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RESEARCH ARTICLE

Phytocenotic characteristics of the vegetation cover of avalanche paths in Central Altai

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Abstract
The article presents the characteristics of plant cenoses in the studied avalanche paths of Central Altai (Aigulaksky, Kuraisky, Listvyaga, North Chuisky Ridges). They were analyzed using the Juss 7.0 software package and divided into 2 main groups: forest and shrub-herbaceous. The forest group includes 8 cenoses with 130 plant species; shrub-herbaceous one includes 16 communities with 205 species. Forest cenoses divided into 2 groups, and shrub-herbaceous – into 3 groups, classified on the basis of diagnostic species, characteristics of tree, shrub and herb layers, as well as the coenoflora core. All the groups of communities, both forest and shrub-herbaceous, according to the geobotanical zoning of G.N. Ogureeva (1980), correspond to two geobotanical districts and regions of Central Altai highland-taiga-forest-steppe province: 1) Kholzunsko-Korgonsky highland-taiga district and Verkhnekatunsky highland-taiga-forest-steppe region (Listvyaga Ridge); 2) Chuisko-Argutsky nival-highland-taiga-forest-steppe district and Chuisko-Argutsky taiga-forest-steppe region (Aigulaksky, Kuraisky, North Chuisky Ridges). Considering the shrub-herbaceous vegetation of the studied avalanche paths of Central Altai, it is possible to assume their annual avalanche activity. In some avalanche paths, the type of avalanche, the time of a catastrophic avalanche, and the approximate last year of a powerful avalanche were estimated.

Keywords
Avalanche, avalanche activity, coenoflora core, diagnostic species, forest and shrub-herbaceous vegetation, geobotanical zoning of Altai, phytoindication, plant communities

Introduction

In the mountains snow avalanches play one of the leading roles in destructive effects on vegetation. Avalanches are characterized by transience, irregularity, and, if directly observed, danger. In this case, phytoindication methods, as indirect methods for studying avalanche activity, become particularly important (Akifyeva 1971; Gorchakovsky and Shiyatov 1985). Forest vegetation exposed to the destructive effects of avalanches contains and retains the maximum amount of traces of this effect for a long time. Avalanches have a mechanical effect on vegetation, forming treeless or poorly forested areas within the forest belt (Gorchakovsky and Shiyatov 1985; Simonson et al. 2010). The mechanical action of a moving mass of snow, sometimes containing a large amount of clastic material, followed by prolonged cold retention and an increase in humidity in the area of the remaining snowfield for a long time – all together these constitute indirect long-lasting traces in the landscape. From the repeated action of avalanches, damage is superimposed, contributing to the creation of a specific appearance of the avalanche accumulation zone, which is exposed to the action with different frequencies (Akifyeva 1971).

The most important signs of avalanche activity in the forest belt are such phenomena as the presence of snowfields at low levels at a time when the seasonal snow cover has already disappeared, the destruction of tree vegetation and its replacement with tree-shrub and shrub-herbaceous vegetation, intense oppression of trees and shrubs (broken trunks and branches, wounds on trunks, tilts and bends of trunks, thickets of shrubs "trimmed" at a certain height, delayed phases of development), the presence of mineral alluvial fans, erosional landforms. Some weak avalanches do not damage vegetation but redistribute the snow cover, which can lead to changes in time and availability of moisture and nutrients necessary for plant growth (Simonson et al. 2010). The azonal nature of vegetation in the avalanche paths in the forest zone is determined by the frequency of avalanches and their type (Akifyeva 1971). In the central part of the avalanche path, the mosaic of the vegetation increases, as a result, this leads to an increase in the floral richness of this area (Rixen et al. 2007; Bebi et al. 2009).

Avalanche activity in Altai has a few features. Above all, it is irregularity, the presence of long breaks between short periods of the avalanche activity. This type of activity is well confirmed by the distribution and condition of forest vegetation on the slopes, the ratio of deciduous and coniferous species, their age and degree of oppression. This is, first of all, the replacement of coniferous forests by adults (approximately 30 years old) deciduous forest or younger coniferous forest.

The effect of avalanches on the appearance of vegetation cover is manifested by such phenomena as the scalloped pattern of the upper border of the forest, its abrupt lowering into the upper reaches of the hollows serving as avalanche paths. This character of the forest vegetation boundaries indicates the regular action of avalanches in the upper part of the slopes. In the upper reaches of large valleys and hollows dissecting the slopes, triangular treeless wedges stretch downwards – avalanche paths of "ribbon" valleys characteristic of the highlands (Kravtsova 1971). In addition, after the destruction of forest vegetation on the avalanche paths, it is replaced by shrub-herbaceous vegetation; in a successional series coniferous forest is replaced by deciduous (more often willow-aspen forest with an admixture of birch), which indicates avalanche activity in the recent past. By the age of the deciduous forest, it is possible to judge the time that has passed since the last avalanche. Bands of coniferous undergrowth are also observed along avalanche hollows and on alluvial fans. This happens in areas where avalanches are generally uncommon, but for some reason avalanches have occurred in recent years.

The frequency of avalanches in an avalanche path can vary from several times a year to only once every three hundred years or more. In addition, the frequency may be high in the upper part of the path, but, as a rule, decrease lower in the accumulation zone. For example, several small descents can occur each winter in the upper part of the avalanche path, while a very powerful avalanche can potentially pass along the entire length of the path and reach the accumulation zone (Simonson et al. 2010).

The variety of constant (the nature of the underlying surface) and variable (climatic) factors of avalanche formation in Altai causes a weak synchronicity of the avalanche regime even in neighboring avalanche paths. In this regard, the rhythmicity of avalanche processes has wide limits. In the investigated avalanche paths of the studied territory, maximum avalanches occur most often with a periodicity of 3–12 years (Revyakin and Kravtsova 1977; Bykov et al. 2024). However, catastrophic avalanches can occur with a frequency of dozens or even hundreds of years.

Thus, in different avalanche paths different time is needed for the restoration of the vegetation cover, which affects its species composition and structure and can serve as an indicator of the time of the last maximum avalanche.

A geobotanical study of the vegetation of the Altai avalanche paths has not yet been conducted purposefully. The first data on the avalanche path vegetation in Altai can be found in V. S. Kravtsova (1971) and V. S. Revyakin and V. S. Kravtsova (1977). In the publications of one of the co-authors of this article N. I. Bykov (2013, 2015), the vegetation cover of two avalanche paths is characterized in more detail: 1) the Korgon River basin (Western Altai) and 2) the Chuya River basin from the White Bom to the Chagan Uzun (Central Altai). In this work, the floral composition, ecological groups in relation to humidification, and the range of life forms of vegetation in avalanche paths and adjacent forest areas were analyzed. However, detailed phytocoenotic characterization has not been carried out.

The purpose of this work was in-depth examination of the plant communities of avalanche paths in Central Altai to study the long-term dynamics of avalanche processes.

Materials and methods

Work area

The peculiarity of the avalanche regime in Central Altai is determined by the extensive development of the alpine zone, in which a complex set of avalanche formation factors usually operates. Avalanches of various genetic types occur here, associated with heavy snowfalls, spring and autumn thaws, and snowstorm transport. The area differs in significant avalanche power and full development of avalanche apparatuses. Central Altai is characterized by a year-round period of avalanche danger, with the maximum development of avalanche activity in spring (Kravtsova 1971).

According to the geobotanical zoning of G. N. Ogureeva (1980), the territory of the studied avalanche collections belongs to the Altai-Sayan region, the Altai province and the Central Altai highland-taiga-forest-steppe subprovince. This part of the Altai territory is characterized by the alpine-tundra-taiga-forest-steppe type of altitudinal zonation and the most fully expressed column of the normal alpine series of belts from the steppes to the nival belt of high peaks. Avalanche paths in the upper reaches of the Katun River belong to the Kholzunsko-Korgonsky highland-taiga district and the Verkhnekatunsky subalpine-taiga-forest-steppe region. The avalanche paths of the Aigulaksky, Kuraisky, and North Chuisky Ridges are located in the Chuisko-Argutsky nival-highland-taiga-forest-steppe district and the Chuisko-Argutsky taiga-forest-steppe region.

The vegetation of the studied avalanche paths of Central Altai is located in the lower and middle bands of the mountain taiga subbelt of the forest belt. On the northern slope of the Listvyaga Ridge, high-grass mixed birch-larch forests are developed with the participation of fir, spruce and *Pinus sibirica*, interspersed with areas of high-grass meadows, as well as dark coniferous forests (mainly spruce-fir), which alternate with sites of high-grass forest meadows. Vegetation cover is formed in conditions of increased moisture in the Listvyaga Ridge, which is a barrier to the western moist air masses (Kuminova 1960; Artemov et al. 2001). Birch-larch (Ogureeva 1980) and spruce-birch forests are developed on the southeastern slopes of the Aigulaksky Ridge in the lower subbelt. Derived willow-aspen forests can form at the exit cones of the avalanche paths. In the middle band of the Kuraisky Ridge, herb types of larch and *Pinus sibirica*-larch forests are common on the southeastern slopes. The northern slopes are occupied by larch forests in combination with dark coniferous species (spruce and *Pinus sibirica*) with a layer of shrubs and low shrubs. The upper band of the mountain taiga subbelt from an altitude of 1800 m is formed by larch-*Pinus sibirica* green mossy forests with an undergrowth of round-leaved birch on the northern slopes (North Chuisky Ridge) (Ogureeva 1980). The slopes of the southern and southeastern exposures of the Kuraisky Ridge in the upper band are characterized by larch-*Pinus sibirica* forests with the participation of subalpine elements (*Neogaya simplex*, *Aegopodium alpestre*, *Swertia obtusata*, *Pedicularis compacta*, etc.) in the herb layer, as well as junipers (*Juniperus communis* var. *saxatilis*, *J. pseudosabina*) in the shrub layer.

In this work, the vegetation cover of 6 avalanche paths in different regions of Central Altai was studied (Figs. 1–3). The expedition studies were conducted in 2024. Avalanche path levels are indicated in accordance with N. I. Bykov (2013). Geobotanical sites were laid mainly at level B, the lower level of the transit zone. For the morphologically complex (with 2 intersecting avalanche swaths) avalanche path No. 12, work was also carried out at levels A – the accumulation zone and C – the upper level of the transit zone.

The work is based on 24 geobotanical descriptions (relevés) of communities (8 forest, 16 shrub-herbaceous). Relevés of forest vegetation were performed on sites measuring 25 × 25 m, herbaceous – 10 × 10 m. Geobotanical sites were laid in areas with different avalanche frequencies (in accordance with the work of N. I. Bykov 2013): X – avalanche trough with the highest frequency; Y – avalanches rarely descend; Z – indigenous forest, avalanches do not descend. The site coordinates are given in the notes to the tables.

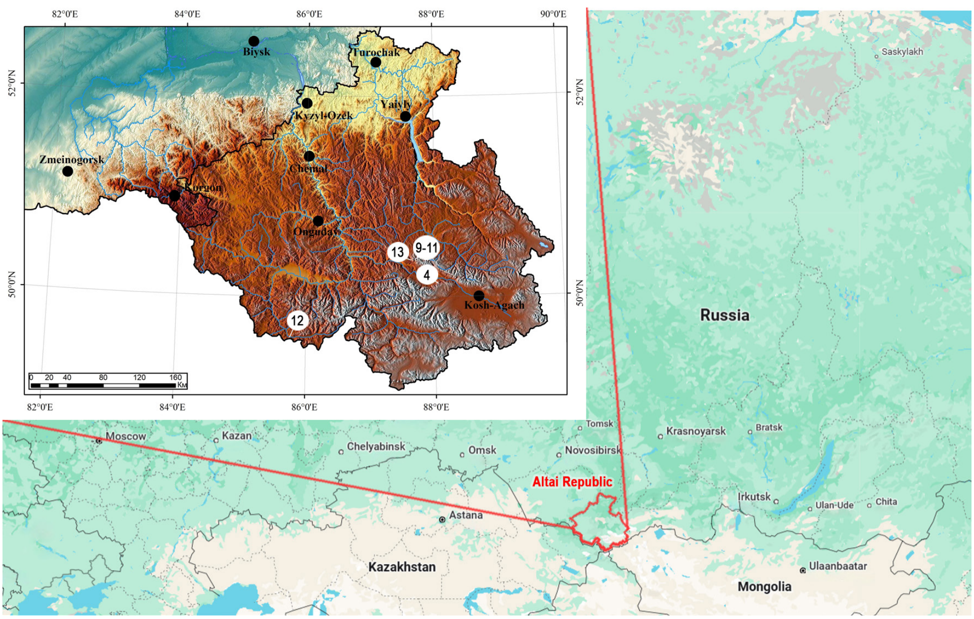

Figure 1. Geographical location and numbers of the investigated avalanche paths.

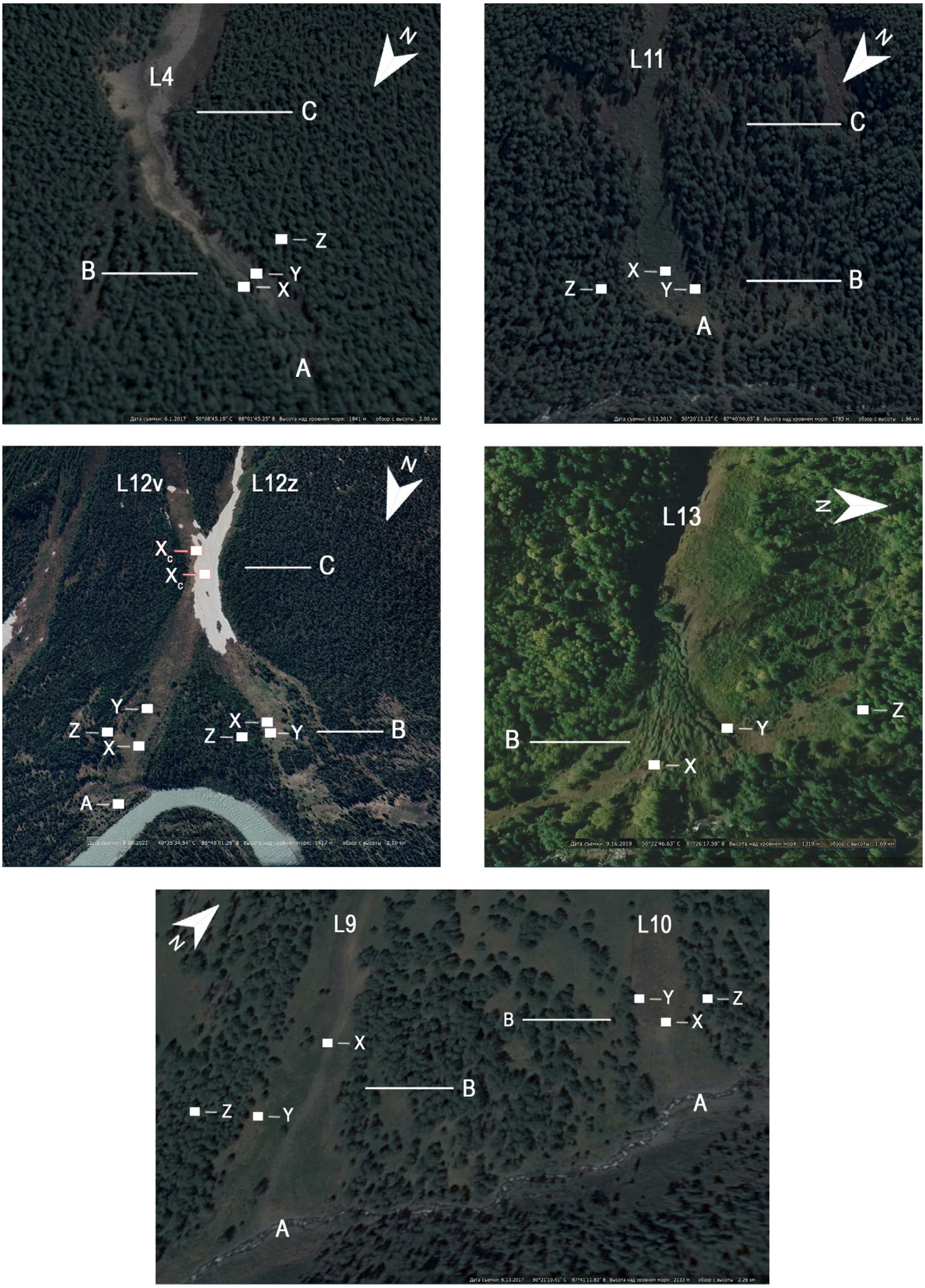

Figure 2. The studied avalanche paths of Central Altai: L4 (North Chuisky Ridge), L11 (Kuraisky Ridge, Korumduayry River valley), L9 and L10 (Kuraisky Ridge, Belenkaya River valley), L12v and L12z (Listvyaga Ridge), L13 (Aigulaksky Ridge, Belgebash River valley).

The participation of species in the vegetation cover was assessed on the Braun-Blanquet scale (Mirkin et al. 2001): r – the species on the site is found in single specimens; + – the species has a projective coverage of up to 1 %; 1 – the species has a projective coverage of 1 to 5 %; 2 – from 5 to 25 %; 3 – from 25 to 50 %; 4 – from 50 to 75 %; 5 – above 75 %. The constancy scale was used in the compilation of synoptic tables: r – 0.1–5 %; + – 6–10 %; I – 11–20 %; II – 21–40 %; III – 41–60 %; IV – 61–80 %; V – 81–100 %. Geobotanical descriptions were entered into the TURBOVEG database (Hennekens 1996). They served as source material for processing phytocenotic tables using the Juice 7.0 software package (Tichy 2002).

Species names are given according to POWO (2025).

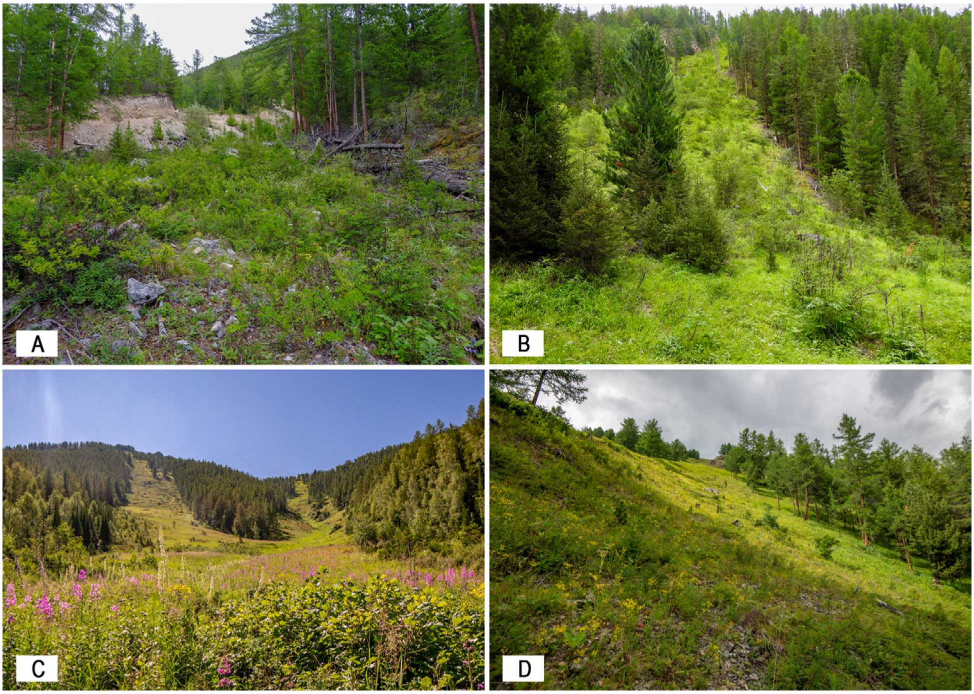

Figure 3. Some landscape photographs of the investigated avalanche paths (A – accumulation zone of the avalanche path L4, B – accumulation zone of the avalanche path L11, C – starting zone and track of the avalanche path L12, D – track of the avalanche path L10).

Results

On the first division level releves set divided into two clusters – forest (8 releves, 130 species) (Table 1) and shrub-herbaceous (16 releves, 205 species) (Table 2).

Then, the forest cluster is divided into 2 groups. **Group 1** consists of communities: forest of *Pinus sibirica*, *Picea obovata* and *Larix sibirica* with *Rhododendron dauricum*, *Vaccinium vitis-idaea* and moss (L4), overgrown with bushes forest of

Pinus sibirica, *Picea obovata* and *Larix sibirica* (L10) and overgrown with bushes forest of *Pinus sibirica*, *Picea obovata* and *Vaccinium vitis-idaea* (L11).

Diagnostic species: *Larix sibirica*, *Picea obovata*, *Pinus sibirica*, *Lonicera caerulea* subsp. *altaica*, *Aegopodium alpestre* (Tables 1, 2).

The tree layer consists of *Larix sibirica*, *Picea obovata*, and *Pinus sibirica*. The dominant tree species are larch and spruce with the participation of *Pinus sibirica*, with a crown density of 0.6–0.7 and a height of up to 25 m. Small-leaved species do not take a significant part in the composition of the forest stand.

The understory is represented by shrubs with a projective cover of up to 30 %: *Lonicera caerulea* subsp. *altaica*, *Caragana arborescens*, with less participation of *Betula glandulosa*, *Cotoneaster uniflorus*, *Ribes nigrum*, *Rhododendron dauricum*, *Spiraea chamaedryfolia*. The total projective cover of the herbaceous layer is up to 35 %. The moss cover is mosaic-like: closed areas of mosses alternate with fragments of herbaceous vegetation.

The main dominants of the herbaceous layer are *Aegopodium alpestre*, *Aconitum leucostomum*, *Carex pediformis* var. *macroura*, *Cerastium pauciflorum*, *Galium boreale*. In the herbage, grass-sedge and mixed-herb plots alternate with shrubby-mossy fragments with V*accinium vitis-idaea*. The grasses is represented by *Poa krylovii* and *P. sibirica*.

The species richness varies from 14 to 45 plant species per 100 m^2.

Group 2 includes communities: forest of *Larix sibirica* and *Pinus sibirica* with *Spiraea chamaedryfolia* (L9), forest of *Abies sibirica*, *Picea obovata*, *Betula pendula* overgrown with *Lonicera caerulea* subsp. *altaica* (L12_3), forest of *Picea obovata*, *Abies sibirica* with *Aconitum leucostomum* and *Carex pediformis* var. *macroura* (L12_6), forest of *Betula pendula* and *Picea obovata* with *Caragana arborescens*, *Spiraea chamaedryfolia* and *Carex pediformis* var. *macroura* (L13, site Z), forest of *Salix viminalis* and *Populus tremula* with *Cirsium serratuloides* and grasses (L13, site X).

Localization: Republic of Altai, Ulagan District, Kuraisky Ridge, Belenkaya River valley; Aigulaksky Ridge, Belgebash River valley; Ust-Koksa District, Listvyaga Ridge, left bank of the Katun River, 5 km above the mouth of the Zaichikha River. Communities are found at an altitude of 1275–2037 m above sea level.

Diagnostic species: *Larix sibirica*, *Picea obovata*, *Pinus sibirica*, *Betula pendula*, *Aegopodium alpestre*, *Aconitum leucostomum*, *Carex pediformis* var. *macroura*, *Cerastium pauciflorum*, *Galium boreale*, *Paeonia anomala*.

The tree layer consists of *Abies sibirica*, *Larix sibirica*, *Picea obovata*, *Pinus sibirica*, *Betula pendula*. The dominant trees are fir and *Pinus sibirica* with the inclusion of larch, spruce, birch with a crown density of 0.5–0.6, with a trunk diameter of up to 25 cm and a height of up to 20–25 m. The sapling is largely expressed in places by *Picea obovata*, *Abies sibirica*, *Pinus sibirica* up to 2 m tall.

The understory is expressed, sometimes reaching 50 % of the projective cover. *Lonicera caerulea* subsp. *altaica*, *Caragana arborescens*, *Spiraea chamaedryfolia* with an average cover of 15 % in total are noted as dominants. The undergrowth is represented with a smaller proportion of cover by *Cotoneaster uniflorus*, *Padus avium*, *Ribes nigrum*, *Clematis alpina* subsp. *sibirica*, *Rosa acicularis*, *Rubus idaeus* subsp. *strigosus*, *Sorbus aucuparia* subsp. *glabrata*, *Spiraea media*. The total projective cover of the herbaceous layer reaches 70 %. The moss cover is sparse and is represented by *Hylocomium splendens*, or it is absent.

The herbage is formed by *Aegopodium alpestre*, *Aconitum leucostomum*, *Carex pediformis* var. *macroura*, *Cerastium davuricum*, *Galium boreale*, *Paeonia anomala*. *Aegopodium alpestre*, *Equisetum pratense*, *Parasenecio hastatus*, *Carex pediformis* var. *macroura*, *Cerastium pauciflorum*, *Galium boreale*, *Geranium krylovii*, *Lathyrus gmelinii*, *Milium effusum*, *Paeonia anomala*, *Primula veris* subsp. *macrocalyx*, *Senecio nemorensis* are often codominants. The grasses is represented by *Calamagrostis epigejos*, *C. pavlovii*, *Elymus sibiricus*, *E. caninus*, *Elytrigia repens*, *Milium effusum*. The total cover changes from 40 to 70 %.

The species richness varies from 20 to 47 plant species per 100 m^2.

Table 1. Species representation of forest communities

Ordinal number of relevé	**Layer**	**1**	**2**	**3**	**K$_1$**	**4**	**5**	**6**	**7**	**8**	**K$_2$**
Field number of relevé		**4_3**	**10_1**	**11_1**		**9_3**	**12_6**	**13_1**	**12_3**	**13_3**	
Altitude, m		**1841**	**2104**	**1727**		**2037**	**1367**	**1306**	**1378**	**1275**	
Number of species		**14**	**45**	**22**		**29**	**20**	**23**	**24**	**47**	
Larix sibirica	4	2	3	3	**V**	2	-	+	+	-	**III**
Picea obovata	4	2	3	3	**V**	-	2	1	2	-	**III**
Pinus sibirica	4	-	3	3	**V**	-	-	-	-	-	**II**
Pinus sibirica	5	2	3	3	**IV**	2	-	-	1	-	**II**
Aegopodium alpestre	6	+	-	-	**II**	1	1	-	1	-	**III**
Carex pediformis var. *macroura*	6	-	-	-	-	2	3	2	3	-	**IV**
Paeonia anomala	6	-	-	-	-	1	1	2	-	1	**IV**
Aconitum leucostomum	6	-	-	-	-	-	2	1	1	+	**IV**
Betula pendula	5	-	-	-	-	-	1	2	2	-	**III**
Cerastium pauciflorum	6	-	-	-	-	-	1	1	1	1	**IV**
Aconitum volubile	6	-	-	-	-	+	-	-	-	+	**II**
Chamaenerion angustifolium	6	-	-	-	-	2	-	-	-	1	**II**
Lilium martagon var. *pilosiusculum*	6	-	-	-	-	r	-	-	-	+	**II**
Lonicera caerulea subsp. *altaica*	6	1	-	-	**II**	+	-	-	-	-	**II**
Picea obovata	5	2	-	-	**II**	-	2	1	3	-	**III**
Abies sibirica	4	-	-	-	-	-	3	-	3	-	**II**
Abies sibirica	5	-	-	-	-	-	3	-	3	-	**II**
Equisetum pratense	6	-	-	-	-	-	-	-	+	2	**II**
Galium boreale	6	-	-	-	-	-	-	1	1	1	**III**

Ordinal number of relevé		**1**	**2**	**3**		**4**	**5**	**6**	**7**	**8**	
Field number of relevé	**Layer**	**4_3**	**10_1**	**11_1**	K_1	**9_3**	**12_6**	**13_1**	**12_3**	**13_3**	K_2
Altitude, m		**1841**	**2104**	**1727**		**2037**	**1367**	**1306**	**1378**	**1275**	
Number of species		**14**	**45**	**22**		**29**	**20**	**23**	**24**	**47**	
Lathyrus gmelinii	6	-	-	-	-	-	1	-	1	-	**II**
Lonicera caerulea subsp. *altaica*	6	-	-	-	-	-	-	-	3	1	**II**
Milium effusum	6	-	-	-	-	-	1	-	2	-	**II**
Solidago virgaurea	6	-	-	-	-	-	-	1	1	-	**II**
Veratrum lobelianum	6	-	-	-	-	-	-	-	1	+	**II**
Angelica sylvestris	6	-	-	-	-	-	1	1	-	-	**II**
Crepis sibirica	6	-	-	-	-	-	1	-	-	+	**II**
Senecio nemorensis	6	-	-	-	-	-	1	-	-	1	**II**
Thalictrum minus	6	-	-	-	-	-	+	-	-	1	**II**
Agrimonia pilosa	6	-	-	-	-	-	-	1	-	1	**II**
Artemisia vulgaris	6	-	-	-	-	-	-	1	-	1	**II**
Parasenecio hastatus	6	-	-	-	-	-	-	1	-	1	**II**
Primula veris subsp. *macrocalyx*	6	-	-	-	-	-	-	+	-	+	**II**
Rubus saxatilis	6	-	-	-	-	-	-	1	-	+	**II**
Spiraea chamaedrifolia	5	-	-	-	-	-	-	2	-	+	**II**
Vicia cracca	6	-	-	-	-	-	-	+	-	1	**II**

Notes: K_1 – the occurrence coefficient in the community of the group 1, K_2 – the occurrence coefficient in the community of the group 2.
Localizations of the relevés (all the relevés have been made in 2024 in Republic of Altai):
1 – 4_3, Kosh-Agach District, North Chuisky Ridge, N 50.14606°, E 88.029169233°;
2 – 10_1, Ulagan District, Kuraisky Ridge, Belenkaya River valley, right bank, N 50.35467°, E 87.69073°;
3 – 11_1, Ulagan District, Kuraisky Ridge, Korumduayry River valley, left bank, N 50.33933°, E 87.668613°;
4 – 9_3, Ulagan District, Kuraisky Ridge, Belenkaya River valley, right bank, N 50.35253°, E 87.68797°;
5 – 12_6, Ust-Koksa District, Listvyaga Ridge, left bank of the Katun River, 5 km above the mouth of the Zaichikha River, N 49.59521°, E 85.75103°;
6 – 13_1, Ulagan District, Aigulaksky Ridge, Belgebash River valley, right bank, N 50.38039°, E 87.43877°.
7 – 12_3, Ust-Koksa District, Listvyaga Ridge, left bank of the Katun River, 5 km above the mouth of the Zaichikha River, N 49.59491°, E 85.75469°;
8 – 13_3, Ulagan District, Aigulaksky Ridge, Belgebash River valley, right bank, N 50.37906°, E 87.43938°.
The author of the relevés is P. A. Kosachev.

Table 2. Synoptis table of forest communities

Species	Constancy of II–V classes / Number of descriptions	
	Group 1	**Group 2**
Larix sibirica	V/3	III/3
Picea obovata	V/3	III/3
Pinus sibirica	V/3	II/2
Betula pendula	-	III/3
Aegopodium alpestre	II/1	III/3
Aconitum leucostomum	-	IV/4
Carex pediformis var. *macroura*	-	IV/4
Cerastium pauciflorum	-	IV/4
Galium boreale	-	III/3
Paeonia anomala	-	IV/4

Shrub-herbaceous communities are presented by 3 groups, including a total of 16 relevés and 205 plant species.

Group 3 includes a meadow with *Lonicera caerulea* subsp. *altaica* and *Betula glandulosa* (L12 – eastern, relevé 12_9, site Xc).

Localization: Ust-Koksa District, Listvyaga Ridge, left bank of the Katun River, 5 km above the mouth of the Zaichikha River. The community is located at an altitude of 1554 m a. s. l.

Diagnostic species: *Lonicera caerulea* subsp. *altaica*, *Salix glauca*, *Veratrum lobelianum*, *Betula glandulosa*, *Aconitum leucostomum* (Tables 3, 4).

The species richness is 15 plant species per 100 m^2.

The shrub layer 1–2 m high is well developed, its projective cover varies from 10 to 40 %. The base of the layer is formed by *Salix glauca* with a projective cover of no more than 5 %, *Lonicera caerulea* subsp. *altaica* with the cover of 15 %, and *Betula glandulosa* with the cover of no more than 5 %.

There are three sublayers in the herbage. The upper sublayer is sparse, up to 160 cm high, and is composed of generative shoots of large-herb species (*Aconitum leucostomum*, *Anthriscus sylvestris*, *Calamagrostis langsdorffii*). The second sublayer is up to 80 cm high with a projective cover up to 80–100 cm almost closed; the main forming species are *Saussurea latifolia*, *Thalictrum minus*, *Veratrum lobelianum*, *Chamaenerion angustifolium*. The main dominants of the third sublayer are *Carex aterrima*, *Milium effusum*, *Cerastium davuricum*, *Poa sibirica*, *Geranium krylovii*, *Cerastium pauciflorum*.

Group 4 includes communities: thickets of *Dasiphora fruticosa* and *Betula humilis* with *Iris ruthenica* and *Poa sibirica* (L9, site Y), thickets of *Caragana arborescens* (L4, site X), thickets of *Caragana arborescens* on a stony-gravelly scree (L4, site Y), thickets of bushes (*Salix jenisseensis*, *Ribes nigrum*, *Lonicera caerulea* subsp.

altaica, *Spiraea chamaedryfolia*) with *Carex pediformis* var. *macroura* and *Trisetum sibiricum* (L11, sites X and Y), *Abies sibirica*, *Picea obovata*, *Betula pendula* mixed-herb grassy woodlands (L12, site A), Juniperus communis var. saxatilis thickets with *Trisetum sibiricum*, *Thalictrum minus* and *Carex pediformis* var. *macoura* (L10, site X), *Juniperus communis* var. *saxatilis* and *Spiraea chamaedryfolia* thicket with sapling of *Pinus sibirica* (L10, site Y).

Localization: Republic of Altai, Kosh-Agach District, North Chuisky Ridge; Ulagan District, Kuraisky Ridge, Belenkaya River valley, Korumduayry River valley; Ust-Koksa District, Listvyaga Ridge, left bank of the Katun River, 5 km above the mouth of the Zaichikha River.

Table 3. Synoptis table of shrub-herbaceous communities

Species	Constancy of I–V classes / Number of descriptions		
	Group 3	Group 4	Group 5
Aquilegia sibirica	-	III/5	-
Bupleurum multinerve	-	IV/6	-
Carex pediformis var. *macroura*	-	III/5	II/2
Chamaenerion angustifolium	-	V/8	V/6
Galium boreale	-	IV/6	V/6
Geranium pseudosibiricum	-	III/5	-
Heracleum dissectum	-	IV/6	II/2
Iris ruthenica	-	IV/6	-
Poa sibirica	-	III/5	V/5
Thesium repens	-	III/5	-
Trisetum sibiricum	-	II/2	III/3
Lonicera caerulea subsp. *altaica*	V/1	III/5	II/2
Paeonia anomala	-	III/5	III/3
Spiraea chamaedrifolia	-	III/5	-
Cerastium pauciflorum	-	II/2	III/3
Saussurea controversa	-	III/5	-
Chamaenerion angustifolium	V/1	I/1	-
Senecio nemorensis	-	I/1	III/3
Betula pendula	V/1	I/1	-
Salix glauca	V/1	I/1	-
Vicia cracca	-	I/1	III/2
Geranium sp.	-	-	III/3
Aconitum krylovii	-	-	III/3
Aconitum leucostomum	-	-	V/5
Calamagrostis langsdorffii	-	-	V/5

Species	Constancy of I–V classes / Number of descriptions		
	Group 3	Group 4	Group 5
Filipendula ulmaria	-	-	III/3
Lamium album	-	-	V/5
Lathyrus pratensis	-	-	III/3
Milium effusum	-	-	V/5
Saussurea latifolia	-	-	V/5
Veratrum lobelianum	-	-	IV/4
Veronica longifolia	-	-	V/5
Anthriscus sylvestris	-	-	IV/4
Cirsium helenioides	-	-	IV/4
Thalictrum minus	-	-	IV/4
Betula glandulosa	V/1	-	I/1
Abies sibirica	V/1	-	-
Aconitum leucostomum	V/1	-	-
Anthriscus sylvestris	V/1	-	-
Calamagrostis langsdorffii	V/1	-	-
Carex aterrima	V/1	-	-
Cerastium davuricum	V/1	-	-
Cerastium pauciflorum	V/1	-	-
Milium effusum	V/1	-	-
Poa sibirica	V/1	-	-
Saussurea latifolia	V/1	-	-
Thalictrum minus	V/1	-	-
Veratrum lobelianum	V/1	-	-

The communities are located at an altitude of 1265–2117 m a. s. l.

Diagnostic species: *Lonicera caerulea* subsp. *altaica*, *Spiraea chamaedryfolia*, *Iris ruthenica*, *Geranium pseudosibiricum*, *Heracleum dissectum*, *Paeonia anomala*, *Carex pediformis* var. *macroura*, *Poa sibirica*, *Galium boreale* (Tables 3; Suppl. material 1: Table 4).

The shrub layer up to 120 cm high is well developed, the projective cover varies from 10 to 30 %. The main dominants are *Lonicera caerulea* subsp. *altaica*, *L. tatarica*, *Cotoneaster uniflorus*, *Caragana arborescens*; codominants are *Spiraea chamaedryfolia*, *S. media*, *Ribes nigrum*, *Rhododendron dauricum*, *Rosa spinosissima*, *Salix jenisseensis*, *S. glauca*, *S. saposhnikovii*. Sparse areas of *Pinus sibirica* and spruce undergrowth up to 3 m high are formed in some open places.

The total projective cover of the herbaceous layer is up to 80 %. Depending on the specific features of the substrate, light and moisture conditions, mosses cover less than 5–10 %. The coenoses are polydominant. The main dominants of the herbaceous layer are *Aconitum leucostomum*, *Anthriscus sylvestris*, *Carex pediformis* var. *macroura*, *Galium boreale*, *Poa sibirica*, *Veratrum lobelianum*, *Saussurea latifolia*, *Trisetum sibiricum*, *Senecio nemorensis*.

The grasses is represented by *Agrostis gigantea*, *Avenula pubescens*, *Deschampsia caespitosa*, *Elymus mutabilis*, *Elytrigia repens*, *Festuca valesiaca*, *Calamagrostis epigejos*, *Poa krylovii*, *P. nemoralis*, *P. sibirica*, *P. urssulensis*. The proportion of legumes is not significant and is represented by species: *Hedysarum neglectum*, *Hedysarum theinum*, *Trifolium lupinaster*, *T. pratense*. A large share of participation is given to mixed herbs: *Aquilegia sibirica*, *Iris bloudowii*, *Gentiana uniflora*, *Veronica krylovii*, *Paeonia anomala*, *Polemonium caeruleum*, *Polygala comosa*, *Phedimus hybridus*, *Thesium repens*, *Thalictrum simplex*.

The species richness varies from 6 (center of the avalanche path, scree) to 48 plant species per 100 m^2.

Abies sibirica, *Picea obovata*, *Betula pendula* mixed-herb grassy woodlands are located in the avalanche path L12. This is an avalanche accumulation zone at level A (Katun River terrace at an altitude of 1265 m a. s. l.). Avalanches rarely descent here, and tree vegetation is being restored through the succession of birch forests. According to the data of dendrochronology, the age of the tree species ranged from 16 to 64 years; so, it can be assumed that the catastrophic avalanche that destroyed the tree vegetation in this place descended around 1960. The last avalanche (but not catastrophic for level A) was recorded in 2017. Despite the significant age of individual trees, the forest did not form due to the mechanical effects of avalanches and the retention of snowfields for a long time. Damage is visible on the tree trunks, as well as part of the birches has a saber-shaped curved trunk in the lower part. The draughtiness reaches 80 % in this woodland, which allows many xerophytes (*Festuca valesiaca*, *Aster alpinus*, *Veronica porphyriana*) and mesoxerophytes (*Geranium pseudosibiricum*, *Iris ruthenica*, *Trifolium lupinaster*) to settle here. A similar composition of xerophytes and mesoxerophytes is also observed in communities of avalanche paths L9 and 10. The total projective cover of the herbaceous layer does not exceed 80 %. These features of the herbaceous layer, as well as the similar composition of grasses, brought this community closer to other phytocoenoses of the group 2: thickets of bushes in avalanche paths of Kuraisky and North Chuisky Ridges.

Group 5 includes communities: overgrown with bushes meadow with *Calamagrostis epigejos* (L13, site Y), thickets of *Betula humilis* with sapling of *Abies sibirica* (L12 western, site Y), thickets of *Spiraea media* in meadow with sapling of *Abies sibirica*, *Betula pendula* and *Picea obovata* (L12 eastern, site Y), meadow with *Lonicera caerulea* subsp. *altaica* (L12 eastern, site X), thickets of *Lonicera tatarica*, *Spiraea media* on *Aconitum leucostomum* and grassy meadow (L12 western, site X), overgrown with bushes meadow with *Chamaenerion angustifolium*, *Aconitum krylovii* and *Calamagrostis langsdorffii* (L12, site Xc).

Localization: Republic of Altai, Ulagan District, Belgebash River valley; Ust-Koksa District, Listvyaga Ridge, left bank of the Katun River, 5 km above the mouth of the Zaichikha River.

The communities are located at an altitude of 1285–1780 m a. s. l.

Diagnostic species: *Bupleurum multinerve*, *Chamaenerion angustifolium*, *Carex pediformis* var. *macroura*, *Heracleum dissectum*, *Lonicera caerulea* subsp. *altaica*, *Poa sibirica*, *Spiraea chamaedryfolia* (Tables 3; Suppl. material 1: Table 4).

This group of communities is characterized by a significant share of shrubs forming the layer with a projective cover up to 20 %: *Caragana arborescens*, *Lonicera caerulea* subsp. *altaica*, *L. tatarica*, *Padus avium*, *Ribes altissimum*, *R. spicatum*, *Rosa acicularis*, *Rubus idaeus* subsp. *strigosus*, *Salix pyrolifolia*, *S. bebbiana*, *Sorbus aucuparia* subsp. *glabrata*, *Spiraea chamaedryfolia*, *S. media*. In some places, communities contain a sapling up to 3–5 m high, formed by species: *Abies sibirica*, *Betula pendula*, *Picea obovata*, *Betula humilis*, *B. glandulosa*. The sapling doesn't form a separate layer, the projective cover is not more than 5 %.

The total projective cover of the herbaceous layer riches 100 % and 150–190 cm height. The appearance of the herbage is determined by the dominance of large-herb plants. Cenoses are often polydominant, and in various combinations next species can dominate: *Aconitum leucostomum*, *Calamagrostis langsdorffii*, *Chamaenerion angustifolium*, *Cirsium helenioides*, *Poa sibirica*, *Saussurea latifolia*, *Milium effusum*, *Veratrum lobelianum*. The grasses is represented by *Agrostis gigantea*, *Calamagrostis langsdorffii*, *Dactylis glomerata*, *Elymus sibiricus*, *E. mutabilis*, *Milium effusum*, *Poa sibirica*. Legumes are not significant in cenoses and are represented by *Hedysarum theinum*, *Lathyrus gmelinii*, *L. pratensis*, *Vicia cracca*.

The species richness varies from 21 to 42 plant species per 100 m^2.

With some exceptions, the communities of group 5 are found in the sites Y (near the forest) identified by us. Communities from group 4 are typical for sites X (center of the avalanche path).

For most avalanche paths, there is a sharp boundary of avalanche swaths and expressed avalanche starting zone. But there is an exception. The L11 avalanche path does not have a sharp boundary of the swath and the clear starting zone; the center of the avalanche path is heavily overgrown (spirea-honeysuckle thickets) with tall willows, and spruce undergrowth 3–4 m high is also marked along the periphery. The entire avalanche path is strewn with large debris. It is likely that there is a shift in the snow mass, rather than a rapid avalanche. In addition, there is an assumption that in 2003, as a result of a strong earthquake, a rock collapse occurred in the upper part of the slope, as evidenced by a high percentage of large detrital material, both throughout the avalanche path and in adjacent plots of the larch-Pinus sibirica-spruce forest.

In the L4 avalanche path, part of the trough is largely occupied by the material brought by the mudslide (large debris with rubble, broken trees and branches). At the same time, it was difficult to distinguish between the avalanche and mudslide zones. Basically, in the mudslide zone, the projective cover of vegetation did not exceed 20 %, and in the avalanche zone – 50 %.

Willow-aspen thickets 5 m high are described in the lower part of the L13 avalanche path, which indicates their approximate age of 5 years. According to satellite images, the last powerful avalanche descended here in 2019, which is consistent with the data on vegetation cover.

Discussion

The forest communities that surround the avalanche path vegetation belong to the polydominant formations of the dark coniferous taiga (Kamelin, 2005). *Abies sibirica* is often dominant in the Verkhnekatunsky subalpine-taiga forest-steppe region and occurs sporadically in the Chuisko-Argutsky taiga forest-steppe region. The sapling of this tree is found in meadows and thickets of shrubs in the avalanche paths only in this botanical and geographical region of Altai. The presence of fir sapling, as well as 100 % coverage in meadow communities, may play an indicator role and specify the avalanche path vegetation in the Verkhnekatunsky subalpine-taiga forest-steppe region.

Avalanche disturbances lead to high vegetation variability, and it is impossible to describe one or more characteristic associations for avalanche paths (Erschbamer 1989). However, it is possible to trace the succession series from herbaceous with individual shrubs, shrub-herbaceous vegetation and thickets of shrubs with a tree sapling to young deciduous forests. This is directly related to the frequency of avalanches. Most often, there are thickets of shrubs, represented mainly by the species *Lonicera caerulea* subsp. *altaica*, *L. tatarica*, *Spiraea chamaedryfolia*, *S. media*, as well as meadows with tall herbs and 100 % projective cover with shrubs, in the lower part of the avalanche paths. Considering that such communities are typical for the avalanche paths, where avalanches descend in the period from 1 to 10 years (Simonson et al. 2010) (with the exception of L13 and L11, where willow-aspen and tall shrubs' thickets are developed, respectively), it can be argued that large avalanches reaching the lower transit zones are frequent. Since the annual disturbance prevents further successional development, the shrub-herbaceous communities presented in this work represent a stopped successional stage in the lower transit zone.

In the Alps, attempts have been made to identify a specific characteristic type of vegetation for avalanche path. For example, W. J. Brücker (1981) in Kanton Uri (Switzerland) identified a meadow community with the species *Tussilago farfara*, *Saxifraga aizoides*, and *Agrostis stolonifera* for the erosion zone (streambed). T. Schauer (1981) described *Petasites paradoxi* as a characteristic association on avalanche paths with pronounced scree transfer. However, in a study by B. Erschbamer (1989), it was found that the associations identified, characteristic of avalanche paths, are not comparable with similar communities in other parts of the Alps. In addition, avalanche path vegetation depends to a large extent on the local relief and geomorphology, and it is difficult to transfer the results obtained for one region to another. Besides, avalanches do not affect the entire avalanche path area with the same intensity, and snow flows often vary in size and strength. Consequently, avalanche paths can be a habitat for species from different successional stages: short-lived pioneers in recently disturbed areas, medium-sized species from open habitats and shade-tolerant species under trees that have survived avalanches, as well as alpine species that have been transported down into the forest belt (Rixen 2007).

In 1997, Ott et al. described 3 types of communities, replacing the forest in the subalpine belt in the Alps. In addition to shrubby vegetation, these are *Calamagrostis* stands (tall grass), *Rhododendron* stands (dwarf shrub), and tall herb stands. Similar types of communities in the subalpine forest belt for the Alps were also provided in the study by Rixen et al. (2007).

In the avalanche paths of Central Altai studied by us, similar types of communities are also represented by thickets of shrubs and tall grass meadows (including *Calamagrostis langsdorffii*). However, the type of *Rhododendron* stands (dwarf shrub) is missing.

Conclusions

Thus, the vegetation of the studied avalanche paths of Central Altai at the lower (B) and middle (C) levels is represented by overgrown with bushes tall-grass forest meadows, thickets of shrubs, as well as small-leaved forests (willow-aspen).

Considering the shrub-herbaceous nature of the vegetation of the studied avalanche paths of Central Altai, we can assume annual avalanche activity. The character of the avalanche path vegetation and the surrounding forest vegetation depends on the altitude above sea level to a large extent, which determines the change in all natural conditions and, above all, the climatic situation, which manifests itself in the formation of altitude-belt rows of vegetation (in our case, 2 for forest and 3 for shrub-herbaceous vegetation).

Our first preliminary study of the avalanche path vegetation of Central Altai showed a complex structure and dynamism of communities. Considering the strong variability of avalanche activity in Altai, the diversity of habitats, different natural conditions and the significant richness of flora, it is possible to assume a high diversity of the avalanche path vegetation, which still to be explored both in Central Altai and in other regions of Altai.

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Supplementary material 1

Table 4. Species representation of shrub-herbaceous communities

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