Vegetation cover at the Maguntan mud volcano (Sakhalin Island, Russia): species composition and spatial distribution

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Research Paper

Vegetation cover at the Maguntan mud volcano (Sakhalin Island, Russia): species composition and spatial distribution

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Abstract: Mud volcano vegetation is not well-studied even in comparison with that of geothermal areas. Mud volcanoes provide opportunities to study the formation of the spatial and species structure of vegetation cover in distinct conditions, showing the trends in vegetation succession. The mud fields of the Maguntan mud volcano (Sakhalin, Russia) are cool, not warm, and their mud fluids have high salinity and alkalinity. In the 20th century some local endemic taxa were found at this place: *Artemisia limosa, Gentianella sugawarae, Primula sachalinensis* and *Deschampsia tzvelevii*. I identified nine plant communities and analyzed floristic richness, vegetation cover and endemism rate using data from 185 1 m × 1 m quadrats. The salinity decreases with distance from the volcano's main eruptive center. The total plant cover, number of plant species, and floristic richness increase with the distance from the volcano's center. Endemic taxa including the local endemic grass species *Deschampsia tzvelevii* are located in young mud substrates. Detrended correspondence analysis showed that the plant communities are arranged along a stress gradient. The spatial distribution of plant communities may be interpreted via succession dynamics.

Keywords: endemism; environmental stress; plant community; plant tolerance; salt vegetation; succession.

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Introduction

Mud volcanoes are geological structures formed as a result of the emission of argillaceous material. Sufficient water and gas is incorporated to make the material semiliquid and to force it up through long, narrow openings or fissures in the crust to produce an outflowing mass of mud on the surface (Dimitrov 2002). Mud volcano water is highly mineralized. While mud in geothermal fields is heated, mud volcanoes are not very hot because they are not magmatic: endogenous energy from the Earth's interior is not a major factor in mud volcano creation. The main power driving a mud volcano's activity are gases emitted as a result of the transformation of organic matter in the Earth's crust (Siryk 1970; Kopf 2002; Dimitrov 2003).

The study of vegetation growing around geological phenomena such as geothermal fields, geysers, hot springs, solfataras and mud volcanoes provides an opportunity to examine the principles underlying the spatial and functional structure of plant communities, and how temporal dynamics progress in areas of strong environmental stress. The plant communities found on formations associated with magmatic volcanism have not been well-studied (Chiarucci et al. 2008).

Environmental conditions due to geothermal activity directly affect the number of coexisting plant species, and the vegetation is thus strongly habitat-determined (Chiarucci et al. 2008). Concentric zonation of vegetation in and around the thermal areas is controlled by environmental conditions and thermal and non-thermal taxa are affected by both soil temperature and soil type (Tercek & Whitbeck 2004). On the Te Kopia geothermal steamfield, New Zealand, canopy height, plant stature, species richness, leaf size, and rooting depth were reduced as soil temperatures increased, and observations indicated that litter quantity was also reduced, suggesting decreasing growth rates (Burns 1997).

Dominance of endemic taxa is characteristic in geothermal habitats (e.g., near hot springs, geysers) where stress conditions are very strong. Plants endemic to these areas have genetic and physiological adaptations to the

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environment (van Manen & Reeves 2012). *Kunzea ericoides* var. *microflora* (G.Simpson) W.Harris is the main endemic plant found in hydrothermal areas of New Zealand with acidic pH and high substrate temperature (Burns 1997; van Manen & Reeves 2012). The endemic *Fimbristylis ochotensis* (Meinsh.) Kom. dominates hot spring areas of Kamchatka magmatic volcanoes (Neshatayeva et al. 2005). The millet grass *Dichanthelium lanuginosum* var. *thermale* (Bol.) Spellenb. is exclusively associated with surface geothermal features, including boiling mudpots, steam vents, and hydrothermally altered soils with elevated levels of boron, sulfur and acidity in the western U.S.A. (Stout et al. 1997; Pavlik & Enberg 2001; Stout & Al-Niemi 2002). Tercek & Whitbeck (2004) reported on the endemic grass *Agrostis rossiae* Vasey in geothermal habitats of the Yellowstone National Park.

The vegetation of mud volcanoes is a phenomenon of genesis and phytosociology (Korzhenevsky & Klyukin 1991). Salts and toxic substances are concentrated near the eruption centers, particularly in superficial horizons of young sediments. During powerful eruptions they are dispersed with mud-volcanic flows up to few hundred meters from craters (Korzhenevsky & Klyukin 1991). Ivanov et al. (1989) investigated the dynamics of vegetation and properties of soils developed on mud flows of the Jau-Tepe mud volcano, Crimean peninsula. During plant succession a progress in soil development has been observed, accompanied by geochemical change. The results of a phytosociological study of mud volcano vegetation in the Crimea were presented in a paper by Korzhenevsky & Klyukin (1991). The floristic composition of plant communities near mud gryphons of the Andaman Islands, Indian Ocean, was described by Srivastava (1962). The understory of mud volcano vegetation in forests of Borneo was studied by Ting & Poulsen (2009). The authors concluded that the species composition is highly correlated with distance from the mud volcano. Plots close to the mud volcanoes had species adapted to open canopies and adverse soil conditions caused by mud flows.

In the first half of the 20th century Japanese botanists described taxa endemic to the Maguntan mud volcano, Sakhalin Island, Russia, such as *Artemisia limosa* Koidz., *Gentianella sugawarae* (H.Hara) Czerep., and *Primula sachalinensis* Nakai. Probatova (1984) described *Deschampsia tzvelevii* Prob., an endemic taxon of Maguntan closely related to, and sometimes included in, the widespread *Deschampsia cespitosa* (L.) P.Beauv. The existence of endemic species on the Maguntan volcano was noted by Popov (1949) who observed microzones of vegetation. By contrast, no endemic species were found on mud flows of the Yuzhno-Sakhalinsk mud volcano (Sakhalin Island, Russia) where *Triglochin palustre* L. and *Phragmites australis* (Cav.) Trin. ex Steud. dominated the first stage of vegetation succession (Korznikov 2014). The most profound research on the flora found on and near mud volcanoes was done by Barkalov et al. (2006).

In this paper I examined the vegetation at the Maguntan mud volcano. I considered two hypotheses: (1) there is a microzonal spatial distribution of plant communities similar to those found at geothermal fields; and (2) a specific floristic composition is developed with endemic taxa associated with the area around the eruption center.

Study area

Sakhalin Island, off Russia's eastern coast, is one of the places in the world where mud volcanoes develop (Ershov & Mel'nikov 2007; Mel'nikov 2011). The Maguntan volcano is the biggest in the group of the Pugachevo mud volcanoes found in the south of the island, 146 km north of the administrative center Yuzhno-Sakhalinsk (Fig. 1). The geographic coordinates of the Maguntan volcano's center are 48°13'40"N 142°33'50"E.

The study area comprises the space around the two main eruptive centers within which trees do not form a canopy. This territory has an ellipsoid shape where the maximum diameter from east to west is about 550 m, and the minimum diameter from north to south is about 420 m. The height of the volcano's center is 58 m a.s.l. The height of the volcano's edge is about 54–55 m, with a slope of less than 5° (the "mud pie" type of volcano configuration). The zonal dominant vegetation of southern Sakhalin consists of forests of *Abies sachalinensis* (F.Schmidt) Mast. and *Picea jezoensis* (Siebold & Zucc.) Carrière (Krestov & Nakamura 2002). There is a patch of these trees near the volcano but the Maguntan volcano is surrounded by *Larix cajanderi* Mayr forest associated with azonal habitats. The mean annual temperature is 0.6 °C and the mean annual precipitation is 1,274 mm (Makarov weather station; altitude 37 m a.s.l., 48°39' North, 142°51' East; supervision period: 1955–1993; http://climatebase.ru/station/32116/).

In the winter of 2013 the volcano's territory measured about 3000 m^2. Weak eruptions occur every 1–3 years, with extremely powerful eruptions occurring about every 70 years (Mel'nikov 2011). The latest strong eruption occurred in 2005, when mud flows covered approximately 10 ha. The mud flows reached the volcano's borders and intruded into the *Larix cajanderi* forest (Ershov & Mel'nikov 2007) and the vegetation cover was disturbed in the north-east sector of the volcano.

The volcano's mud substrate is a thin clay with a temperature of about 16 °C that increases to 36 °C during eruptions. The mud volcano's water is mineralized up to 3.6–28.0 ‰. The pH of the volcano's freshly erupted mud exceeds 11. In the water Na^+ and K^+ dominates among the cations, while HCO_3^- dominates among the anions. The compounds boric acid and aluminum, which are toxic to

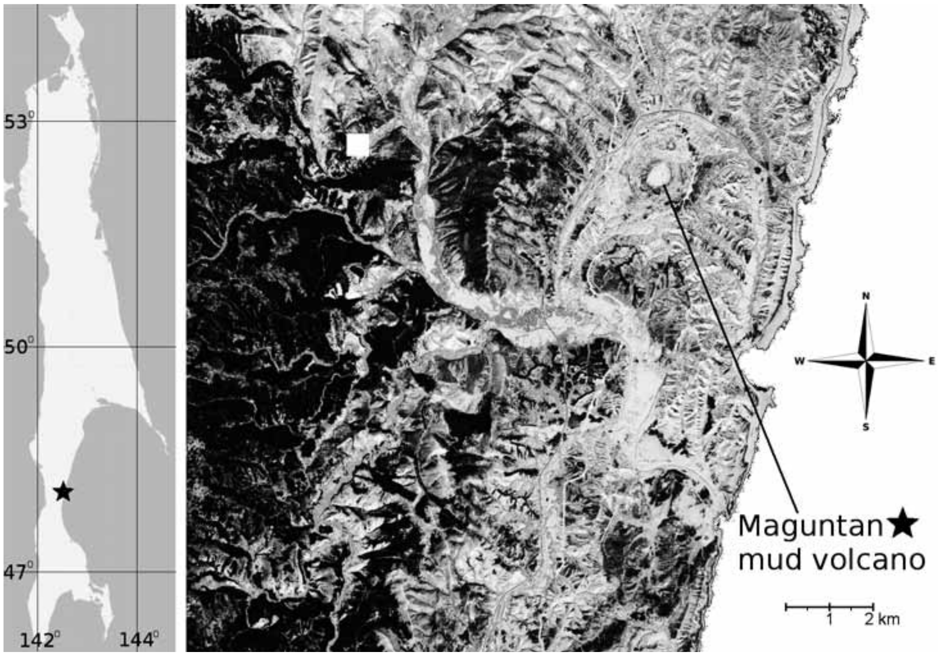

Fig. 1. The location of the Maguntan mud volcano in south Sakhalin. Photo by GeoEye-1 (12 April 2012).

plants, can be found in the emissions of mud volcano eruptions (Siryk 1970). Mud volcanoes produce a high volume of organically created gas (Dimitrov 2003), but gases are of no significant influence to vegetation except when they physically damage plants at the beginning of powerful eruptions (Mel'nikov 2011). Salts and toxic substances are concentrated near the eruption centers.

Material and methods

Sampling

In June and August 2013 I established 185 quadrats (1 m × 1 m) within the area of the Maguntan volcano. Plots were sampled with the goal of including all the previously identified visually distinct plant stands. I did not sample the *Deschampsia tzvelevii* pioneer plant community established on land formed as a result of the 2005 eruption. The location of each quadrat was determined by a Garmin eTrex30 GPS device. Within each plot I recorded species composition and plant cover. The vascular plant cover was recorded using the following scale: 5 (50–100% cover), 4 (25–50%); 3 (10–25%); 2 (5–10%); 1 (1–5%); + (< 1%), r (< 0.01%). Cover was estimated visually. I did not assess the cover of bryophyte (moss) species separately, but considered the total bryophyte cover on a plot. The plant names used follow Czerepanov (1995) and the bryophyte names Ignatov et al. (2006).

Samples of the mud substrate erupted in 2005 were collected at 0–0.1 m depth at a distance of 50 m from the eruptive center, and older mud at a distance of 95 m from the center. Each soil sample ($n = 2$) was at least 400 g and consisted of 20 subsamples. The pH, degree of mineralization, and concentrations of cations and anions were analyzed. The salt was extracted and pH determined by CINAO method (Mineev 2001) in Sakhalin Agrochemical Service. Levels of Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-} were determined by titration of the aqueous extract. The SO_4^{2-} level was established by deposition done with the help of $BaCl_2$. Na^{+} and K^{+} levels were established via incineration on a photoelectric flame photometer. With only two samples, the data are not representative and can only indicate the tendency of change in the chemical parameters of the substrate with increasing distance from the eruption center.

Statistical analysis

For each quadrat I calculated the distance from the main eruption center using GPS coordinates. Median distances were correlated with plant community attributes. I did not calculate distances from the second, younger eruption center created 2005 because the volcano's vegetation was formed around the older center: only the activity around this center should be considered a factor in community composition and structure. To characterize communities I used attributes such as total number of vascular plant species, number of vascular plant species with > 30% frequency, species richness (number of species per quadrat), vascular plant cover, total cover, and endemism rate (proportion of endemic species to the total number of species). These attributes were calculated

Table 1. Species composition, frequency (%) and range of cover scale values (superscript) of the classified plant communities (*Deschampsia tzvelevii* community not included). Abbreviations of plant community names: TP–DT – *Triglochin palustre–Deschampsia tzvelevii*, PS–DT – *Primula sachalinensis–Deschampsia tzvelevii*, GS-PS – *Gentianella sugawarae–Primula sachalinensis*, FR–AL – *Festuca rubra–Artemisia limosa*, EC – *Eleocharis kamtschatica*, D–SF – *Dicranum–Salix fuscescens*, SF–HS – *Salix fuscescens–Hedysarum sachalinensis*, SF–CN – *Salix fuscescens–Calamagrostis neglecta*. * – local endemic. Growth forms: A – annual herb; B – biennial herb; P – perennial forb; G – graminoid; S – shrub; T – tree.

	Growth form	Plant community							
		TP–DT	**PS–DT**	**GS–PS**	**FR–AL**	**D–SF**	**SF–HS**	**SF–CN**	**EC**
Number of quadrats		**8**	**26**	**36**	**19**	**26**	**28**	**31**	**11**
		Most frequent species							
Deschampsia tzvelevii Prob.*	G	**100** $^{+–3}$	**100** $^{1–5}$	72 $^{+–3}$	42 $^{r–2}$	31 $^{1–2}$			27 $^{+–1}$
Triglochin palustre L.	P	100 ^{2}	39 $^{+–1}$	64 $^{r–3}$	84 $^{+–1}$	81 $^{+–1}$	11 $^{+}$	10 $^{r–+}$	18 $^{+–2}$
Primula sachalinensis Nakai *	P	25 $^{+}$	**100** $^{+–4}$	**100** $^{+–4}$	**74** $^{r–2}$	42 $^{+–2}$	7 $^{r–+}$		9 ^{r}
Gentianella sugawarae (H.Hara) Czerep. *	A,B		19 $^{r–3}$	**86** $^{r–3}$	37 $^{r–1}$				
Artemisia limosa Koidz. *	A,B			8 ^{r}	**68** $^{r–2}$	31 $^{+–3}$	11 $^{r–+}$		
Eleocharis kamtschatica (C.A.Mey.) Kom.	G	13 ^{2}	4 ^{2}	3 $^{+}$		42 $^{+–2}$	14 $^{+}$	32 $^{1-2}$	**100** $^{1–5}$
Allium maximowiczii Regel	P		27 $^{+}$	**83** $^{+–2}$	**79** $^{r–2}$	58 $^{r–2}$	39 $^{r–2}$	10 $^{+}$	9 $^{+}$
Festuca rubra L.	G		31 $^{r–1}$	42 $^{+–2}$	**63** $^{+–2}$	50 $^{r–1}$	25 $^{r–1}$	3 ^{1}	
Bryophyta			23 $^{+–2}$	72 $^{+–5}$	37 $^{+–4}$	77 $^{2–5}$	54 $^{+–5}$	90 $^{+–5}$	
Salix fuscescens Andersson	S		8 $^{+–1}$	11 $^{r–2}$	58 $^{r–3}$	**100** $^{1–5}$	**89** $^{+–5}$	**97** $^{+–5}$	
Hedysarum sachalinense B.Fedtsch.	P				5 $^{+}$	27 $^{1–5}$	**86** $^{+–5}$		
Calamagrostis neglecta (Ehrh.) G.Gaertn., B.Mey. & Scherb.	G				5 ^{3}		39 $^{+–2}$	**84** $^{+–4}$	27 $^{+}$
Sanguisorba tenuifolia Fisch. ex Link	P						61 $^{+–3}$	45 $^{r-4}$	
Carex limosa L.	G						4 $^{+}$	61 $^{+–5}$	18 $^{1–4}$
		Low frequent species							
Juncus gracillimus (Buchenau) V.I.Krecz. & Gontsch.	G			6 $^{+-2}$		15 $^{+-3}$	14 $^{+}$	3 ^{2}	
Parnassia palustris L.	P			6 $^{r-+}$		4 $^{+}$		6 $^{+}$	
Juncus nodulosus Wahlenb.	G			3 $^{+}$			11 $^{+-2}$	16 $^{+-2}$	18 ^{1}
Pentaphylloides fruticosa (L.) O.Schwarz	S					8 $^{1-2}$	32 $^{1-5}$		
Ptarmica alpina (L.) DC.	P					8 $^{r-+}$	32 $^{r-+}$	6 $^{r-+}$	
Larix cajanderi Mayr	T					4 ^{3}	18 $^{r-2}$	3 $^{+}$	
Phragmites australis (Cav.) Trin. ex Steud.	G					8 $^{+}$	21 $^{r-2}$	29 $^{1-3}$	9 ^{4}
Carex cespitosa L.	G					4 ^{4}	32 $^{1-5}$	3 ^{2}	9 ^{3}
Artemisia integrifolia L.	P						11 $^{r-+}$		
Rosa acicularis Lindl.	S						4 ^{1}		
Cirsium kamtschaticum Ledeb. ex DC.	P						32 $^{+-4}$	6 $^{1-2}$	
Oxycoccus palustris Pers.	S							3 $^{+}$	
Dactylorhiza aristata (Fisch. ex Lindl.) Soó	P							3 ^{r}	
Caltha palustris L.	P							29 $^{r-3}$	9 $^{+}$
Carex cryptocarpa C.A.Mey.	G							16 $^{1-4}$	27 $^{1-4}$
Sium suave Walter	P							10 $^{+-1}$	27 $^{+-1}$

for each quadrat and the medians of all quadrats were also calculated.

The composition data of all quadrats were classified using TWINSPAN (Hill 1979) in PC-ORD 4.35 for Windows. The analysis was based on cover scale (bryophytes were counted as equal to one species of vascular plant). I defined 7 pseudospecies cut levels from 1 to 7 by abundance classes and 5 levels of division. The classification resulted in eight clusters interpreted as plant communities.

Indirect gradient analyses efficiently summarize complex data and the trends found were used to examine the relationship between environmental variables and plant communities. The ordination was performed using Detrended correspondence analysis (DCA) from PC-ORD (Hill & Gauch 1980; McCune et al. 2002). DCA was used despite its well-known disadvantages (McCune et al. 2002), because it is robust with vegetation data sets of low β-diversity and it is suited to estimating gradient lengths (del Moral, 2007). A matrix of quadrats was created using the ordinal scale 1–7. The statistical analyses were conducted using STATISTICA 8.0. The Kruskal-Wallis one-way analysis of variance and Mann-Whitney *U* test were used to compare significant differences in data. The correlations between the distance from the main eruption center and plant community attributes (including DCA scores) were calculated using the Spearmen rank correlation.

Results

On my sample plots I identified 29 species of vascular plants (Table 1) and seven species of bryophytes (*Barbula unguiculata* Hedw., *Bryum* sp., *Campylium stellatum* (Hedw.) C.E.O.Jensen, *Ceratodon purpureus* (Hedw.) Brid., *Dicranum japonicum* Mitt., *Dicranum leioneuron* Kindb., *Pohlia* sp.). *Larix cajanderi* was the only gymnosperm species recorded; it also grows sparsely at the periphery of the mud fields. The heights of 30-year-old trees range from one to three meters. Eight community types were recognized by TWINSPAN, furthermore occurred the pioneer community of *Deschampsia tzvelevii*. The community characteristics and composition are presented in tables 1 and 2, the spatial distribution of quadrats and communities in Fig. 2. The results of the chemical analyses of the substrate samples are presented in Table 3.

Fresh mud substrate was not colonized by plants ("death zone"). Endemic taxa and their communities were located near the main eruptive center. The 2005 substrate was inhabited by only one species: *Deschampsia tzvelevii*. On the older substrate near the center of the volcano other endemic taxa were growing (involving the communities DT, PS-DT, GS-PS, FR-AL, Table 1). In these communities I found five species of bryophytes: *Barbula unguiculata*, *Bryum* sp., *Ceratodon purpureus*, *Dicranum japonicum*, *Pohlia* sp. The latter four can also

Table 2. Attributes of mud volcano communities (*Deschampsia tzvelevii* community not included). Abbreviations of community names as in Table 1.

Attribute	Plant community							
	TP–DT	PS–DT	GS–PS	FR–AL	SF–CN	D–SF	SF–HS	EC
Number of quadrats	8	26	36	19	31	26	28	11
Median distances from eruption center (m)	107.5	92.0	110.5	146.0	271.0	165.5	209.0	150.0
Total number of vascular plant species in community	4	9	12	10	21	16	20	13
Number of vascular plant species in community with frequency >30%	2	4	7	8	5	8	9	1
Number of vascular plants in quadrats (min-max)	2–4	2–6	3–10	4–7	3–7	3–10	4–12	1-7

Table 3. Means produced by the substrate analysis (n = 2) of the *Deschampsia tzvelevii* community (DT) and the *Primula sachalinensis–Deschampsia tzvelevii* community (PS–DT) in the central area of the volcano. Salinity is expressed in %, ions in mmol ×100 g^{-1}.

Community	Distance from main eruption center (m)	pH	Salinity	Na^{+}+K^{+}	Ca^{2+}	Mg^{2+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}
DT	50	9.35	0.76	4.70	1.15	2.00	1.24	8.00	0.76
PS-DT	90	8.85	0.38	2.19	0.45	1.20	1.19	1.90	0.38

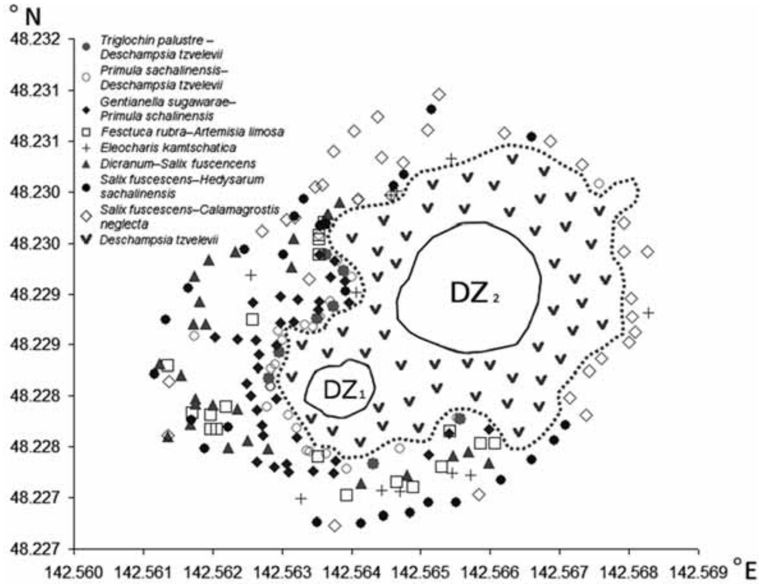

Fig. 2. The distribution of quadrats and plant communities. DZ_1 – death zone generated after a minor eruption in 2012 near the main eruption center. DZ_2 – generated after a 2012 eruption near the 2005 eruption center.

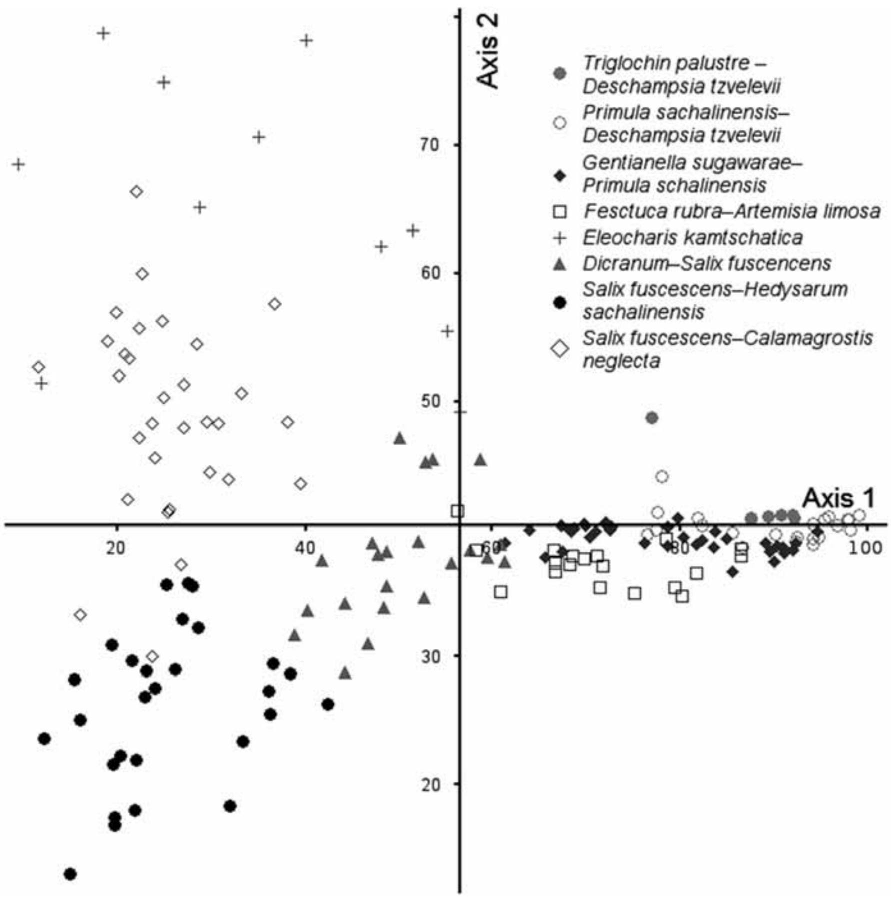

Fig. 3. DCA ordination with quadrats and classified plant communities. Axis 1: length 4.42 SD units, eigenvalue 0.65; axis 2: length 4.0 SD units, eigenvalue 0.41.

be found in the *Deschampsia tzvelevii* pioneer community with low frequency and sparse cover.

Endemics do not dominate at medium distance from the volcano's center, and are neither found in plant communities in the volcano's periphery and on the border with the *Larix cajanderii* forest. *Dicranum japonicum*, *D. leioneuron* and *Salix fuscescens* dominated from the middle to the periphery (communities D-SF, SF-HS, SF-CN). *Campylium stellatum* was sparse in all communities. The quadrats of EC community were scattered in wet microhabitats, not drying out even in the driest years. Eleven species have been observed in this community, but only *Eleocharis kamtschatica* occurred with > 30% frequency of quadrats.

Plant communities from the volcano's central zone formed by endemics have high DCA scores at the first axis (Fig. 3). Quadrats of SF-HS community were observed at medium distances from the central volcano zone and distributed near the middle of the first axis. Plots of communities on the volcano's periphery have low scores on the first axis (Table 4). Accordingly, the first axis correlated with distance from the volcano's major eruption center. The second axis may be interpreted as

Table 4. Spearman's rank correlation between distance from main eruption center and plant community attributes. n=179 (data from six quadrats near mud gryphons at the volcano's periphery were omitted)

Parameter	Distance	p
DCA1	0.743	< 0.001
DCA2	0.03	n. s.
Endemism rate	–0.741	< 0.001
Total cover	0.467	< 0.001
Vascular plant cover	0.283	< 0.001
Floristic richness	0.402	< 0.001

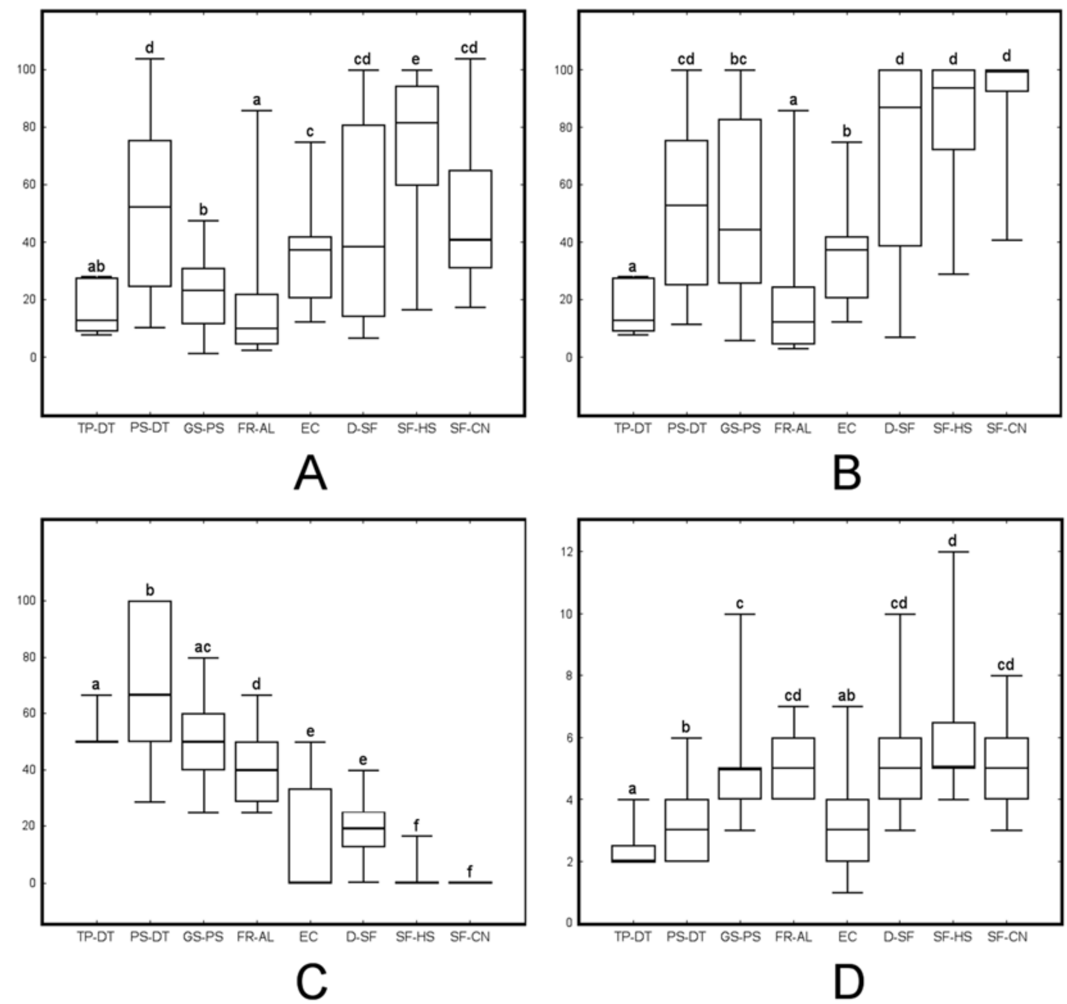

Fig. 4. Medians of vascular plant cover (A), total plant cover (B), endemism rate (C) and species richness (D) in plant communities. The ends of the vertical line indicate min and max values, box - interquartile ranges. Superscripts indicate homogeneous groups by Mann-Whitney test (p < 0.05). The significance among community attributes was compared using Kruskal-Wallis test (p < 0.01). Abbreviations of community names as in Table 1.

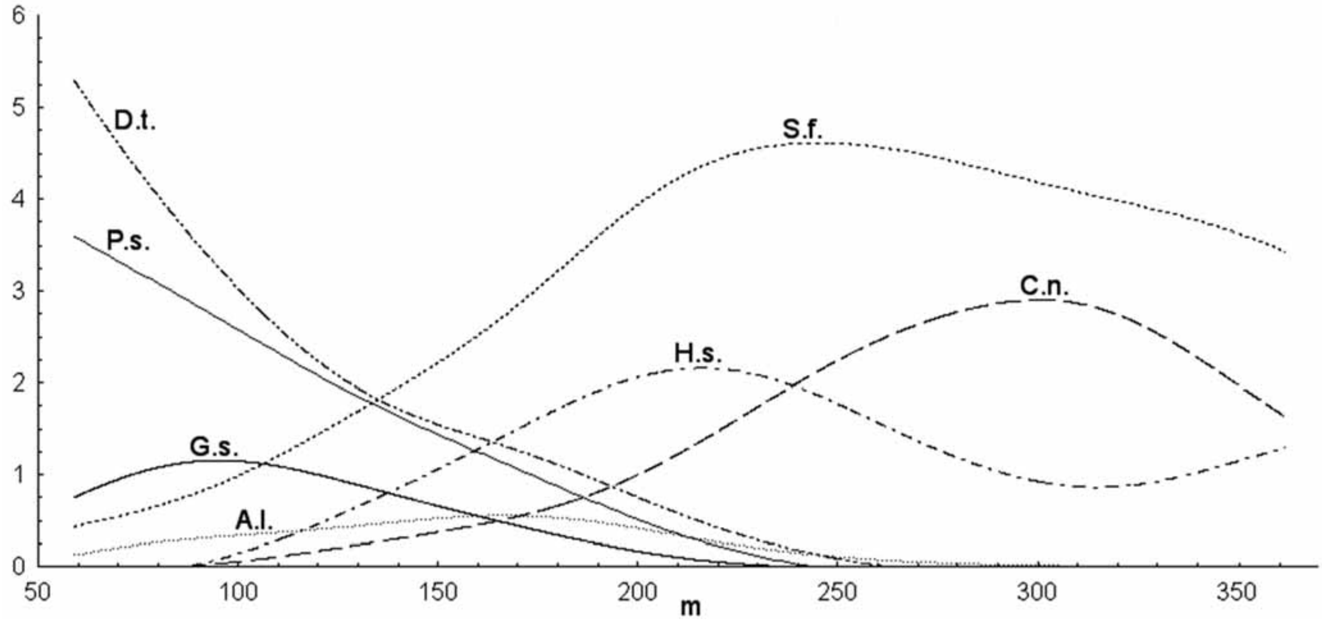

Fig. 5. Variation in cover (vertical axis, cover scale values) of selected dominant species and endemic taxa along the distance gradient from the main eruption center (horizontal axis). Lines are constructed by ordinary least squares. In the 30–55 m range only *Deschampsia tzvelevii* grows (cover abundance > 5). D.t. – *Deschampsia tzvelevii*; P.s. – *Primula sachalinensis*; G.s. – *Gentianella sugawarae*; A.l. – *Artemisia limosa*; S.f. – *Salix fuscescens*; H.s. – *Hedysarum sachalinensis*; C.n. – *Calamagrostis neglecta*.

A

B

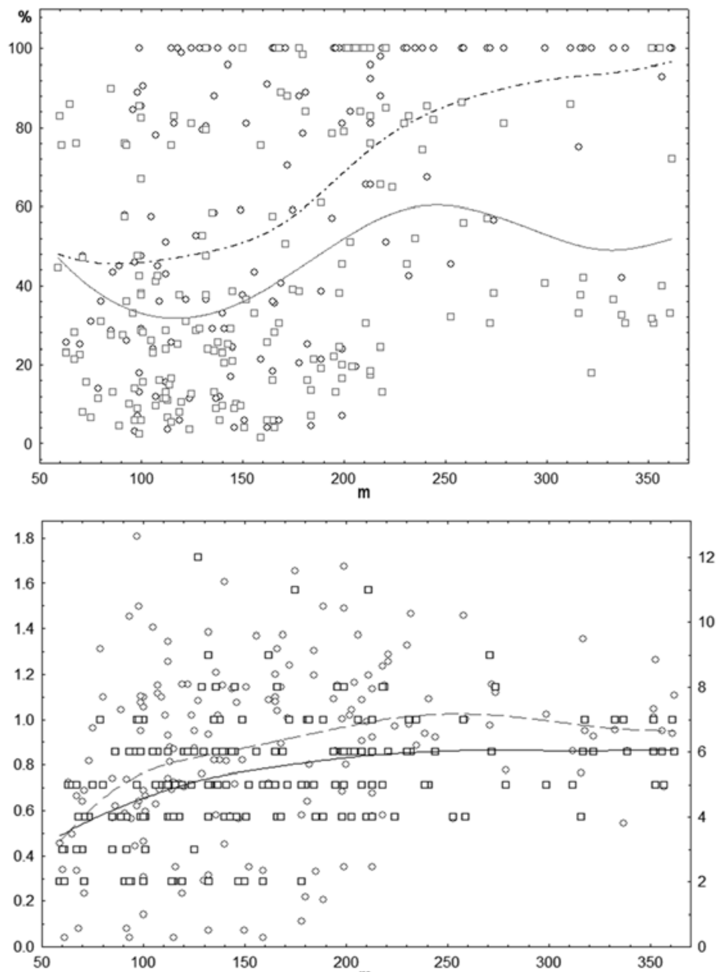

Fig. 6. Variation in total cover (dashed line, circles, vertical axis) and vascular plant cover (unbroken line, squares, vertical axis) along the distance from the main eruption center (horizontal axis) (A); change in floristic richness (dashed line, circles, right vertical axis) and endemism rate (unbroken line, squares, left vertical axis) along the distance from the main eruption center (horizontal axis) (B).

being correlated with degree of moisture. Wet microhabitats in communities CN-SF and EC are characterized by high scores on the second axis, while SF-HS occurred in drier conditions.

The number of vascular plants and floristic richness increased with distance from the main eruptive center (Fig. 4, Table 4). Differences in floristic composition and abundance of species among equidistant communities (e.g. TP-DT and GS-PS) were chiefly due to moisture variation.

A low cover of vascular plants in communities GS-PS and FR-AL may be explained by the morphology and leaf size of the dominant species while *Deschampsia tzvelevii* gradually decreases. The total cover of communities GS-PS by PS-DT was the same because bryophyte abundance increased. The bryophyte cover and frequency is low and total cover is lower in the FR-AL community, which is developed in dry microhabitats, although it is located farther from the eruptive center (Figs. 5, 6).

Discussion

The results confirmed my hypotheses. The typical peculiarities of vegetation on geothermal formations, such as microzonal vegetation pattern and locally endemic taxa dominated of areas near the eruptions centers (Burns 1997; Neshatayeva 2005; Chiarucci et al. 2008; Channing & Edwards 2009; van Manen & Reeves 2012) were observed on the Maguntan mud volcano without high surface temperature.

The spatial distribution of plant communities showed a microzonal pattern on the volcano. While there were no obvious boundaries the plant communities change gradually, both spatially and with regard to the main characteristics of the communities, including the dominance of a particular species. The only exception to this is the *Deschampsia tzvelevii* community. It is clearly distinguishable from other plant assemblages and its territory corresponds with the area where the volcano deposited emissions in the 2005 eruption.

The pioneer communities, as well as the communities that developed on the young substrate, are characterized by a small number of species, but these are locally endemic plants. The radial change of plant community composition from the eruption center is correlated with the decrease of stressors: the reduction of toxic salt concentrations in the older substrate triggers the process of primary succession. Summarizing the above, the leading factor of succession is not only habitat transformation by plants and other organisms and the accumulation of nutrients, but also the washing-out of salts and toxic substances during erosion (Ivanov et al. 1989).

The moisture level in a specific microsite can have a strong influence on the floristic composition. When the moisture level varies on a substrate of the same age the communities vary in floristic composition and dominant species. It is characteristic for wet microsites to be dominated by coastal halophytic species. Similar patterns were observed at Borneo's mud volcanoes where mangroves were found far from the seashore (Ting & Poulsen 2009). Yellowstone's saline geothermal wetlands are almost exclusively dominated by *Eleocharis rostellata* (Torr.) Torr. and *Triglochin maritimum* L. (Channing & Edwards 2009). Apparently, this is due to the species' complex pre-adaptation to the conditions of such habitats, as these species are generally widespread in places with excessive moisture and high salinity. However, in areas with lower levels of moisture of the Maguntan mud volcano *Eleocharis kamtschatica* and *Triglochin palustre* are less plentiful than volcanic endemic plants.

In the end, at least two of these factors – the distance from the eruptive center of the volcano and the level of moisture – provide the conditions for the formation of communities and the micro-zones of the vegetation cover. The presence of mud fields of different age with different soil chemical composition provides heterogeneous microsites causing microzonality and the observed diversity patterns of communities and species. Specific plant communities of the Maguntan mud volcano are of high nature conservation and scientific value for ecological research.

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