and perennial forbs such as *Sanguisorba sitchensis* C. A. Mey. and *Veratrum nigrum* L. var. *ussuriense* Nakai are distributed at the bottoms of valleys and the hollows of leeward slopes. Wind-blown heath communities composed of dwarf shrubs dominate largely at the ridges and the upper parts of gentle slopes. The snowbed communities occupy little space, while the wind-blown heath communities occupy large space in this mountain. The study site was selected in a wind-blown heath community dominated by *Vaccinium uliginosum* var. *alpinum*, *Rhododendron confertissimum* Nakai, and *Dryas octopetala* L. var. *asiatica*（Nakai）Nakai（42° 02.4'N, 128° 04.0'E, and 2,268 m a.s.l.; Wada et al. 2006）. In Mt. Tateyama in central Japan, the alpine life zone is distributed above the timberline at ca. 2,400 m a.s.l., and snowbed communities composed of perennial forbs, graminoids, and dwarf shrubs such as *Sieversia pentapetala*（L.）Greene are well established, while the alpine tundra communities occupy very little space. The alpine tundra communities are only found on the ridge of a northward slope at ca. 2,700 m a.s.l. The study site was chosen for investigating a wind-blown heath community dominated by *Arcteria nana*（Maxim.）Makino, *Diapensia lapponica* L. var. *obovata* F. Schm. and *D. octopetala* L. var. *asiatica*（Nakai）Nakai（36° 33.8'N, 137° 36.5'E, and 2710 m a.s.l.; Wada et al. 2006）.

Figure 1 shows the monthly means of the daily maximum and minimum air temperatures at both study sites. The temperatures were calculated from data recorded at meteorological observatories located near each study site（Tianchi meteorological observatory at 2,623 m a.s.l. on Mt. Changbai and Kurobe dam meteorological observatory at 1,459 m a.s.l. on Mt. Tateyama（Wada et al. 2004））, on the basis of an altitudinal lapse rate of 0.65℃ per 100 m. The yearly mean daily maximum temperatures was 4.6℃ higher, while that of daily minimum tempera-

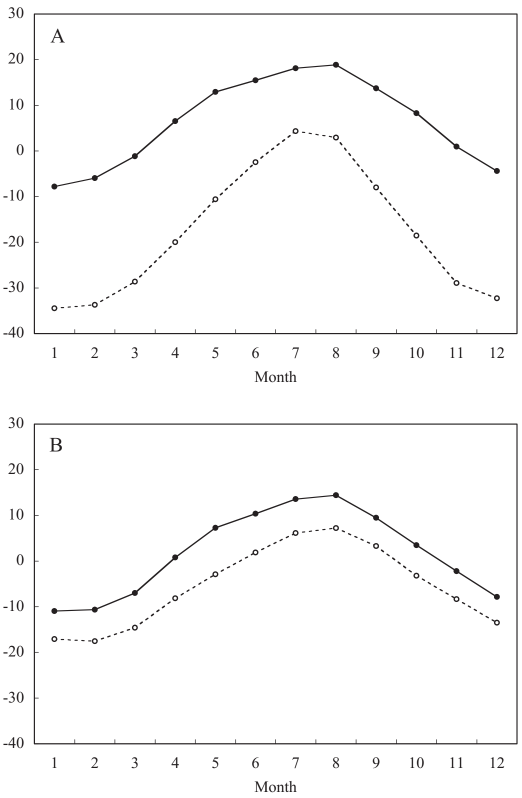

Fig. 1. Monthly mean air temperatures of daily maximum（solid circles and solid lines）and daily minimum（open circles and broken lines）at each study site were calculated from data recorded by the meteorological observatories located near each site based on an altitudinal lapse rate（0.65 ℃ per 100 m）. A, Mt. Changbai（data from Tianchi Meteorological Observatory from 1959 to 1988）and B, Mt. Tateyama（data from Kurobe Dam Meteorological Observatory 1965 to 2001）.

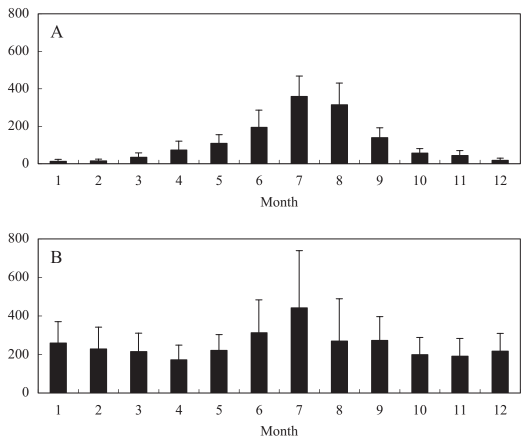

Fig. 2. Monthly precipitation（mean + 1 standard deviation）. A, Mt. Changbai（data from Tianchi Meteorological Observatory from 1959 to 1988）; B, Mt. Tateyama（data from Kurobe Dam Meteorological Observatory 1965 to 2001）.

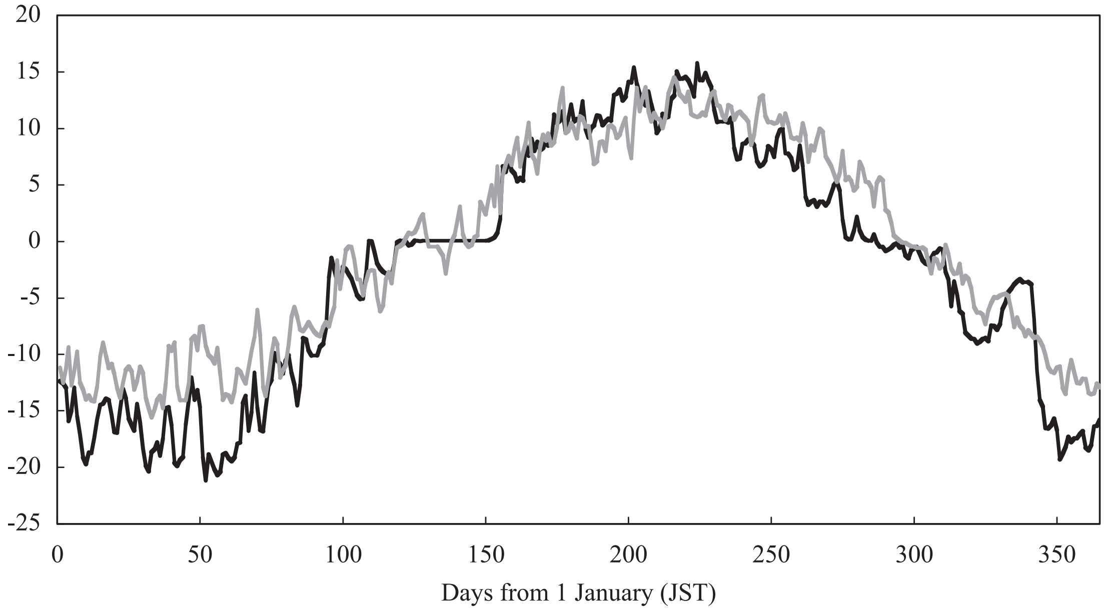

Fig. 3. Daily mean soil temperature (five cm below the ground surface) measured at one-hr intervals from 1 January to 31 December in 2005 (JST) on Mt. Changbai (black line) and Mt. Tateyama (gray line).

tures was 12.0℃ lower on Mt. Changbai than on Mt. Tateyama. Throughout the year, the difference between the maximum and minimum temperatures was larger on Mt. Changbai than on Mt. Tateyama. Monthly precipitation, recorded by the meteorological observatories, is shown in Figure 2. The annual precipitation was 1,373 mm on Mt. Changbai, while it was 3,002 mm on Mt. Tateyama. More than 70% of the annual precipitation was concentrated in the summer months from June to September on Mt. Changbai, while it was evenly distributed each month on Mt. Tateyama. These meteorological data indicate that Mt. Changbai belongs to the continental climatic zone, while Mt. Tateyama belongs to the oceanic climatic zone.

Materials and methods

To evaluate thermal conditions in the soil, a thermometer with a data logger (StowAway TidbiT data logger, Onset Computer Co., USA) was deposited five cm below the ground surface at each study site in the summer of 2004. Data recorded at one-hour intervals from 1 January 2005 to 31 December 2005 were used in this study.

To compare fine-scale species richness of alpine tundra communities under similar ecological conditions between the two study sites, we targeted wind-blown heath communities including a glacial relict *Dryas octopetala* var. *asiatica* located on the upper parts of the slopes at each site. Our preliminarily study revealed a high similarity of thermal conditions and seasonal variations in soil temperature on the two study sites (Wada et al. 2006). In the summer of 2004, three 0.25×5 m^2 belt transects were randomly established in the wind-blown heath community at each study site. The transect was divided into twenty 0.25×0.25 m^2 subquadrats, and the number of vascular plant species and the coverage of each species were recorded for each subquadrat.

Mean species richness, i.e., number of vascular plant species per given area, was calculated from 0.0625 m^2 (0.25×0.25 m^2) to 1.25 m^2 (0.25×5 m^2) for each belt transect. For the smallest area ($i = 1$), the mean species richness was obtained from 20 of the 0.25×0.25 m^2 subquadrats ($n = 20$). For the subsequent area ($i = 2$), 0.25×0.50 m^2, two adjacent subquadrats were combined, and the mean species richness was calculated from the 19 0.25×0.50 m^2 samples ($n = 19$); for the i-th area ($i = 1 \ldots 20$), the mean species richness was calculated from ($20 - i + 1$) samples

Table 1. Coverage (%) of vascular plant species in a 0.25×0.25 m² area in each belt transect in Mt. Changbai Mean values are shown here (n = 20 subquadrats).

Species	Belt-1	Belt-2	Belt-3	Average
Evergreen shrub				
Rhododendron aureum Georgi.	23.2			7.7
Rhododendron confertissimum Nakai		5.0	7.3	4.1
Phyllodoce caerulea (L.) Bab.	7.9			2.6
Deciduous shrub				
Vaccinium uliginosum L. var. *alpinum* Nakai	15.2	18.6	17.1	17.0
Rhododendron redowskianum Maxim.	8.1	11.3	15.6	11.7
Dryas octopetala L. var. *asiatica* (Nakai) Nakai	2.3	1.4	3.2	2.3
Salix rotundifolia Trauntv.	0.3			0.1
Forb				
Tofieldia coccinea Rich.	1.4	4.3	6.9	4.2
Bupleurum euphorbioides Nakai	2.2	2.4	1.7	2.1
Lloydia serotina (L.) Rchb.	1.4	1.1	0.3	0.9
Oxytropis anertii Nakai	0.4	0.6	0.4	0.5
Bistorta vivipara (L.) S. F. Gray	0.3	0.4	0.8	0.5
Saussurea tomentosa Kom.	0.7	0.3		0.3
Gentiana algida Pall.		0.3		0.1
Pedicularis verticillata L.		0.1		0.0
Graminoid				
Anthoxanthum nipponicum Honda	1.1	0.8	2.1	1.3
Hierochloe alpina (Swartz) Roem. et Schult.	0.3	1.0	1.3	0.9
Carex siroumensis Koidz.	0.5	0.4	0.8	0.6

Table 2. Coverage (%) of vascular plant species in a 0.25×0.25 m² area in each belt transect in Mt. Tateyama Mean values are shown here (n = 20 subquadrats).

Species	Belt-1	Belt-2	Belt-3	Average
Evergreen shrub				
Diapensia lapponica L. var. *obovata* F. Schm.	2.0	10.0	17.8	9.9
Arcterica nana (Maxim.) Makino	14.3	5.8	0.7	6.9
Loiseleuria procumbens (L.) Desv.	9.8	8.2	0.8	6.3
Pinus pumila (Pall.) Regel	0.1	0.1	0.1	0.1
Deciduous shrub				
Dryas octopetala L. var. *asiatica* (Nakai) Nakai	3.2	7.1	5.7	5.3
Arctous alpinus (L.) Niedenzu		1.2	8.9	3.4
Forb				
Arenaria arctica Steven ex Seringe var. *hondoensis* (Ohwi) Hara	1.9	3.6	0.4	2.0
Potentilla matsumurae Th. Wolf	1.5	2.3	2.1	2.0
Bistorta vivipara (L.) S. F. Gray	0.6	0.9	0.7	0.7
Campanula chamissonis Fedorov	0.3	0.6	0.8	0.6
Gentiana algida Pall.		0.3	1.2	0.5
Lloydia serotina (L.) Rchb.	0.1	0.2	0.4	0.2
Tilingia tachiroei (Franch. et Sav.) Kitag.	0.1	0.6		0.2
Geum calthifolium Smith var. *nipponicum* (F. Bolle) Ohwi	0.2			0.1
Graminoid				
Carex stenantha Franch. et Sav.	0.1	2.5	2.4	1.7
Calamagrostis deschampsioides Trin.	0.2	1.0	2.0	1.1
Deschampsia flexuosa (L.) Trin.	0.1	0.1	0.1	0.1
Calamagrostis sachalinensis F. Schm.		0.3		0.1
Luzula arcuata (Wahlenb.) Sw. var. *unalaschkensis* Buchenau.			0.1	0.0

Table 3. Frequency (%) of vascular plant species occurring in twenty 0.25×0.25 m^2 subquadrats in each belt transect in Mt. Changbai

Species	Belt-1	Belt-2	Belt-3	Average
Vaccinium uliginosum L. var. *alpinum* Nakai	85	90	100	91.7
Rhododendron redowskianum Maxim.	60	75	100	78.3
Bupleurum euphorbioides Nakai	70	80	75	75.0
Tofieldia coccinea Rich.	20	60	85	55.0
Lloydia serotina (L.) Rchb.	60	80	20	53.3
Rhododendron confertissimum Nakai	0	60	90	50.0
Anthoxanthum nipponicum Honda	15	40	70	41.7
Bistorta vivipara (L.) S. F. Gray	20	40	55	38.3
Dryas octopetala L. var. *asiatica* (Nakai) Nakai	25	25	40	30.0
Rhododendron aureum Georgi.	85	0	0	28.3
Hierochloe alpina (Swartz) Roem. et Schult.	5	20	55	26.7
Oxytropis anertii Nakai	15	25	15	18.3
Carex siroumensis Koidz.	10	10	25	15.0
Phyllodoce caerulea (L.) Babingt.	40	0	0	13.3
Saussurea tomentosa Kom.	20	15	0	11.7
Gentiana algida Pall.	0	10	0	3.3
Salix rotundifolia Trautv.	5	0	0	1.7
Pedicularis verticillata L.	0	5	0	1.7

Table 4. Frequency (%) of vascular plant species occurring in twenty 0.25×0.25 m^2 subquadrats in each belt transect in Mt.Tateyama

Species	Belt-1	Belt-2	Belt-3	Average
Arcterica nana (Maxim.) Makino	95	85	90	90.0
Bistorta vivipara (L.) S. F. Gray	65	90	85	80.0
Calamagrostis deschampsioides Trin.	45	90	95	76.7
Potentilla matsumurae Th. Wolf	65	55	60	60.0
Arenaria arctica Steven ex Seringe var. *hondoensis* (Ohwi) Hara	55	55	20	53.3
Campanula chamissonis Fedorov	45	35	65	48.3
Carex stenantha Franch. et Sav.	35	50	55	46.7
Diapensia lapponica L. var. *obovata* F. Schm.	5	55	75	45.0
Loiseleuria procumbens (L.) Desv.	35	50	50	45.0
Lloydia serotina (L.) Rchb.	30	30	60	40.0
Arctous alpinus (L.) Nied.	0	25	85	36.7
Gentiana algida Pall.	0	15	80	31.7
Deschampsia flexuosa (L.) Trin.	40	15	25	26.7
Luzula arcuata (Wahlenb.) Sw. var. *unalaschkensis* Buchenau.	0	0	45	15.0
Dryas octopetala L. var. *asiatica* (Nakai) Nakai	35	30	45	11.7
Pinus pumila (Pall.) Regel	5	20	10	11.0
Tilingia tachiroei (Fr. et Sav.) Kitag.	10	10	0	6.7
Geum calthifolium Sm. var. *nipponicum* (F. Bolle) Ohwi	20	0	0	6.7
Calamagrostis sachalinensis F. Schm.	0	10	0	3.3

with a $0.25 \times 0.25 \times i$ m^2 area. The species-area relationships were analyzed by using the following formula (cf. Drakare et al. 2006):

$$S = c A^z \quad (1),$$

$$S = a + b \ln A \quad (2),$$

where S is the number of species, A is the area under investigation and a, b, c and z are regression parameters. Parameters z and b represent the rate of increase in species richness within the area, and parameters c and a represent the number of species per m^2. These parameters were compared between the wind-blown heath communities of the two mountains.

Results and discussion

Seasonal variations in the daily mean soil temperature are shown in Figure 3. Soil temperature during winter was below zero degrees

Table 5. Coefficients (c, z, a, and b) of regression and correlation coefficient (r^2) for species-area regressions based on equations (1) and (2)

Transect	Equation 1			Equation 2		
	c	z	r^2	a	b	r^2
Changbai belt-1	14.1	0.344	0.999	13.9	3.43	0.978
Changbai belt-2	15.3	0.272	0.943	15.1	2.98	0.977
Changbai belt-3	12.0	0.140	0.911	11.9	1.39	0.945
Average	13.8	0.252	0.981	13.6	2.60	0.999
Tateyama belt-1	14.4	0.291	0.979	14.2	3.01	0.998
Tateyama belt-2	17.5	0.279	0.942	17.1	3.46	0.973
Tateyama belt-3	16.6	0.149	0.816	16.4	1.96	0.973
Average	16.1	0.234	0.939	15.9	2.81	0.973

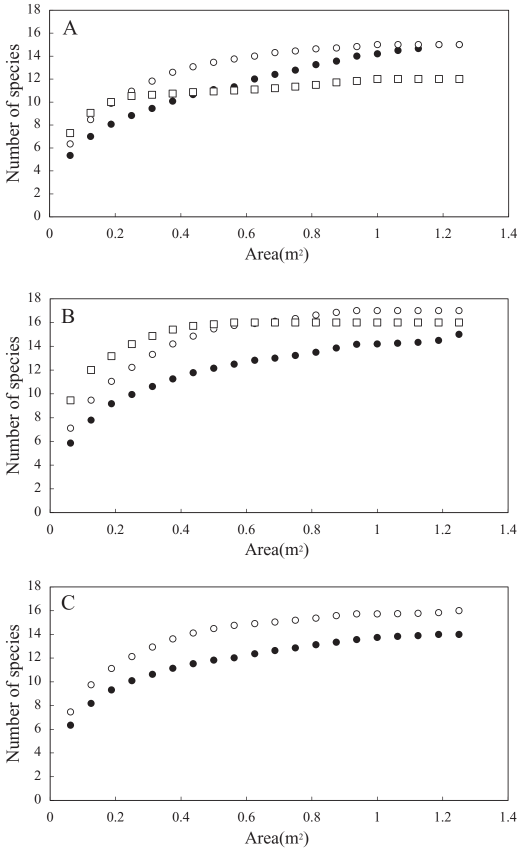

Fig. 4. Species-area curves of three belt-transects. A, Mt. Changbai and B, Mt. Tateyama; C, average values of three transects for both mountains. In A and B, solid circles, open circles, and open squares represent belt-1, belt-2, and belt-3 transects, respectively. In C, solid circles and open circles represent the average values of the three belt-transects in Mt. Changbai and Mt. Tateyama, respectively.

at each study site, suggesting little accumulation of snow and soil freezing in this season. Soil temperature in winter tended to be lower on Mt. Changbai than on Mt. Tateyama. However, the soil temperature in the middle of summer (Day 180 to 230 from 1 January) was mostly higher on Mt. Changbai than on Mt. Tateyama, even though this was opposite at the end of the growing season.

Tables 1 and 2 list the vascular plant species and the coverage for each belt transect on Mt. Changbai and Mt. Tateyama. Common species at the two sites were circumpolar plants: a deciduous shrub *Dryas octopetala* var. *asiatica*, and perennial herbs *Bistorta vivipara* (L.) S. F. Gray, *Gentiana algida* Pall. and *Lloydia serotina* (L.) Reichb. The coverage of the deciduous shrub was higher on Mt. Changbai than on Mt. Tateyama. Evergreen shrubs were the most dominant functional group on Mt. Tateyama. As shown in Figures 1 to 3, low temperatures with little precipitation during winter, i.e., a cold and dry winter climate, might favor deciduous habit in the alpine tundra community of Mt. Changbai. Frequency (%) of each vascular plant species is listed in Tables 3 and 4. Deciduous shrubs *Vaccinium uliginosum* var. *alpinum* and *Rhododendron redowskianum* Maxim. occurred at high frequencies on Mt. Changbai (Table 3), and an evergreen shrub *Arcterica nana* occurred with the most frequency on Mt. Tateyama (Table 4). Forbs and graminoids also occurred at higher frequencies on Mt. Tateyama than on Mt. Changbai : the number of herbaceous species occurring at frequency greater than 30% was eight on Mt. Tateyama and five on Mt. Changbai.

Species-area relationships are shown in Figure 4 and Table 5. Equation (2), i.e., semi-log species-area relationship, has a better line of fit than equation (1). Parameters c and a, representing the number of species per m^2, varied between transects at each study site. On average, parameters c and a were higher on Mt. Tateyama than on Mt. Changbai : two species richer on Mt. Tateyama. The mean number of species per m^2 was 14 on Mt. Changbai and it was 16 on Mt. Tateyama. Parameters z and b, representing the rate of increase in species richness, varied between transects at each study site. However, on average, the difference between the two mountains appeared to be small. Using averaged data from the three transects at each study site, the difference in parameters was analyzed by using analysis of covariance (ANCOVA). For equation (1), parameter z was not significantly different between the mountains ($F = 1.16$, $P = 0.289$), but parameter c was significantly higher on Mt. Tateyama than on Mt. Changbai ($F = 86.09$, $P < 0.0001$). Similarly, for equation (2), parameter a was significantly higher on Mt. Tateyama than on Mt. Changbai ($F = 393.25$, $P < 0.0001$). However, parameter b was slightly significantly higher on Mt. Tateyama than on Mt. Changbai ($F = 3.46$, $P = 0.079$). Thus, we concluded that the number of species per given space in the alpine tundra community was significantly higher and the increasing rate of species richness with area was slightly higher on Mt. Tateyama than on Mt. Changbai. We could not provide an answer for this with the data obtained in this study. However, one possible reason might be attributed to the greater dominance of shrub species in wind-blown heath communities on Mt. Changbai. As listed in Tables 1 to 4, two species of deciduous shrubs (*Vaccinium uliginosum* var. *alpinum* and *Rhododendron redowskianum*) were dominant in their coverage and frequency in each belt transect on Mt. Changbai, while the coverage of two evergreen shrub species (*Diapensia lapponica* var. *obovata* and *Arcterica nana*) was not so high and varied between transects on Mt. Tateyama. *Diapensia lapponica* var. *obovata* occurred at low frequency in one of the three transects (Table 4). This suggests that dominant species were uniformly distributed with relatively higher coverage on Mt. Changbai, while the dominant species on Mt. Tateyama were heterogeneously distributed with relatively lower coverage. Thus, in wind-blown heath communities on Mt. Changbai, the dominant deciduous species might serve as strong competitors and exclude other species in the community. A unimodal relationship between species richness and vegetation cover was reported in the *Dryas* heath communities in Western Norway : fine-scale species richness decreased when the vegetation coverage increased over an optimum value for species richness (Grytnes 2000). Grytnes (2000) suggests that competition for light may be an important factor influencing species richness. This may be applicable to the alpine tundra communities on Mt. Changbai, where the cold and dry winter climate and the warm summer climate during the daytime might permit deciduous shrubs to be dominant. Although circumpolar plant species were widely distributed in the alpine life zone of Mt. Changbai, fine-scale species richness in the alpine tundra vegetation was not higher when compared to Mt. Tateyama, suggesting that recent ecological factors such as competition between plants and climatic condition rather than historical factors such as migration processes seem to be more important in determining small-scale species richness in the alpine tundra vegetation. However, because we obtained the results from very limited area (0.25×5 m^2) with few replications ($n = 3$ belt transects), so it is doubtful whether dominant species are uniformly distributed or not, and whether competition between plants is the most important factors for determining species richness or not. To clarify species richness in the alpine life zone of both mountains, further investigations focusing on the relationships between species richness and growing condition are necessary for various community types at different altitudes and microtopographies.

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和田直也[1]・刘　琪璟[2]・谷　友和[1,3]・川田邦夫[1]：中国長白山と日本国立山の高山ツンドラ群落における微小スケール種多様性と気象条件の比較

中国北東部の長白山と日本国中部の立山における高山ツンドラ群落について維管束植物の種多様性と気象条件を比較した。0.0625 m^2 から 1.25 m^2 までの範囲内において微小スケールでの種数ー面積関係を調査し，一定面積当たりの種数と面積の増加に伴う種数の増加率を両山岳で比較した。長白山における優占種は落葉性矮生低木の二種（*Vaccinium uliginosum* var. *alpinum* と *Rhododendron redowskianum*）であり，立山における優占種は常緑性矮生低木の二種（*Diapensia lapponica* var. *obovata* と *Arcterica nana*）であった。それらの被度と出現頻度は立山より長白山で高かった。平方㍍当たりの維管束植物の種数は立山で多く，種数の増加率も立山で若干高かった。これらの理由を両山岳間の気象条件の違いと長白山における落葉性低木の高い優占性に関する観点から考察を行った。

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