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Editor-in-Chief
Vladimir N. Bolshakov

Member of the Russian Academy of Sciences
Director of the Institute of Plant and Animal Ecology,
Ural Division of the Russian Academy of Sciences

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Environmental Conditions, Composition, and Seasonal Rhythms of Cryophilous Meadows in the Polar Urals

P. L. Gorchakovskii and N. I. Igosheva

Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences, ul. Vos'mogo Marta 202, Yekaterinburg, 620144 Russia

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Abstract—Characteristics of the environmental conditions, floristic composition, and rhythms of seasonal development in subnival communities of cryophytes situated near the extreme limit of the possible existence of vascular plants are reported.

Indigenous plant communities found high in the mountains in places of thick snow accumulation first attracted the attention of researchers of the Alps. In European scientific literature, the name "snow coombs" (*Schneetälchen* in German (Ellenberg, 1963), *combe à neige* in French (Favarger, 1956)) was assigned to these communities not because of their own features, but features of their habitats. Russian researchers named these communities "nival lawns" (Igoshina, 1966) or "cryophilous meadows" (Gorchakovskii, 1975). We consider the latter the most apt.

The object of this study was cryophilous meadows distributed in the belt of mountain tundra in the polar Urals in the basin of River Sob' and its tributary the Bol'shoy Khanmei, largely in the vicinity of the Slantsevaya and Yar-Kei mountains. During field studies, the floristic composition of the meadows was determined, the four most typical plant communities were described, the rhythms of seasonal development were observed.

The cryophilous meadows studied were located high in the mountains, usually above the timberline in the belt of mountain tundra and rarely in subgoltsy elevational belt. They occupied small canyons, ravines, and other depressions, where, in winter, deep snow (up to 2.5–3.5 m) accumulated as a result of wind-blown snow from adjacent areas (passes, upland terraces, gentle slopes). The complete meltage of snow in places of its abundant accumulation (snow patches) did not occur until the beginning and sometimes the middle of July, resulting in a significant (to 50–70 days) decrease in the plant growth season (vegetative period). The beginning of the growth season in cryophilous meadows of the polar Urals varied over multiyear observations between June 28 and July 20.

Communities of cryophilous plants were formed among stone fields, mountain tundra, and, rarely, low subgoltsy forests in the immediate vicinity of the extent of snow patches, mostly in the valleys of brooks flowing from the accumulated snow or in places freed after the melting of snow patches.

The existence of plants of cryophilous meadows closely depended on snow patches. Snow cover protected plants in winter from winterkilling. Snow meltage in places of its abundant accumulation occurred slowly in the first half of the warm season. When valleys were freed from snow, rapid vegetation immediately began. Plants in the first phenological phases were under the cooling influence of adjacent snow masses. The surface was permanently heavily moistened due to the flow of cold melt water from snow patches. The decomposition of plant remains occurred slowly because of low temperatures, so the soil contained a lot of coarse humus and was peaty.

COMMUNITIES OF CRYOPHILOUS MEADOWS AND THEIR FLORISTIC COMPOSITION

The cryophilous lawns studied were very labile, occupied small areas, and were patchy. The determination of plant associations in the common meaning of this term was hard in these areas. Nevertheless, in the region under investigation, the four most typical communities, distinct in the composition of their dominant species, could be defined.

Snakeweed meadows occupied relatively flat ledges. The soil showed signs of peat formation, and cooling influence of moistening was abundant and partly stagnant. Shrubs were represented by single individuals of *Salix glauca*. Grass cover was of average density (with a projective coverage of 60–70%) involving 15 species of vascular plants: six grass species, one sedge species, and eight species of herbs. In this layer dominated: $cop._1$–$cop._2$—*Polygonum bistorta*, $cop._2$—*Calamagrostis lapponica*, sp.—*Alopecurus alpinus*, *Anthoxanthum alpinum*, *Deschampsia glauca*, *Poa alpina*, and *Veratrum lobelianum* var. *misae*. The moss layer covered 10–30% of the surface. *Drepanocladus uncinatus*, *Pleurozium schreberi, Dicranum spadiceum, D. congestum, Brachytecium reflexum, Aulacomnium palustre*, and *Oncophorus wahlenbergii* dominated.

Geranium albiflorum meadows were connected with abundantly moistened soils, but were somewhat drained in places with relatively more developed soils enriched with humus. The shrub layer was absent; of dwarf shrubs, single *Empetrum hermaphroditum* were found. The herb stand was well developed (projective coverage 80–90%) and consisted of 23 species, including four grass species, one sedge species, and 18 species of herbs. Dominant species were: cop.$_1$–cop.$_2$—*Geranium albiflorum*, sp.—*Sibbaldia procumbens, Anthoxanthum alpinum, Deschampsia glauca, Pachypleurum alpinum, Rhodiola rosea, Polygonum bistorta, Polygonum viviparum, Valeriana capitata*, and *Carex bigelowii* ssp. *arctisibirica*. The moss layer (with a projective coverage of 10–15%) was formed by *Drepanocladus uncinatus, Polytrichum juniperinum, P. hyperboreum, Dicranum congestum, Hylocomium pyrenaicum*, and others.

Viola biflora–herbs meadows occupied relatively flat, poorly drained places with excessive semiflowing moistening and moderately peaty soil. Individuals of the shrubs *Salix polaris* and *S. reticulata* and the dwarf shrubs *Harrimanella hypnoides* and *Phyllodoce coerulea* were found. The herb stand was low with average density (with a projective coverage of 60–75%) and consisted of 17 species, including 4 grass species, 1 sedge species, and 12 species of herbs. The main components of the herb stand were: cop.$_1$–cop.$_2$—*Viola biflora*, sp.–cop.$_1$—*Sibbaldia procumbens*, sp.—*Anthoxanthum alpinum, Gnaphalium supinum, Pedicularis oederi, Carex glacialis, Trollius europaeus* var. *apertus*, and *Polygonum bistorta*. Mosses covered 20–30% of the soil. Among them were *Drepanocladus uncinatus, Pleurozium schreberi, Dicranum spadiceum, Polytrichum hyperboreum*, and *P. juniperinum*.

Lagotis meadows formed narrow stripes in valleys of brooks flowing out of snow patches, sometimes in the immediate vicinity of snow patches. Moisture was abundant and flowing, mostly due to water from melting snow patches. Shrubs were represented by single *Salix polaris* and *S. reticulata*, and dwarf shrubs, by single *Harrimanella hypnoides*. There were 22 species in the composition of the herb stand (with a projective coverage of 70–80%), including 5 grass species, 1 sedge species, and 16 species of herbs. Lagotis meadows were obviously dominated by cop.$_2$ *Lagotis minor*; other abundant plants were sp.–cop.$_1$—*Ranunculus borealis*, sp.—*Hedysarum arcticum, Deschampsia glauca, Epilobium uralense, Potentilla gelida, Carex umbrosa* ssp. *sabynensis*, and *Pedicularis sudetica*. The moss layer covered 10–15% of the surface and consisted of *Polytrichum juniperinum, Polytrichum hyperboreum, Calliergon stramineum, Drepanocladus uncinatus, Pleurozium schreberi*, and *Dicranum spadiceum*.

The floristic composition of communities in cryophilous meadows was poor (see table). The shrubs (species of the genus *Salix*) only occurred in the composition of the communities solitarily; dwarf shrubs were also scarce. The moss cover was usually well developed. Club-mosses and horsetails were rare. The most characteristic flowering plants for these habitats were *Sibbaldia procumbens, Gnaphalium supinum, Anthoxanthum alpinum, Alopecurus alpinus, Calamagrostis lapponica, Deschampsia glauca, Poa alpina, Lagotis minor, Pedicularis sudetica, P. oederi, Viola biflora, Geranium albiflorum, Potentilla gelida, Stellaria peduncularis*, and *Taraxacum nivale*. Some species with a wide ecological range were no less common and were represented in these habitats by peculiar forms: *Veratrum lobelianum* var. *misae* and *Trollius europaeus* var. *apertus*.

At first glance, it seemed surprising that such widely distributed species as *Polygonum bistorta* grew at the very edge of snow patches and were dominant in one association in cryophilous meadows. Nevertheless, this species was highly viable under such extreme conditions. We observed young shoots of this plant piercing a layer of ice-covered snow on the mountain massif Sablya in the polar Urals (Gorchakovskii, 1958, p. 119). In high mountains near snow patches, this species was sometimes represented by some peculiar (most likely ecological) form too.

PECULIARITIES OF PHENOLOGICAL RHYTHMS

Some main features of cryophilous meadow plants can be defined on the basis of our study, taking into consideration the literature data.

(1) Rapid phenological phases, greatly shortened growth season. Plants began to grow immediately after snow melting; in some species, aboveground shoots began to grow even under snow. This rapid progression of development phases was provided by the ability of cryophytes to use heat effectively: the ability to realize photosynthesis at low temperatures, fast recovery after night frost (Larcher, 1983), and the formation of incipient flowers in advance during the summer of the previous year in dormant buds and, in some species, of already roughly formed flowers (Gavrilyuk, 1966). Therefore, most plants achieved budding and flowering quickly and in unison. In some species (*Polygonum bistorta, Trollius europaeus* var. *apertus*, and *Viola biflora*), simultaneous flowering of 60–70% of the individuals was observed in sampling plots.

(2) Displacement of the flowering maximum to the second half of the warm season. Peaks of flowering, determined by the maximum number of simultaneously flowering species, somewhat varied from year to year and from community to community, but usually fell in late July or early August. In this manner, the maximum flowering in communities of cryophilous meadows,

Floristic composition of cryophilous meadows

No.	Species	Snakeweed meadow	*Geranium albiflorum* meadow	*Viola biflora*-herbs meadow	*Lagotis* meadow
	Shrubs				
1	*Salix glauca* L.	sol.	–	–	–
2	*S. polaris* Wahl.	–	–	sol.	sol.
3	*S. reticulata* L.	–	–	sol.	sol.
	Dwarf shrubs				
4	*Empetrum hermaphroditum* Hagerup	–	sol.	–	–
5	*Harrimanella hypnoides* (L.) Cov.	–	–	sol.	sol.
6	*Phyllodoce coerulea* (L.) Bab.	–	–	sol.	–
	Herbaceous plants				
7	*Alopecurus alpinus* Smith	sp.	sol.	sol.	sol.
8	*Anthoxanthum alpinum* A. et D. Love	sp.	sp.	sp.	–
9	*Calamagrostis lapponica* (Wahl.) Hartm.	$cop._1$	–	–	–
10	*Carex bigelowii* Torr. ex Schwein. ssp. *arctisibirica* (Jurtz.) A. et D. Love	sol.	sp.	–	–
11	*C. glacialis* Mackenzie	–	–	sp.	–
12	*C. umbrosa* Host. ssp. *sabynensis* (Less. ex Kunth.) Kuk.	–	–	–	sol.
13	*Deschampsia glauca* Hartm.	sp.	sp.	–	sp.
14	*Diphasiastrum alpinum* (L.) Holub	–	sol.	–	sol.
15	*Epilobium uralense* Rubr.	–	–	–	sp.
16	*Equisetum variegatum* Schleich. ex Web. et Mohr.	–	–	–	sol.
17	*Festuca ovina* L. ssp. *ruprechtii* (Boiss.) Tzvel.	–	–	sol.	sol.
18	*Geranium albiflorum* Ldb.	–	$cop._1$–$cop._2$	–	sol.
19	*Gnaphalium supinum* L.	–	–	sp.	sol.
20	*Hedysarum arcticum* B. Fedtsch.	–	–	–	sp.
21	*Hieracium alpinum* L.	–	sol.	sol.	sol.
22	*Lagotis minor* (Willd.) Standl.	–	–	–	$cop._2$
23	*Luzula spicata* (L.) DC.	sol.	sol.	–	sol.
24	*Pachypleurum alpinum* Ldb.	–	sp.	sol.	–
25	*Pedicularis lapponica* L.	–	sol.	–	–
26	*P. oederi* Vahl.	–	–	sp.	–
27	*P. sudetica* Willd.	–	–	–	sp.
28	*Poa alpina* L.	sp.	sol.	sol.	sol.
29	*Polygonum bistorta* L.	$cop._1$–$cop._2$	sp.	sp.	–
30	*P. viviparum* L.	sp.	sp.	sol.	sol.
31	*Potentilla gelida* C.A. Mey	–	–	–	sp.
32	*Ranunculus borealis* Trautv.	–	–	–	sp.–$cop._1$
33	*Rhodiola rosea* L.	–	sp.	sol.	sol.
34	*Rubus arcticus* L.	sol.	–	–	–
35	*Rumex alpestris* Jacq.	–	sol.	–	–
36	*Saussurea alpina* (L.) DC.	sol.	–	sol.	–
37	*Sibbaldia procumbens* L.	–	sp.	sp.–$cop._1$	–
38	*Solidago virgaurea* L.	sol.	sol.	–	–
39	*Stellaria peduncularis* Bge	sol.	–	–	–
40	*Tanacetum bipinnatum* (L.) Sch. Bip.	–	sol.	–	–
41	*Taraxacum nivale* Lange ex Kihlm.	–	sol.	–	–
42	*Trisetum spicatum* (L.) Richt.	sol.	–	–	sol.
43	*Trollius europaeus* L. var. *apertus* Perf.	–	sol.	sp.	sol.
44	*Valeriana capitata* Pall. ex Link.	–	sp.	–	–
45	*Veratrum lobelianum* Bernh. var. *misae* Sirj.	sp.	sol.	sol.	–
46	*Viola biflora* L.	–	sol.	$cop._1$–$cop._2$	sol.
	Total number	16	24	21	25

due to tardy release of their habitats from snow cover, came essentially later than in communities of mesophilous meadows of subgoltsy and mountain forest belts.

(3) Considerable variability in the duration and dates of phenological phases. In different years, depending on the weather conditions of both the warm and cold season, the duration and dates of the beginning and end of individual phenological phases widely varied. The life of plants in cryophilous meadows completely depended on the pattern of snow accumulation in winter and its melting in the warm period. In years when especially deep snow was accumulated, melting was retarded, and cryophilous lawns were freed from snow in the middle, or even the end, of July. This displaced of the beginning of the growth season to late dates and shortened its duration.

(4) Accelerated progression through phenological phases. When the beginning of the growth season was greatly delayed, plants developed at an accelerated rate, and individual phenological phases were completed in shorter time. Even when the growth season decreased to 50 days, most plants succeeded in passing through the whole generative cycle. However, in years with unfavorable weather conditions, complete ripening did not occur.

(5) Simultaneous occurrence of individuals of the same species in different phenological phases. As the snow patch melted, plant development literally followed its retreating margin. Thus, within one community, individuals of the same species could be found in different phenological states. Our observations showed that, when *Lagotis minor, Geranium albiflorum, Pedicularis oederi, Ranunculus borealis*, and others at the margin of a snow patch were only represented by etiolated seedlings, plants of the same species some distance away had green leaves or had even begun to enter the budding phase. However, individuals that began to grow later passed through subsequent stages of development at a faster rate and, by the time of the complete melting of the snow, were comparable in their phenological state with the others. In populations of some plant species (*Geranium albiflorum, Sibbaldia procumbens*, and *Stellaria peduncularis*), budding and flowering took place simultaneously; in populations of other species (*Lagotis minor, Viola biflora, Saussurea alpina*, and *Pachypleurum alpinum*), budding was synchronized with both flowering and fructification.

The success of completing the generative phase in particular species was determined by the weather conditions of the previous year, when the establishment of incipient flowers in dormant buds took place, as well as of the current year, when generative organs were developed and completely formed. In some years, certain species did not flower and fruit; in some species, seeds did not succeeded in ripening due to the early beginning of autumn frosts.

CHANGE OF ASPECTS

Three periods can be distinguished in the phenologic rhythms of cryophilous meadows: spring, early and middle summer, and late summer–autumn.

Spring was the shortest (5–8 days) and began immediately after the melting of the snow patch or any part of it. The average daily temperatures of the air and soil were still low, and frost still occurred. On the brown background of last year's foliage, the catkins of *Salix reticulata* became visible. Unsightly inflorescences of *Carex glacialis, Carex bigelowii* ssp. *arctisibirica*, and *Anthoxanthum alpinum* soon appeared, as well as bluish-white inflorescences of *Lagotis minor.*

Early and middle summer (18–28 days) coincided with the period of the highest daily temperatures of the air and soil and the absence of any stable frosts. This period was characterized by an abundance of flowering plants and the diversity of their color. Plants with brightly colored flowers were particularly distinguishable: pink *Polygonum bistorta*, white *Geranium albiflorum* and *Pachypleurum alpinum*, yellow *Viola biflora, Pedicularis oederi*, and *Trollius europaeus* var. *apertus*, and blue *Phyllodoce coerulea.*

Late summer–autumn (21–41 days) coincided with the period of the gradual lowering of daily temperatures and the appearance of frosts. The few flowering species were not abundant. We observed yellow inflorescences of *Hieracium alpinum, Solidago virgaurea*, and *Tanacetum bipinnatum* and lilac-violet ones of *Saussurea alpina*. In the foliage background, plain inflorescences of *Deschampsia glauca, Calamagrostis lapponica*, and *Festuca ovina* ssp. *ruprechtii* were poorly visible.

From the middle of August, leaves of meadow grasses first became variously bright (purple, red, and yellow) and, then, as they died off, became brown and turned into mulch.

In different associations, each period was characterized by its own set of flowering species, its dominant color, and specific dates of beginning and ending. These dates significantly varied in different years. The duration of the late summer–autumn period especially varied, because its end was determined by the time of the beginning of stable frosts. At the time of mass plant flowering, communities of cryophilous meadows were clearly differentiated by the prevailing color of the dominant species: pink in snakeweed meadows, white in *Geranium albiflorum* meadows, yellow in *Viola biflora*–herb meadows, and bluish-white in *Lagotis* meadows.

CONCLUSION

Cryophilous meadows of the polar Urals only remotely (mainly by the character of the habitat) resembled "snow coombs" of the Alps (Favarger, 1956), though they had some species in common (*Sibbaldia procumbens, Gnaphalium supinum, Poa alpina*, and *Polygonum viviparum*). They are closest to analogous communities of the prepolar and northern Urals (Gorchakovskii, 1975), but differ in the composition of dominants.

In the polar Urals, cryophilous meadows occupied small areas and were sporadically distributed. They were extremely peculiar from ecological, floristic, and phytocenological standpoints and had many rare plants in their composition, including the endemic *Epilobium uralense*. However, these communities have undergone increasing anthropogenic effects, mainly because they were favorite places of reindeer for summer grazing and rest, since they can escape heat and bloodsucking insects here. Under the impact of overgrazing, cryophilous meadow communities were totally destroyed. It is necessary to preserve the unique gene pool and cenofond of cryophilous meadows by the organization of preserves, where reindeer grazing could be completely excluded.

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