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RESEARCH ARTICLE

Development of biota within the Seliverstov Glacier deglaciation zone after the Little Ice Age maximum (Mongun-Taiga mountain range, Southeastern Altai)

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Abstract

Recognized as part of the so-called Third Pole, the highlands of the Tuvan Altai represent the most arid part of the Russian Altai with a sharply continental climate, despite these features being a large glaciation node. Deglaciation caused by global climate change creates conditions for the initiation of postglacial vegetation successions. However, if the newest dynamics of glaciers of the high mountain massif of Mongun-Taiga, located at the junction of the mountain structures of the south-east of the Russian Altai and the mountain systems of the Sayan and Mongolian Altai, is well studied from a glaciological point of view, the issues of postglacial successions of biota in this region remain practically unstudied. This article is an attempt to give the first characteristics of the biota in the deglaciation zones of the Seliverstov Glacier in relation to deglaciation zones of different ages and typologies.

Keywords
Mongun-Taiga, Russian Altai, glaciers, deglaciation zones, biota, species composition

Introduction

The Third Pole (TP) region includes the highlands of Asia, including the Tibetan Plateau, the Himalayas and surrounding mountains, as well as the Pamir Highlands, the Tien Shan Mountains, and the Altai Mountains (Yao et al. 2022). Glaciers with an area of more than 100,000 km2 are located here, containing the largest volume of ice outside the Arctic and Antarctic (Yao et al. 2022). This mountainous region is crucial for water security and socio-economic sustainability in many countries. It supports a population of 1.7 billion people (Yao et al. 2018). It is important to note that the rate of global warming is twice the global average over the past half century (Chen et al. 2015; Pepin et al. 2015). Climate warming has changed the water vapor reserves and regional climatic characteristics of TP (Yang et al. 2014). Changes in the cryosphere, such as glacial retreat, permafrost degradation, and a change in precipitation patterns from snow to rain (Kang et al. 2010) alter greatly the hydrological cycle (Yang et al. 2014) and the state of the land surface (for example, vegetation, soils, lakes, and topography). This leads to noticeable differences between the main TP river basins in terms of such indicators as actual total evaporation, land water reserves, and river runoff (Bibi et al. 2018).

Materials and methods

Characteristics of the area and the state of its exploration

The study area is the Mongun–Taiga high mountain massif (3970 m, 50°15.84'N; 90°9.16'E), located at the junction of mountain structures in the south-east of the Russian Altai and the mountain systems of the Sayan and Mongolian Altai (Fig. 1). The mountainous part of the massif is represented by an alpine relief with modern glaciation and the ubiquitous traces of the glaciation of the Little Ice Age (LIA).

The climate of the massif is sharply continental with cold, dry winters. According to the nearest weather station Mugur-Aksy (1850 m), the average annual air temperature is -3.0 °C, the average air temperature in July is +13.1 °C, in January -20.5 °C. According to our estimates, due to the shielding of the massif by the Chikhachev ridges (from the west), Shapshalsky and Tsagan-Shibetu ridges (from the north), the average annual precipitation at the top of Mongun Taiga does not exceed 310 mm. An average of 160 mm is recorded in the orographic shadow of the massif, while only 20% of precipitation falls in the cold season. The winter anticyclone causes cloudless weather, and as a result, thin and fragmented snow cover (Chistyakov et al. 2015).

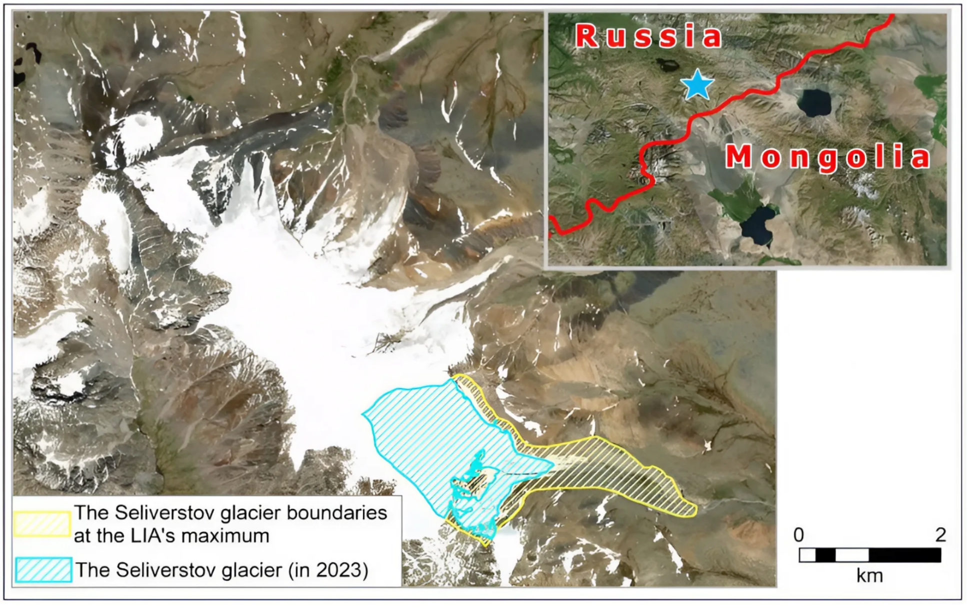

Figure 1. The study area is the Seliverstov glacier of the Mongun-Taiga mountain range.

Despite the low amount of precipitation, modern glaciers are located on the territory of the massif. The first description of the glaciers of the Mongun-Taiga massif was published by Yu.P. Seliverstov (Seliverstov 1972): 30 glaciers with a total area of 44 km^2. Over the next 40 years, the extent of glaciation and the number of glaciers were reviewed and clarified (Table 1). The current glaciation of the massif as of 2021 is estimated at 17.18±1.13 km^2 and represented by 38 glaciers (Griga et al. 2023).

Table 1. Information on the glaciation of the Mongun-Taiga mountain range over the past 40 years

Number of glaciers, pcs	Total glaciation area, km^2	Link to the publication
30	44	Seliverstov 1972
36	28	Revyakin 1978
52	23.3	Seliverstov et al. 1997
32	20.3	Chistyakov et al. 2015
38	17.2	Griga et al. 2023

Seliverstov Glacier (Shara-Khoragai) is a complex valley glacier, one of the main glaciers in the Mongun-Taiga glacier complex (Fig. 2). The glacier consists of several ice streams. The main (northern) ice flow begins on the northeastern slope of the Kyrgyz peak (3803 m above sea level). The upper part of the glacier at altitudes of approximately 3760 m is part of a dome-shaped glacial complex with relatively low slopes of less than 100 m/km. Next, the glacier descends into the cirque, the bottom of which is located at the level of 3300–3350 m here the stream takes a southeasterly direction in accordance with the aspect of the latter. The other stream begins at a level of about 3620 m and is confined to the cirque of the northeastern aspect (the bottom is at about 3400 m), and the walls of the northern part of this cirque have completely lost their ice shell over the past decade. The confluence of the two streams, further separated by a medial moraine, occurs at an altitude of about 3270 m. The length of the glacier tongue is about 730 m. In 2023, the lowest point of the glacier corresponded to an altitude of 3142 m. The tongue of the glacier is slightly pollute, with the exception of two medial moraines. One of them, right in the center of the tongue, appears only within 200 m from the lower point of the glacier (also confined to it). The second is located in the southern part of the tongue. It is more clearly defined and can be traced to a rocky outcrop separating the two main glacial streams. There is an outwash plain complex below the glacier periodically flooded by meltwater from the glacier, bordered by a moraine ridge of the Little Ice Age (LIA) with a relative height of 30–40 m.

Figure 2. Seliverstov Glacier and its terminal moraine complex (photo by E.S. Derkach, July 2023).

Colonization of the territory by biota at the micro-level begins already at the glacial stage, as revealed, for example, by the neighboring Vostochny Mugur glacier (Vlasov et al. 2025), where colonization of cryoconite material by microbiota was established. The vegetation of the periglacial zone of the highlands of the massif is fragmentary and represented mainly by unclosed groupings of cryopetrophytic mixed grasses and pioneer vegetation (Ogureeva 1980; Dirksen and Smirnova 1997). The flora of the Mongun-Taiga mountain range is still insufficiently studied, and publications directly related to the diversity of vascular plants in the Shara-

Khoragai River valley are generally rare. No special studies have been conducted within the deglaciation zone of the Seliverstov Glacier. The first information about the flora of the territory under consideration is contained in the published diaries of the Tomsk botanist V.V. Sapozhnikov (Sapozhnikov 1911), who visited the valley of the Shara-Khoragai River in August 1909 on his way home, when his expedition group was returning from the Mongolian Altai. The next researcher to visit the valley was also Tomsk botanist A.S. Revushkin, who in 1976–1978 conducted a study of the high-altitude flora of the Mongun Taiga. The result was the characterization of two specific high-altitude flora, the Northern Mongun Taiga (405 species) and the Southern Mongun Taiga (387 species), published in the summary of the Altai high-altitude flora (Revushkin 1988), the latter covering the high-altitude belt of the entire southern macro-slope, including the upper reaches of the Shara-Khoragai River. Since 1980, employees of the Central Siberian Botanical Garden of the Siberian Branch of the USSR Academy of Sciences (CSBG, Novosibirsk) V.M. Hanminchun, A.V. Kuminova and V.E. Golovanova have been working in the valley of the Shara-Khoragai River for various purposes. The materials they collected are stored in the Herbarium of the Central Siberian Research Library (NSK). Since 1993, the research of the Mongun Taiga vegetation cover by the CSBG staff in connection with the organization of the Ubsunur Basin State Nature Reserve, which includes the Mongun Taiga cluster has been continued. The results in the form of a summary of the flora of the reserve are summarize by D.N. Shaulo (Shaulo 2009). In total, 786 species for the Mongun-Taiga cluster, including those that are may be found in this area in principle are listed.

The following critically revised generalization for the entire Mongun-Taiga massif was presented by I.A. Artyomov (Artyomov 2014), who compiled a catalog including 653 plant species. We would like to focus on the long-term studies of the glacial flora of the Altai-Sayan mountain region conducted by N.V. Revyakina (Revyakina 1996). Materials on the periglacial flora in the Seliverstov Glacier area were collected in 1986. However, it should be noted that the periglacial flora, in the author's understanding, includes all plants growing near the glacier, that is, they include both species growing on postglacial landforms and on surfaces that have never been subjected to glaciation. Thus, these are, in fact, parts of the high-altitude flora, isolating territories determined by the presence of modern glaciation. A convincing confirmation is the comparison of the species composition of the periglacial flora of the entire Mongun Taiga according to N.V. Revyakina (250 species) and 2 specific high-altitude flora of the Southern and Northern Mongun Taiga by A.S. Revushkin (387 and 405 species, respectively). This is the end of the publications covering the study of the flora of the Shara-Khoragai river valley to one degree or another. In addition, as we can see, all of them were organize as part of work that covered a wider area.

It should be noted that no special studies of invertebrate fauna have been conducted in this area before. Information about the presence of ground beetles here and in the adjacent high-altitude territories is available in works devoted to the study of ground beetles in the highlands of Tuva (Dudko 2008; Dudko et al. 2010). In particular, a new carabid beetle species *Nebria* (*Catonebria*) *lyubechanskii* sp., similar to *N. sajana* and *N. roddi* (Dudko et al. 2010), is described from Tsagan-Shibetu and Western Tannu-Ola high altitude mountain ranges in South-Western Tuva. Information about the faunal finds of spiders is contained in the work of Fomichev (2015) and in review work on *Parasyrisca* (Araneae, Gnaphosidae) of Holarctic (Ovcharenko et al. 1995). The latest work indicates that *Parasyrisca asiatica* is one of the endemic species for the Altai-Sayan mountain region.

Results

Factors determining the development of biota in the glacial zone of the Seliverstov Glacier

The possibilities of biota development in the glacial zone are determine by a number of factors.

The fact and time of deglaciation of the territory

Let us consider the process of deglaciation of the Seliverstov glacier from the maximum of the LIA (Table 2). The Seliverstov Glacier at the maximum of the LIA had an area of 4.84 km^2 and a length of 4.9 km. The gentle tongue of the glacier, 3 km long, was located in a slightly indented valley of the eastern exposure. Prior to 1966, the glacier's retreat rates were low. Subsequently, the glacier experienced two periods of accelerated retreat of the glacier tongue: the first with a peak in the late 1990s – early 2000s and the second, the most significant and sharp, after 2013. The rate of glacier area reduction in recent years has exceeded 1% per year in 2023. The glacier area has decreased to 2.81 km^2, i.e. by 42% by 2023. The length of the glacier decreased by 2.25 km, and the glacier lost most of its tongue.

Table 2. Reduction of the Seliverstov glacier since the maximum of the LIA

Retreat of the Seliverstov Glacier since the maximum of the LIA		The change in the area of the Seliverstov Glacier from the maximum of the LIA		
Time interval, years	**Average annual retreat, m**	**Time interval, years**	**Absolute reduction, km^2/year**	**Relative reduction, %/year**
1952–1961	6.7	1850–1966	0.959	0.17
1961–1966	5.2			
1966–1981	13.4			
1981–1986	12.8	1966–1989	0.058	0.07
1986–1995	19.0			

Retreat of the Seliverstov Glacier since the maximum of the LIA		The change in the area of the Seliverstov Glacier from the maximum of the LIA		
Time interval, years	Average annual retreat, m	Time interval, years	Absolute reduction, km²/year	Relative reduction, %/year
1995–1999	35.3	1989–2000	0.181	0.46
1999–2001	21.5			
2001–2003	33.5	2000–2006	0.209	1.01
2003–2007	26.3			
2007–2011	8.5	2006–2011	0.055	0.34
2011–2013	3.0	2011–2016	0.136	0.86
2013–2016	44.2			
2016–2019	47.0	2016–2019	0.019	0.21
2019–2023	45.5	2019–2023	0.197	1.23

Summer thermal regime of the valley

To identify the thermal features of the summer season in the valley of the Shara-Khoragai River, the data from standard meteorological observations obtained during the expeditions of St. Petersburg State University in 1990 and 2013 were used. The observations were carried out at the base camp of both field seasons at coordinates 50°15.36'N; 90°13.36'E, at an altitude of 2770 m above sea level. The data from the nearest weather station (hereinafter referred to as m/s) were used for climatic reference Mugur-Aqsa, located at an altitude of 1850 m above sea level. This relationship was based on the close statistical relationship of summer surface air temperature between Mugur-Aksy m/s and the base camp, expressed by a high correlation coefficient of 0.93 in 1990 and 0.95 in 2013, as well as almost identical linear approximation equations $y = 1.04\,x - 6.18$ in 1990 and $y = 1.01\,x - 6.14$ in 2013 (where y – is the temperature at the base camp and x – is the temperature at Mugur-Aksy m/s). The reconstruction of a series of average seasonal temperatures allowed us to determine the nature of the course and identify trends in the summer thermal regime of the studied valley (Fig. 3).

A linear trend of 0.41 °C/10 years over the period 1963–2024 indicates a general warming trend, but a polynomial approximation suggests that over the past 25 years there has been a neutral trend in summer temperatures, if not negative. It should be noted that in the period 1984–2002, an extreme warming rate was recorded with a trend coefficient of 2.15 °C/10 years. The study of the spatiotemporal dynamics of biogeocenoses also implies the determination of changes in the main phytoclimatic periods: frost-free (BP), vegetative with average daily temperatures above 5 °C (VP5), 7 °C (VP7) and 9 °C (VP9). Based on the average monthly data, graphs of the intra-annual temperature distribution were constructed, according to which the dates and duration of all 4 periods were determined (Table 3).

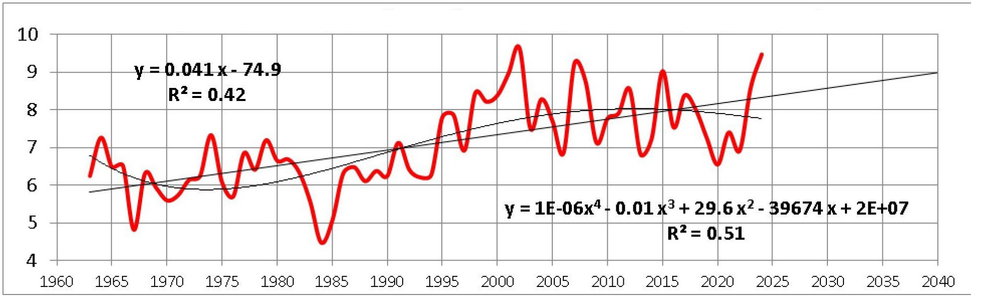

Figure 3. Variations and trends in average summer temperature in the valley of the Shara-Kharagai river.

Over the 60-year time period of 1963–2024, the average phytoclimatic periods in days increased significantly, with BP increasing by only 10 days, VP5 by 16, and VP7 by 34 days, and in this case, the impact of the dramatic warming in the late 20th and early 21st centuries is clearly evident. VP9 was not observe at all in 1963–1990 and there is no comparison with it. By 2024, there is a clear slowdown in these trends due to a change in the temperature trend, as mentioned above. Under the influence of this slowdown, the linear forecast until 2040 also does not indicate a significant increase in the duration of temporary phytoclimatic indicators. It should also be noted that BP and VP9 increased to the greater extent at the beginning of summer, while VP7 increased at the end. VP10 was not record at the height of the base camp, but given the summer vertical temperature gradient of 0.64 °C/100 m, this important indicator can occur annually below the altitude of 2600 m.

Table 3. Duration of the main phytoclimatic periods

Periods	BP (days)			VP5 (days)		
Indicators (days)	Start	End	Duration	Start	End	Duration
Average value for the period CN1 1963-1990	15 May	13 September	121	09 June	18 August	70
Average value for the period CN2 1991-2020	09 May	17 September	131	01 June	26 August	86
Increase compared to CN1	6	4	10	8	8	16
Linear trend value for 2024	08 May	18 September	133	30 May	27 August	89
Increase compared to CN1	7	5	12	10	9	19
The value of the linear forecast for 2040	07 May	19 September	135	29 May	29 August	92
Increase compared to CN1	8	6	14	11	11	22

Periods	VP7 (days)			VP9 (days)		
Indicators (days)	**Start**	**End**	**Duration**	**Start**	**End**	**Duration**
Average value for the period CN1 1963-1990	28 June	26 July	28	0	0	0
Average value for the period CN2 1991-2020	12 June	13 August	62	04 July	20 July	16
Increase compared to CN1	16	18	34	0	0	0
Linear trend value for 2024	09 June	16 August	67	26 June	25 July	29
Increase compared to CN1	19	21	40	8*	5*	13*
The value of the linear forecast for 2040	07 June	18 August	71	21 June	29 July	38
Increase compared to CN1	21	22	44	13*	9*	24*

Note: * The comparison is made with the period CN2 1991–2020 (CN1 and CN2 are climatic norms).

The interrelationships of precipitation amounts between the Mugur-Aksy m/s and the valley of the Shara-Khoragai River are much weaker than the temperature ones and have practically no statistically significant dependence. Nevertheless, some comparative calculations suggest that the amount of summer precipitation is approximately 2 to 2.5 times greater in the valley than at the meteorological station and can reach an average of 200–250 mm per summer. This assumption is based on the following facts: in 1990, during the field observation period, 78 mm of precipitation fell in the Shara-Khoragai river valley, and 36 mm with a positive vertical pluviometric gradient of 4.7 mm/100 m fell on Mugur-Aksy. In 2013, this ratio was already 37 mm by 14 mm with a gradient of 2.5 mm/100 m. Thus, for the average heights of the upper part of the Shara-Khoragai valley, the previously revealed power-law dependence of annual precipitation $p = 0.346 \times H^{0.82}$ underestimates the proportion of summer precipitation.

The microclimatic features of the studied section of the Shara-Khoragai river valley are largely determined by the degree of proximity to the glacier, the openness of the surface to the effects of winds and the exposure factor. Observations in the summer of 1990 in the mountainous part of the valley of the Shara-Kharagai River (Moskalenko et al. 1993) show that the mountain-valley circulation is characterized by low intensity, dominated by westerly winds, i.e. blowing down the valley. Over the glacier, the predominance of westerly winds increases due to the coincident direction of the glacial wind: here, the wind of the western quarter of the horizon prevails during the day, the proportion of winds with a westerly component is 76% on average (at night, when the valley wind weakens, its frequency is 90%). The average daily wind speed on the tongue of the Seliverstov Glacier, according to observations, was 3.7 m/s, in the valley of the Shara-Khoragai river – 2.2 m/s, on average for each period the wind speed over the glacier is also higher than over the non-glacial part of the valley.

Thus, the areas of recent deglaciation directly adjacent to the glacier and the crest of the LIA moraine complex are the most susceptible to wind effects, which contributes to the blowing away of the already thin snow cover and effective freezing of these areas in winter, and their drying out in summer. On the contrary, the outer slopes of this moraine complex, which have a downwind position and protected from the thermal effects of the glacier, are relatively little exposed to wind. An additional factor of wind protection for these external slopes in the areas of lateral moraine shafts is the proximity of the valley slopes, especially to the north of the glacier. In the latter case, this slope also has a southern exposition, it warms up strongly during the daytime, which contributes to warmer conditions in these areas in the summer.

The factor of ice-free surfaces stability in the process of postglacial transformation

We have identified a number of geomorphological forms associated with glacier degradation after the LIA maximum (Fig. 4). The largest age among them is the finite moraine shaft bordering the entire complex along the perimeter. Its formation occurred in the period 1850–1966, but its formation continues due to the influence of postglacial exogenous processes. The ridge is asymmetrical: its outer slope is short (due to the greater height of the foot) and has a relative height of about 5–10 m, while the relative height of the inner slope averages about 35–40 m. The outer slope of the shaft is practically not subject to erosion, since it does not come into contact with permanent watercourses and is relatively low and generally stable. The exception is the slope section in the eastern part of the complex, which is in a downwind position relative to the sandstone complex, where aeolian processes play a major role, namely, sand material from the sandstone is transported by winds through the moraine and accumulates on this section of the outer slope of the shaft. The ridge of the moraine in some areas, primarily in the northern part of the complex, expands and has a flattened character, in some places dissected by inactive relict thermokarst forms. Exogenous processes are practically reduced to zero here.

The inner slope of the moraine is unstable, this is due to the higher relative height of the shaft, the erosion of the shaft by meltwater from the glacier and a change in the basis of erosion during the degradation of the glacier, which initially dammed it, but gradually lost contact with this slope from the bottom up the valley. As a result, the slope is dotted with thermal shells, in places exposing buried ice, obviously forming the core of the moraine. Thermokarst-landslide cones are numerous in the lower part of the slope. The greatest intensity of exogenous processes is observed here in areas close to the end of the glacier. In the summer of 2013 we conducted observations of the rate of retreat of the edge of thermocells (retrograde erosion). According to the results, the rate of retreat of the walls of thermal shells for 15 days in the first half of July increased from an average of 7 cm/day to 13 cm/day, reaching 33 cm/day in the last pentade (Chistyakov et al. 2015). The frontal part of the ridge, corresponding to the end of the glacier at the maximum of the LIA, is located on a site of a fairly steep valley drop (approximately 23.5 m by 100 m) and is partially eroded both by watercourses along the perimeter of the moraine and by the main river originating on the glacier and cutting through the shaft from the inside.

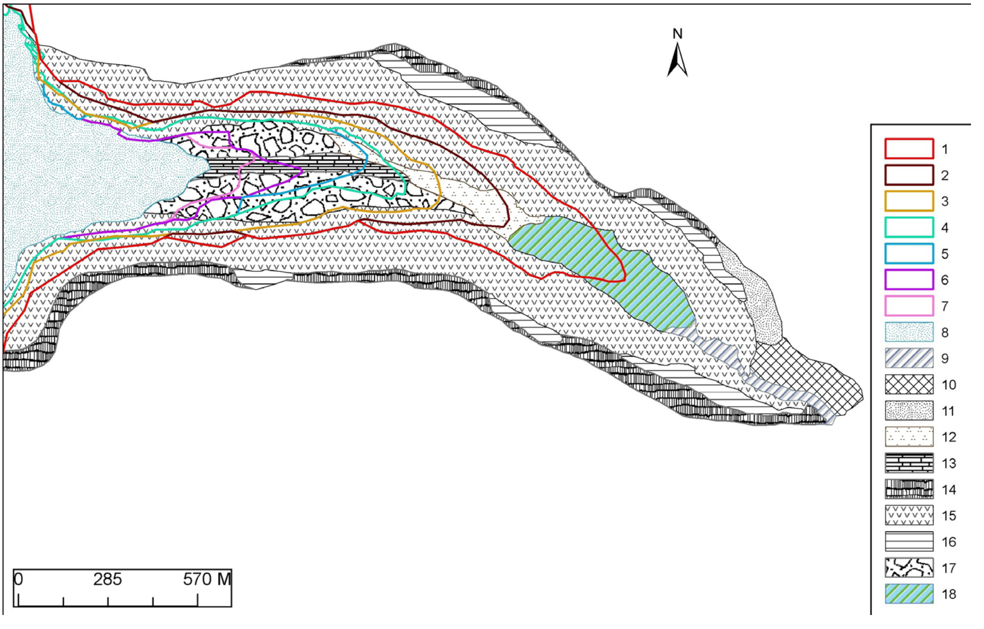

Figure 4. Geomorphological plan of the young moraine complex of the Seliverstov glacier. Symbols: glacier boundaries: **1** – 1966, **2** – 1989, **3** – 2000, **4** – 2006, **5** – 2011, **6** – 2016, **7** – 2019, **8** – 2023; **9** – erosive incision, **10** – frontal part of the LIA moraine complex, **11** – Aeolian inflows, **12** – ground moraine, **13** – medial moraine, **14** – distal slope of the moraine, **15** – proximal unstable slope of the moraine, **16** – stable flattened sections of the moraine crest, **17** – young moraine complex, **18** – outwash plain.

The moraine ridge of the LIA dams the sand field with an area of about 0.092 km^2. During the period of ablation and abundant runoff from the glacier, this area floods in the afternoon and turns into a shallow lake. In 1966, the edge of the glacier was still located in the middle of this section; its formation ended by the end of the 1980s, when the glacier reached a steeper section of the valley. From the late 1980s to the early 2000s, there was a gradual accumulation of moraine material on the surface of the glacier, which was associated with the gradual release of ice between its northern and southern streams. The beginning of its liberation probably occurred about a decade earlier than 1966, since the median moraine associated with it in 1966 had not yet reached the edge of the glacier, being located no further than the middle part of its tongue. The strong rooting of the glacier tongue was noted by R.M. Mukhametov in 1986 (Arefyev and Mukhametov 1996). This period of glacier contraction is marked by a section of the main moraine above the zander, the amount of material pulling out of the ice during this period was insufficient to form a moraine shaft, and the material was freely eroded and is currently being eroded.

A further increase in the amount of moraine material as new rocky areas were released in the middle and upper part of the glacier led to the formation of a young moraine complex in the period from about 2000 to the present (Fig. 4). Probably, the weakening of glacial runoff against the background of a rapid decrease in the area of the ablation zone during this period played some role in its preservation. The complex contains a significant amount of buried ice, which guarantees instability of its surface in the coming years. We have separately identified the medial moraine, which, although it was formed synchronously with the complex and divides it into 2 parts, is very unstable and undergoes intense erosion and thermokarst processes.

Sections of the moraine complex are exposed to varying degrees to winds that blow away snow and interfere with the consolidation of vegetation. In this regard, the most advantageous areas are the zander and the outer slope of the moraine on the border of the LIA complex, where there is additional shielding from the wind by closely located rocks and neighboring slopes.

Species composition of flowering plants within the deglaciation zone of the Seliverstov Glacier

The results of studying the flora within the deglaciation zone of the Seliverstov Glacier are presented below. The research was carried out in July 2024 using the route method. During the work, the species composition, phenological condition, and species adherence to different landforms and ecotopes, as well as photo of individual species and the pioneer plant groups were recorded. In some cases, the herbarium was collected to further clarify the taxonomic affiliation in the office conditions. As a result, 91 species belonging to 59 genera and 26 families were identified (Table 4). The families in the table, as well as genera within the family and species within the genus, are arranged in alphabetical order.

For each species, the occurrence within the deglaciation zone is indicated for three easily distinguishable habitat groups:

1. The median, main moraine, the sand field and the inner (proximal) slopes of the lateral moraines (the most unstable areas of the moraine complex).
2. Flattened ridge sections and external (distal) slopes of lateral moraines (stable sections of the moraine complex).
3. The outer slopes of the terminal (frontal) moraine (relatively stable areas of the moraine complex).

It is important to note that in all cases we did not deal with formed plant communities, so even on older moraines, separately growing plants can be called pioneer plant groups. This also did not allow us to make standard geobotanical descriptions, and to operate only with species lists.

Table 4. List of flowering plant species within the deglaciation zone of the Seliverstov Glacie

Family	Species	1	2	3
Berberidaceae	*Berberis sibirica* Pall.	-	-	+
Ranunculaceae	*Ranunculus altaicus* Laxm.	-	-	+
	Ranunculus pseudohirculus Schrenc.	-	+	+
	Thalictrum alpinum L.	+	+	-
Papaveraceae	*Papaver pseudocanescens* M. Pop.	+	+	+
Portulacaceae	*Claytonia joanneana* Schult.	-	+	+
Caryophyllaceae	*Cerastium lithospermifolium* Fisch.	+	+	+
	Cerastium pusillum Ser.	+	+	+
	Dianthus versicolor Fisch.	-	+	+
	*Dichodon cerastoide*s (L.) Reichenb.	+	+	+
	Eremogone formosa (Fisch. ex Ser.) Fenzl	-	+	+
	Eremogone mongolica (Schischk.) Ikonn.	-	+	+
	Gastrolychnis apetala (L.) Tolm. et Kozanczicov	-	+	+
	Minuartia arctica (Stev. ex Serg.) Graebn.	-	+	+
	Minuartia biflora (L.) Schinz et Thell.	+	+	+
	Minuartia verna (L.) Hiern.	-	+	+
	Sagina procumbens L.	-	+	-
	Silene chamarensis Turcz.	-	-	+
	Stellaria petraea Bunge	-	+	+
Polygonaceae	*Oxyria digyna* (L.) Hill.	+	+	+
Brassicaceae	*Aphragmus involucratus* (Bunge) O.E. Schulz	-	+	-
	Draba fladnizensis Wulf.	-	+	-
	Draba nemorosa L.	-	+	+
	Draba ochroleuca Bunge	-	+	-
	Draba oreades Schrenk.	-	+	-
	Eutrema edwardsii R. Br.	-	+	-
	Smelovskia calycina (Ledeb.) Botsch.	-	+	-
Salicaceae	*Salix arctica* Pall.	-	-	+
	Salix berberifolia Pall.	-	-	+
	Salix brayi Ledeb.	-	-	+
	Salix coesia Vill.	-	-	+
	Salix divaricata Pall.	+	-	+

Family	Species	1	2	3
	Salix nummularia Anderss.	-	-	+
	Salix rectijulis Ledeb.	-	-	+
	Salix reticulata L.	-	-	+
	Salix sajanensis Nasarow	-	-	+
Primulaceae	*Androsace fedtschenkoi* Ovcz.	+	+	+
	Primula nivalis Pall.	+	+	-
Saxifragaceae	*Saxifraga cernua* L.	-	+	+
	Saxifraga hirculus L.	-	+	-
	Saxifraga macrocalyx Tolm.	-	+	+
	Saxifraga asiatica Hayek	+	+	+
	Saxifraga sibirica L.	+	+	+
Crassulaceae	*Rhodiola quadrifida* (Pall.) Fisch. et Mey.	+	+	+
	Rhodiola krylovii Polozh. et Revjakina	-	+	+
	Rhodiola rosea L.	-	+	+
Rosaceae	*Dryadanthe tetrandra* (Bunge) Juz.	-	+	+
	Potentilla exuta Soják	-	-	+
	Potentilla gelida C.A. Mey.	-	+	+
	Potentilla kryloviana Th. Wolf.	-	-	+
	Potentilla nivea L.	-	+	+
Fabaceae	*Oxytropis oligantha* Bunge	-	+	+
	Oxytropis tschujae Bunge	-	+	-
	Oxytropis sp. (sect. Orobia)	-	-	+
	Trifolium eximium Stephan ex DC.	+	+	+
Onagraceae	*Chamerion latifolium* (L.) Holub.	+	-	+
Apiaceae	*Bupleurum multinerve* DC.	-	-	+
	Pachypleurum alpinum Ledeb.	-	+	+
Gentianaceae	*Comastoma falcatum* (Turcz.) Toyok.	-	-	+
Valerianaceae	*Patrinia sibirica* (L.) Juss.	+	+	+
Boraginaceae	*Eritrichium villosum* (Ledeb.) Bunge	-	+	-
Lamiaceae	*Dracocephalum bungeanum* Schischkin et Serg.	-	+	-
	Dracocephalum imberbe Bunge.	-	-	+
	Dracocephalum nutans L.	-	-	+
	Lagopsis marrubiastrum (Steph.) Ik.-Gal.	-	+	+
Orobanchaceae	*Lagotis integrifolia* (Willd.) Schischkin	+	+	-
	Pedicularis anthemifolia Fisch. ex Colla	-	+	+
	Pedicularis oederi Vahl.	-	+	+
Campanulaceae	*Campanula rotundifolia* L.	+	+	+

Family	Species	1	2	3
Asteraceae	*Artemisia borealis* Pall.	-	+	+
	Aster alpinus L.	-	+	+
	Crepis chrysantha (Ledeb.) Turcz.	-	+	+
	Crepis nana Richards.	+	+	-
	Erigeron eriocalyx (Ledeb.) Vierh.	-	+	+
	Leontopodium ochroleucum Beauverd	-	+	+
	Pyrethrum pulchrum Ledeb.	-	-	+
	Saussurea subacaulis (Ledeb.) Serg.	+	+	+
	Taraxacum glabrum DC.	+	+	+
	Tephroseris heterophylla (Fisch.) Konechn.	-	+	+
	Tephroseris pricei (N.D. Simpson) Holub	-	-	+
	Tephroseris turczaninovii (DC.) Holub	-	-	+
	Waldheimia tridactylites Kar. et Kir.	+	+	+
Liliaceae	*Lloydia serotina* (L.) Reichenb.	+	+	+
Juncaceae	*Luzula spicata* (L.) DC.	-	+	+
Cyperaceae	*Eriophorum scheuchzeri* Hoppe	+	-	-
	Kobresia myosuroides (Vill.) Fiori	-	+	+
Poaceae	*Deschampsia altaica* (Schischk.) O.D. Nikif.	+	+	+
	Festuca rubra L.	-	-	+
	Paracolpodium altaicum (Trin.) Tzvelev	+	+	-
	Poa alpina L.	-	+	-
	Trisetum spicatum (L.) Richt.	-	+	+

The families of Caryophyllaceae (13 species), Asteraceae (13), Salicaceae (9), Brassicaceae (7), Saxifragaceae (5), Rosaceae (5) are distinguished by the greatest wealth of pioneer species. At the same time, 11 families are represented by one species each only. Salix (9 species) stands out among the genera, which is almost twice as rich as Saxifraga (5), which occupies the 2nd place. 44 genera are represented by only one species, which is almost half of the total species diversity. Among the interesting flora representatives within the deglaciation zone of the Seliverstov Glacier are *Oxytropis tschujae* and *Rhodiola rosea*, listed in the Red Book of the Russian Federation (2024). An exceptionally rare endemic species of Altai (Pyak et al. 2008) *Aphragmus involucratus* (Fig. 5), included in the Red Data Books of the Altai Republic (2017) and the Republic of Tyva (2018), is found in the exposed areas of the ridge.

Features of plant distribution within the deglaciation zone of the Seliverstov Glacier

A preliminary analysis of the distribution of pioneer species within the deglaciation zone of the Seliverstov Glacier is based on reconnaissance route surveys mainly of the central and left-bank parts of the moraine complex. The analysis showed that there may be noticeable differences between the relatively stable sections of the complex (these are primarily the flattened ridges and the outer slopes of the lateral and terminal moraines) and unstable areas (the bottom of the valley with sandstone and the inner slopes of the lateral moraines).

Considering that the leading environmental factors affecting plant development in the deglaciation zone are heat and moisture availability, wind protection, and relative stability of ice-free surfaces, this is in good agreement with the observed situation. As noted earlier, the most unstable relief forms are the median moraine and the inner slopes of the lateral moraines facing it. As a result, it is here that we observe a random distribution of plants, which was noted at vegetation fixation points at different distances from the edge of the glacier.

Figure 5. The endemic of Altai – *Aphragmus involucratus* (Bunge) O.E. Schulz.

Regardless of the degree of remoteness of the studied area from the edge of the glacier, all pioneer plant groups on the median moraine are characterized by a very low species diversity of plants that have mastered this place. They are composed mainly of pronounced erosiophiles, which are able to easily disperse their seeds over considerable distances (*Crepis nana*, *Waldheimia tridactylites*) or gain a foothold in such dynamic relief forms as, for example, constantly and rapidly renewing surfaces of the sand field or thermokarst-landslide cones (*Chamaenerion latifolium*). In the latter case, such pioneer groups can achieve a relatively high abundance due to the rapid development of the territory and the increase in partial individuals by spreading long rhizomes (Fig. 6).

The pioneer plant groups that are located on the border between the median moraine and the main moraine, at a distance of 400–500 m from the edge of the glacier, and are confined to the lower parts of the slope of the main moraine in the places where it is cut by the Shara-Khoragai River, do not differ much in diversity. As noted earlier, these areas are characterized by relative instability of the surface, as well as pronounced slope denudation processes. This is due to the slightly different species composition, which is dominated by plants developing a powerful deep-submerged (*Rhodiola quadrifida*) or lobed (*Deschampsia altaica*) root system capable of resisting the "fluidity" of the soil.

Figure 6. *Chamaenerion latifolium* on the zander field.

The more stable exposed ridge surfaces and especially the outer slopes of the moraine complex are noticeably different in plant diversity, which, depending on the exposure, may also differ significantly in heat supply. Thus, the diversity of species on the exposed surfaces of the moraine ridges is many times higher than on those considered earlier, but the strong effect of wind on these areas leads to noticeable blowing of small particles and the formation of stony-gravelly surfaces with a low content of fine earth. This contributes to the selection of small plants that are content with limited nutritional resources and often "hiding" in the hollows between the stones (*Minuartia biflora*, *Stellaria petraea*, *Draba fladnizensis*, *D.*

ochroleuca, *Lagopsis marrubiastrum*, *Crepis nana*, *Waldheimia tridactylites*, *Luzula spicata*, *Poa alpina*, etc.).

The situation is different on the outer slopes of the moraine complex. The relative stability due to the lower severity of the height difference (lateral moraines) or, conversely, the steepness and relatively huge height difference of the terminal moraine, combined with the diverse effects of wind (blowing on windward and exposed surfaces or accumulation of sandy material on leeward slopes), create an incomparably greater variety of ecotopes here. The increase in the number of species is also due to the direct contact of these territories with pioneer plant groups developed in periglacial areas that have not been covered by glaciers in the last hundreds of years.

In general, it can to note that the composition of the species growing on the outer slopes of the lateral moraines is similar to that on adjacent ridge sites, but have enriched due to the accidental penetration of species from periglacial sites. The species composition depends on the nature of these adjacent areas (rocks, rocky-gravelly slopes, tundra, runoff hollows, etc.). For example, *Eutrema edwardsii*, *Ranunculus pseudohirculus* can be in the area adjacent to the runoff hollow.

The situation on the outer slopes of the final (frontal) moraine is completely different. Since the frontal part of the shaft, corresponding to the end of the glacier at the maximum of the LIA, is located in a rather steep valley drop (approximately 23.5 m per 100 m). There are several slopes here, which vary in direction and steepness. The "successful" southeastern orientation of the frontal shaft also plays a role, which leads to significantly better insolation of individual sections of the slope. In combination with the increased content of clay particles in the substrate, enhanced drainage due to the steepness of the slope and better heat supply, conditions are created here for the successful growth of many species that are unusual in the rest of the moraine complex (*Berberis sibirica*, *Bupleurum multinerve*, *Tephroseris pricei*, *T. heterophylla*, *Pyrethrum pulchrum*, etc.).

Some finds of invertebrates within the deglaciation zone of the Seliverstov Glacier

In July 2024, preliminary study of invertebrate fauna in the deglaciation zone of the Seliverstov Glacier was conducted. During the route surveys, the species composition and biotopic association of invertebrate species and groups were noted. The invertebrate population within the glacier deglaciation zone is characterized by extremely poor taxonomic diversity and is mainly represented by inhabitants of the ground and soil layers. The basis of the soil population consists of representatives of the following taxa: enchytreids, spiders, primarily wingless insects (springtails), Diptera insect, Coleoptera (ground beetles and rove beetles).

Small ringed worms (Enchytraeidae) are among the most cold-resistant representatives of the soil fauna. They are found mainly in boreal and subarctic ecosystems. In the research area, Enchytraeidae form the basis of the soil population along temporary and permanent watercourses and in runoff hollows. In near-water areas, Enchytraeidae are concentrated in the root system of plants, mainly in decaying rhizomes (in particular, in *Rhodiola quadrifida*). Single specimens of Enchytraeidae have been found in the soil under plant roots both on the median moraine and on the outer slopes of the moraines. Diptera insects in the larval stage of development are also attached to plant roots, but they are significantly inferior in number to Enchytraeidae.

The only spider species we have found, *Parasyrisca asiatica* (Ovcharenko et al. 1995), is endemic to the Altai–Sayan mountain system, found in isolated specimens on the outer slope of the terminal moraine. Previously, its presence was indicated on the territory of the Mongun-Taiga massif; it was also noted in the mountain tundra and mountain scree of the Southeastern and Mongolian Altai (Ovcharenko et al. 1995; Fomichev 2015).

Ground-dwelling Coleoptera are represented by several species of the families of ground beetles (Carabidae) and rove beetles (Staphylinidae). All three species of ground beetles found in the deglaciation zone were found in significantly moistened areas. Thus, *Notiophilus aquaticus* (L.) was recorded under rocks near a stream, while *Nebria nivalis* (Payk.) and *Bembidion aeruginosus* (Gebl.) were recorded near the border of melting snow patches and also along the banks of streams. Previously, these species of ground beetles were recorded on the territory of southwestern Altai (Shapshalsky district and Chikhachev Ridge) (Dudko et al. 2010). Both staphylinid species found in the study area (*Geodromicus plagiatus* F. and *Olophrum rotundicolle* Sahlb.) were found under moss curtains and under rocks on the bank of a stream.

Most of the pioneer invertebrates we have noted belong to surface–dwelling animals, but they find refuge in crevices between rocks, grains of sand, and substrate particles on the surface. Springtails and Enchytraeidae are saprophages, while species from other groups are mainly predators. The territories freed from ice are primarily populated by first settlers with high migration opportunities: beetles of the families Carabidae and Staphylinidae; as well as springtails, which serve as prey for predatory beetles.

Conclusion

The young moraine complex of the Seliverstov Glacier is considered in this study comprehensively: from the glaciological, geomorphological, climatic, floristic, geobotanical and faunal sides. The considered process of deglaciation of the territory allowed us to determine the average rates of reduction of the glacier area and retreat of its edge. The glacier has shrunk by 42% since its peak, and it has been found that the rate of decline has increased over the past 10 years. The process of glacier retreat leads to the formation of glacial landscapes of the deglaciation zone. Geomorphologically, they are very different, which causes a different degree of their stability in the process of postglacial transformation. While some components of the complex (median moraine, sandstone, inner slopes of lateral moraines) are extremely unstable and subject to thermal erosion and re-deposition of loose material, other components of the complex (exposed ridges and outer slopes of lateral moraines, terminal moraine) are relatively stable. This diversity of the moraine complex causes differences in the distribution of pioneer species and the plant communities they form. Unstable sites are characterized by low species diversity, composed mainly of erosiophiles. At the same time, in more stable areas of the moraine complex, the species diversity and the projective coverage of species increases. The list of flowering plant species consists of 91 species, some of which were found only on the outer slope of the frontal moraine. Preliminary studies of the invertebrate fauna have shown their low taxonomic diversity. Enchytraeidae are found in both stable and unstable areas of the moraine complex. *Parasyrisca asiatica*, endemic to Altai, was found on the outer slope of the moraine. An analysis of changes in phytoclimatic periods, which largely determine the dynamics of biogeocenoses, has shown that there will be no significant increase in the duration of phytoclimatic indicators by 2040. This suggests a further gradual, without sudden jumps, development of biota in the deglaciation zone of the Seliverstov Glacier.

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