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Shigeru Uemura[1], Fusayuki Kanda[2], Tatsuichi Tsujii[3] and Alexander P. Isaev[4] : **Concentric Pattern and Asymmetry in the Vegetation of Alas, Eastern Siberia**

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Abstract

Natural vegetation of the Model Alas, thermokarst depression in the permafrost zone of Eastern Siberia, was surveyed in the midsummer of 1994. Grassland vegetation dominates on the greater part of the basin including aquatic vegetation in the central pond. Aquatic vegetation of the marginal part of the pond was similar to the terrestrial vegetation of the surrounding area. Distribution pattern of the vegetation was primarily in concentric circles from the aquatic vegetation at the central pond to open forest at the circumference terrace scarp, and similar vegetation was observed between corresponding northern and southern areas in the basin. Some differences were, however, found between northern and southern areas, such as dominant species of the open forest on the terrace scarp ; pattern of species replacement in the intermediate plain ; presence of woodland at the marginal areas of the basin ; and restricted distribution of some plants in the southern margin of the central pond. Such differences were considered to be due to different thickness of the active soil layer developped by ill-balanced sunlight throughout the succession.

Key words : alas, Eastern Siberia, grassland, permafrost, similarity.

In the circumpolar region of Eurasia and North America, continuous permafrost zone broadly extends, and various types of topographic structure are formed due to the periodic repetition of frost and thawing, for instance, alas, pingo, polygon, ice-wedge, solifluction, etc. (French 1979 ; Sakai and Kinoshita 1974). Of these land forms, circular thermokarst depression, usually called alas, is particularly found in Eastern Siberia, in particular, densely concentrated to the east of the Lena River, between approximately 60° to 65° latitude, where boreal forests predominated by *Larix dahurica* and *Betula platyphylla* are widely distributed (Fig. 1). The size of alases ranges from ca. 0.1 to over 10 km in diameter, and the depth of basin occasionally attains to 20 m (Kinoshita 1984).

Alas is generally considered to be irreversiblly formed after disappearance of forest by, for instance, fire or artificial cutting. The removal of canopy vegetation induces the increase in the soil temperature by direct sunlight on the ground surface, resulting in melting of the underlying ice-complex body, which is usually called edoma, and in final slumping of ground (Sakai and Kinoshita 1974 ; Fukuda 1994). In the earlier stages of the succession, the lower

Fig. 1. Airscape of scattering alases on the east of Lena River, near Yakustk (Photo by Dr. M. Fukuda).

part of the basin is usually filled by water from the melting of the ice-complex; thereafter the pond becomes dried and finally changes to grassland. As intense evaporation of the pond water and ion accumulation in the active soil layer occur throughout the later stage, only specific vegetation tolerating a high saline condition can be estabished there.

Recently, alas interests us from the standpoint of global warming because a huge mass of methane is contained in the underlying edoma (Fukuda 1994). To date, however, little information on the natural vegetation of alas has been published, because the vegetation is quite suitable for pasturage and, probably, most alases have been substantially disturbed by the grazing of domestic animals over a long period. The Model Alas belonging to the Alas Experimental Field Station, Yakutsk Institute of Biology, is conserved for scientific research exclusive of artificial disturbance. In this alas, the toposequence and chemistry of the pond water were investigated (Matsuura *et al.* 1994; Kanda *et al.* 1995).

We surveyed the vegetation of the Model Alas in the midsummer of 1994, and here we describe some features of the floristic structure and vegetation.

Study area and methods

Field survey was conducted in the Model Alas, which is located at about 60 km ENE of Yakutsk, Republic of Sakha, Russia (Fig. 2). The parent material of the soil is fluvial deposits of the Lena River (Matsuura *et al.* 1994). The shape of the alas basin is almost circular and the size is about 300 m in diameter and about 5 m in maximum depth from the surrounding plateau. At the lowest area of the basin, i.e., slightly south of the center, a circular pond is located, whose size is about 100 m in diameter. Pastures and forests are distributed like a mosaic on the plateau of the circumference. Secondary open forest consisting of *Betula platyphylla* occupies the south-facing terrace scarp of the alas, while coniferous forest consisting of *Larix dahurica* extends on the north-facing terrace scarp (Fig. 3 A).

The edaphic condition of the former is steep and dry, and in contrast, the latter is wet and gentle.

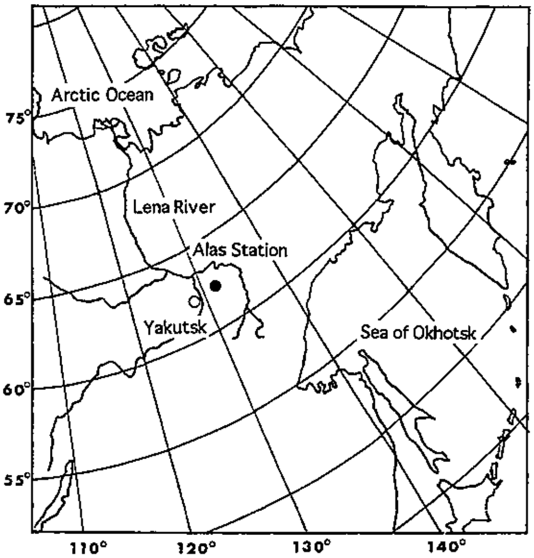

Fig. 2. Location of the area studied.

From the base of south-facing terrace scarp to the opposite side, we set a line transecting the basin through the central pond (Fig. 4). The line was about 280 m long and is located on almost the same line as the one used for soil survey carried out in the summer of 1993 (Matsuura *et al.* 1994). The pond was situated at 105–205 m of the line, whose size was, however, obviously larger than that in the previous summer: ca. 150–190 m (Matsuura *et al.* 1994). After a tentative classification of the vegetation by physiognomy, we set 18 quadrats in each recognized vegetation unit along the line and assessed the coverage and sociability of plant species after Braun-Blanquet (1964). The size of each quadrat is 2 x 2 m. Quadrats from N 1 to N 12 were set in the northern area of the line and those from S 1 to S 6 were in the southern area. In six quadrats set in the pond (N 10–N 12, S 1–S 3), we also measured the depth of water. Based on the similarity ratio (*RS*) of species composition and abundance, the 18 quadrats were clustered by the Mountford average-linkage method. According to the proposal of Van Der Maarel (1979), abundance of each species was converted from the coverage.

Results and discussion

The floristic structure of the 18 quadrats sur-

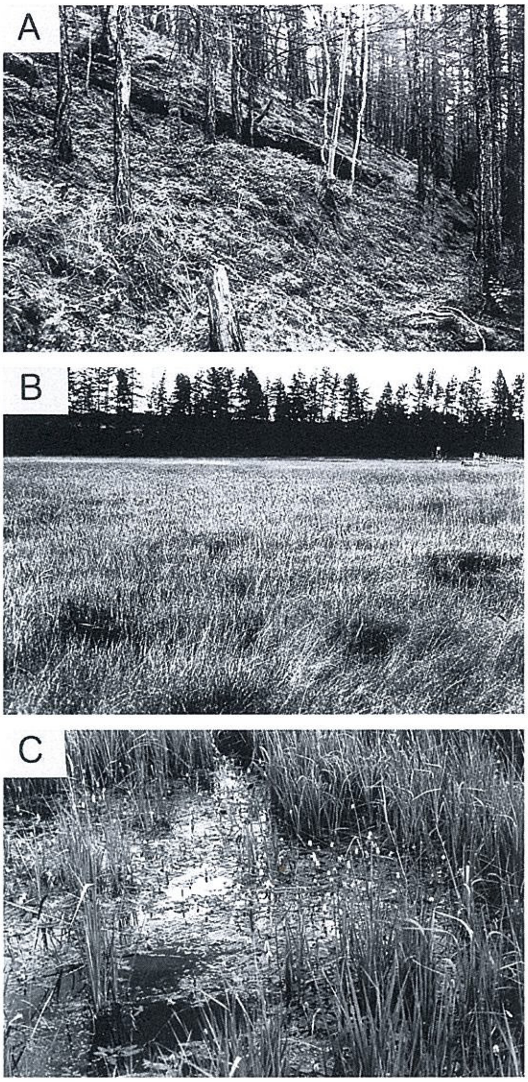

Fig. 3. Landscapes of the Model Alas surveyed. A: larch forest on the north-facing terrace scarp; B: grassland on the intermediate plain; C: aquatic vegetation in the marginal area of the central pond.

veyed was shown in Table 1. Clustering of the quadrats was shown in Fig. 5. A total of 41 species were recognized in the quadrats. Of those only three species, viz., *Betula platyphylla, Larix dahurica* and *Salix* sp. were woody plants, and they were restricted to the marginal area of the basin. Distribution pattern of the vegetation was primarily in concentric circles around the central pond, and most clustered groups were composed of corresponding northern and southern quadrats.

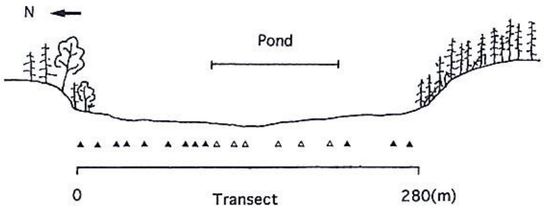

Fig. 4. Schematic representation of the topography and the location of quadrats surveyed. Solid triangles denote terrestrial vegetation and open as aquatic vegetation. The vertical scale is enlarged x 4.

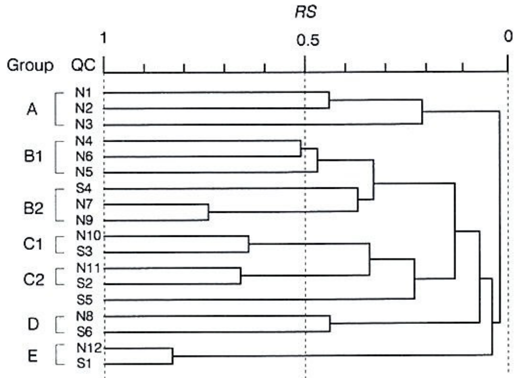

Fig. 5. Dendrogram of the 18 quadrats based on the similarity (*RS*) of species abundance by means of the Mountford average-linkage method. Groups from A to E were clustered at the level of 0.2 in *RS*. QC denotes quadrat code.

From the base of south-facing terrace scarp to the place about 8 m distance on the line, open birch forest including larch trees, whose canopy height was about 6 m, dominated. It showed asimilar physiognomy to the forest on the neighboring terrace scarp. The highest score of species richness was observed in the quadrats: a total of 14 species was recorded in N 1. Some herbaceous species such as *Artemisia commutata, Artemisia tanacetifolia, Poa pratensis* and *Galium verum* also occurred at the inner 10–25 m area (higher plain). Wide spread *Polygonum sibiricum, Thalictrum simplex* and *Poa* sp. were common to the opposite site S 6.

In the zone of 35–105 m area (intermediate plain, N 4–N 9), quite simple and similar vegetation was developed. There *Polygonum sibiricum, Puccinellia tenuifolia* and *Potentilla anserina* dominated (Fig. 3 B). Each quadrat was composed of only three to four species, and their

Table 1. Species composition of the line transect in the Model Alas

Quadrat code (QC)	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	S1	S2	S3	S4	S5	S6
Distance (m)	3	18	32	41	54	72	87	94	103	111	127	134	162	178	202	219	256	267
Depth of water (cm)										3	40	50	60	40	5			
Total coverage (%)	75	90	85	98	90	100	100	100	100	100	90	65	90	80	100	100	100	100
Number of species	14	11	7	4	3	4	3	3	3	2	5	4	2	4	5	3	1	8
Betula platyphylla	5,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Larix dahurica	1,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Campanula langsdorffiana	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sedum purpurea	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vicia multicaulis	1,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Convolvulus arvensis	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Achillea cartilaginea	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lychnis sibirica	1,1	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Artemisia commutata	2,2	3,3	3,3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Artemisia tanacetifolia	1,1	2,2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Galium verum	2,2	1,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saussurea amara	1,1	1,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa pratensis	1,2	3,3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa sp.	2,3	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,1
Polygonum sibiricum	-	1,1	-	3,3	5,5	1,1	+	-	-	-	-	-	-	-	-	-	-	+
Veronica incana	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euphrasia jacutica	-	2,2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sanguisorba officinalis	-	1,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalictrum simplex	-	1,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,4
Agropyrum repens	-	-	1,2	1,1	-	-	-	4,4	-	-	-	-	-	-	-	-	-	-
Taraxacum ceratophorum	-	-	1,1	4,4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria acutiloba	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peucedanum baikalense	-	-	1,1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Puccinellia tenuiflora	-	-	-	3,3	+	5,5	2,2	-	5,5	-	-	-	-	-	-	4,4	-	-
Chenopodium viride	-	-	-	-	1,1	+	-	-	-	-	-	-	-	-	-	-	-	-
Descurainia sophia	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Potentilla anserina	-	-	-	-	-	-	5,5	4,4	4,4	2,2	-	-	-	-	2,2	-	-	3,3
Agrostis sp.	-	-	-	-	-	-	-	3,3	-	-	-	-	-	-	-	-	5,5	-
Alopecurus arundinaceus	-	-	-	-	-	-	-	-	+	5,5	5,5	+	-	4,4	5,5	3,3	-	2,3
Polygonum amphibidium	-	-	-	-	-	-	-	-	-	-	3,3	-	-	4,4	-	-	-	-
Lemna trisulca	-	-	-	-	-	-	-	-	-	-	4,4	-	-	1,1	-	-	-	-
Sporodela polyrhiza	-	-	-	-	-	-	-	-	-	-	1,1	-	-	-	-	-	-	-
Scirpus pauciflorus	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
Glyceria triflora	-	-	-	-	-	-	-	-	-	-	-	4,4	5,5	-	-	-	-	-
Beckmannia syzigachne	-	-	-	-	-	-	-	-	-	-	-	1,1	1,1	4,4	-	-	-	-
Calamagrostis neglecta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,3	-	-	-
Inula britannica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2,2	-	-	-
Potentilla sibirica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,1	-	-	-
Ranunculus borealis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,4		1,1
Lactuca sibirica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,3
Salix sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,1

dominance gradually changed from the outside to the inside of the basin. Similar vegetation was also found in the southern area (S 4). This type of vegetation occupied the largest area in the alas. Floristic structure of this zone seemed to be suitable for foraging of domestic herbivores. In this type of vegetation both amounts of carbon and nitrogen in the soil organic matter were about twice of those in the higher plain but about half of those in the lower basin (Matsuura *et al.* 1994). Less organic carbon and nitrogen and more carbonate were contained in the dried lacustrine deposits than those of the lower basin, indicating that this area has been inundated in the past.

In the central area of the basin, aquatic or semi-aquatic vegetation developed (N 10–N 12, S 1–S 3). These quadrats were divided into three groups : (1) Group C 1, those whose water depth was 3–5 cm ; (2) Group C 2, ca. 40 cm depth ; and (3) Group E, more than 40 cm depth. Dominant species of the marginal area *Alopeculus arundinaceus* and *Potentilla anserina* also occurred in the intermediate plain around the pond (N 9, S 4). A dimorphic plant *Polygonum amphibidium* (aquatic and aerial formings) was abundant in the transition zone (N 11, S 2), suggesting that the marginal area of the pond may be occasionally dried up (Fig. 3 C). In contrast, the central area of the pond (N 12, S 1) dominated by *Glyceria triflora* and *Beckmannia syzigachne* showed high intra-group *RS* (0.83) and low inter-group *RS* (0.04). This area almost coincided with the pond area observed in the previous summer (Matsuura *et al.* 1994), suggesting that the area was always submerged. This was, however, indirect evidence of shrinking of the pond, even if temporal extension by capricious rainfall has occurred. Chemical properties of the pond water analyzed by Kanda *et al*. (1995) showed that the high concentration of cations, especially those of Mg^{2+} and Ca^{2+}, was characteristic of the water. The pH of the water was weakly alkaline (pH 7.7), and the alkalinity was not so high (6.67 meq/l), probably because of the higher concentration of HCO_3^-. In the lower basin of this alas, further saline concentration in the soil is expected to occur in the subsequent succession.

Although similar vegetation pattern between northern and southern places of the basin was observed, there were some differences : for instance, clear replacement of dominant species and lack of common species except for *Alopecurus arundinaceous* among S 4–S 6 ; absence of woodland at the base of the north-facing terrace scarp ; dominant species of the terrace scarp forests ; and restricted distribution of *Calamagrostis neglecta, Inula britannica* and *Potentilla sibirica* to the S 3. A lesser amount of solar radiation in the southern area of the basin by shading of the terrace scarp including the forest would have induced a different thickness of active layer (Matsuura *et al.* 1994) : i.e., deepest at the margin of northern area (260 cm), shallower at the southern margin (90 cm) and central areas (80 cm). Furthermore, content of the soil organic matter of the southern area exceeded that of the northern area, probably because of the colluvial mass movement of woody debris from the terrace scarp, in contrast, cryotubation and accumulation of organic matter and silt/clay fractions were evident in the northern plain (Matsuura *et al.* 1994), indicating the different history of soil formation between these areas. Hence, we speculated that the expansion of the basin promoted by the thawing of ice-complex (Sakai and Kinoshita 1974) occurred only to the north, at least after the begining of the pond shrinking, and the different history between northern and southern areas had lead to the asymmetry in spite of the concentric pattern in the vegetation.

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植村　滋[1]・神田房行[2]・辻井達一[3]・アレキサンダー P. イサエフ[4]：**アラスの同心円状植生配列と非対称性**

シベリア東部レナ川の右岸にはアラスと呼ばれる円形の陥没地形が多数みられ，イネ科を主体とする草本植生が発達する。アラスは地下の氷体（エドマ）の融解によって地表が陥没して形成された特異な地形で，氷の融解にともなって大量のメタンが大気中に放出されることから地球環境への大きな影響が予想されるが，ほとんどのアラスが放牧による強度の撹乱を受けているために，本来の植生を知ることは困難である。1994年夏期に自然状態がよく保全されているヤクーツク生物学研究所の所有するモデルアラス野外研究ステーションで，アラスの中心を通る南北方向にライントランセクトを設けて植生調査を行った。植生配列のパターンは池の水生植物群落から周辺を取り囲む斜面基部の疎林へと至る同心円状の配列がみられた。水深の浅い池の周辺部の植生は，水深の深い池の中央部に成立する植生との類似度が低く，逆に池の周囲の植生との類似度が高い。また地上葉と浮葉の二型をもつ*Polygonum amphibidium*が池の周辺部に生育していることなどから，恒常的に水面下にあるのは池の中央部だけと考えられた。同心円状の植生配列の一方で，アラスの南側では優占種の交代が明確なことや，周辺斜面上に成立する疎林の優占種が北部の*Betula platyphylla*に対して南部では*Larix dahurica*であること，さらにその内側に疎林を欠くことなど，南北間の非対称もみられる。池の南側と北側では土壌の形成プロセスや活動層の深さをはじめとする地下構造が大きく異なっており，それが植生の違いに反映しているものと考えられた。

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