Plant diversity and spatial vegetation structure of the calcareous spring fen in the "Arkaulovskoye Mire" Protected Area (Southern Urals, Russia)

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SUMMARY

The plant communities of base-rich fens are locally rare and have high conservation value in the Republic of Bashkortostan (Russian Federation), and indeed across the whole of Russia. The flora and vegetation of the calcareous spring fen in the protected area (natural monument) “Arkaulovskoye Mire” (Republic of Bashkortostan, Southern Urals Region) was investigated. The species recorded comprised 182 vascular plants and 87 bryophytes (67 mosses and 20 liverworts), including 26 rare species listed in the Red Data Book of the Republic of Bashkortostan and seven species listed in the Red Data Book of the Russian Federation. The study area is notable for the presence of isolated populations of relict species whose main ranges are associated with humid coastal and mountainous regions in Central Europe. The vegetation cover of the protected area consists of periodically flooded grey alder - bird cherry forests, sedge - reed birch and birch - alder forested mire, sparse pine and birch forested mire with dominance of *Molinia caerulea*, base-rich fens with *Schoenus ferrugineus*, islets of meso-oligotrophic moss - shrub - dwarf pine mire communities, aquatic communities of small pools and streams, etc. Examination of the peat deposit indicates the occurrence of both historical and present-day travertine deposition. A retrospective assessment of the seasonal development of vegetation and surface temperature at Arkaulovskoye Mire, using earth observation data, suggests that the microclimatic conditions of the mire habitat can mitigate extremes of continental climate in the forest-steppe zone and thus support the survival of the mire’s relict floristic complexes. Finally, a comparison of climatic data between the Arkaulovskoye Mire and Nätsjöbäcken Mire in Sweden, which is a site for *Schoenus ferrugineus* within its main European range, shows that the annual temperature regimes of these two locations are rather similar.

KEY WORDS: base-rich fens, bryophytes, flora, nature protected areas, relict species, vascular plants

INTRODUCTION

The term “calcareous fen” describes a base-rich or alkaline mire type that develops on mineral-rich bedrock under the influence of a constant diffuse supply of calcareous water from subsurface seepage or surface springs (Joosten *et al.* 2017). Calcareous mire ecosystems are usually situated on gently sloping terraces in river valleys and lake basins. They are characterised by a combination of tufa (travertine) deposition at the surface of the mire and peat formation within it (Weeda *et al*. 2011). Travertine deposition prevents acidification of the mire and sustains populations of basiphilous species (Grootjans *et al*. 2006). Calcareous mires have high nature conservation value, due to their high biodiversity and the presence of many rare and specialised plant species that are highly endangered in Europe (Wolejko *et al*. 2019). Their unique species composition arises from the specific combination of habitat features including high water level, high concentration of dissolved calcium salts and low concentrations of solutes required by plants (‘plant nutrients’). In particular, there is a shortage of plant available phosphorus owing to its immobilisation by iron and calcium complexes. Phosphorus availability appears to limit the productivity of plant communities in calcareous mires (Boyer & Wheeler 1989), but in managed (mown) mires the productivity appears to be co-limited by phosphorous and nitrogen availability (van Duren 2000, van Duren & Pegtel 2000). The critical precondition for preserving calcareous fens is the maintenance of permanently high water level. Even moderate drainage leads to a major increase in biomass (Boyer & Wheeler 1989) and a decrease in, or even loss of, typical basiphilous species.

Calcareous mires may be variously referred to in the literature as base-rich fens, alkaline fens, small-sedge fens, brown-moss fens, etc. They are intrazonal, occurring in almost all biogeographical regions of Europe from Malta to Svalbard, in both uplands and lowlands (Joosten *et al*. 2017). Their main known eastern limit in Europe occurs in Finland, the Baltic countries (Latvia, Lithuania, Estonia, Poland), Slovakia and Ukraine (Jiménez-Alfaro *et al*. 2014, Joosten *et al*. 2017). Some small occurrences are known from the Balkan Mountains, Belarus (Pugachevskiy *et al*. 2013), north-western Russia i.e. Republic of Karelia, Murmansk, Leningrad, Pskov, Novgorod, Vologda and Arkhangelsk Regions (Smagin 2008, Blinova & Uotila 2013, Smagin & Denisenkov 2013, Smagin *et al*. 2015), central Russia i.e. Bryansk, Tula, Moscow and Samara Regions, Republic of Tatarstan, and the Southern Urals i.e. Republic of Bashkortostan and Chelyabinsk Region (Kulikov & Filippov 1997, Fedotov 2011, Ivchenko 2012, Bakin 2014, Volkova 2018). Farther east, moderately calcium-rich sedge - moss fens have been described in the river valleys of Western Siberia (Lapshina *et al*. 2018).

The plant communities of calcareous mires have much in common with those of rich meadows and rich fens. The herb layer of these communities is mostly dominated by sedges (Cyperaceae). The bryophyte layer is usually well developed and consists of *Sphagnum* species or peat forming brown mosses (*Campylium stellatum*, *Scorpidium cossonii*, *S. scorpioides*, etc.), or both. From a syntaxonomical point of view, Eurosiberian fens are traditionally assigned to the class *Scheuchzerio palustris-Caricetea fuscae* Tuxen 1937 (Udd *et al*. 2015, Peterka *et al*. 2017). A biogeographical analysis of the variation in species composition of the plant communities of calcareous mires referred to as base-rich fens was undertaken by Jiménez-Alfaro *et al*. (2014), who identified three major vegetation types in the base-rich fens of Europe. The variation in species composition is mainly correlated with temperature, precipitation and latitude, showing a major gradient from (1) alpine belt fens characterised by spring species to (2) small sedge fens occurring mainly in mountain regions and (3) boreo-temperate fens reflecting waterlogged conditions (Jiménez-Alfaro *et al*. 2014).

To a large extent, calcareous mires have been destroyed by historical drainage. According to Šefferová Stanová *et al*. (2008), the main causes of habitat destruction in calcareous mires across Europe are: drainage for agriculture or forestry, changes in regional hydrology, eutrophication, abandonment of traditional land uses involving mowing and grazing, and water abstraction for local use. The habitat of this mire type is included in Natura 2000 as "7230 Alkaline fens" and "7210 Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*" (EU 2013). Because of the natural rarity of calcareous mires and their vulnerability to human-related threats, knowledge of their vegetation in different regions is a priority for all aspects of their conservation (Šefferová Stanová *et al*. 2008, Jiménez-Alfaro *et al*. 2014, Joosten *et al*. 2017).

Calcareous mire is a rare vegetation type in the Republic of Bashkortostan (Russian Federation) where there are about 30 calcareous mire sites, most of which are located in the Mesyagutovo forest-steppe region in the north-eastern part of the Republic. From a botanical-geographical point of view, these mires are assigned by Yurkovskaya (1992) to the class 'herbal and herbal-hypnic mire types'. Within this framework, all types represented in Bashkortostan (in particular) would be placed in the group of types 'East European herbal and herbal-hypnic mires', due to their intrazonal distribution. Calcareous mires were not considered when the distribution of mires in the European part of Russia was described (Sirin *et al*. 2017), and are not amongst the mire massif types that are used for mapping purposes. However, they could be placed within the type 'minerotrophic soligeneous mires of gentle slopes with mixed development process' in the landscape classification of mire massifs (Galkina & Kiryushkin 1969) and the hydrogenetic classification (Masing 1975).

The earliest information about the original mosaic of vegetation complexes on what is now the protected area "Arkaulovskoe Mire" dates from the first half of the 20th century (Matyushenko 1929, Bradis 1946). In 1928–1929, the research group of the Bashkir Commission of the USSR Academy of Sciences under the leadership of A.K. Noskov gathered a large herbarium collection (more than 4,000 specimens) which included plants from Arkaulovskoe Mire. These specimens are currently stored in the herbaria of the Botanical Institute of the Russian Academy of Sciences in Leningrad (LE), Moscow University (MW) and Ufa Institute of Biology (UFA). Some data on rare vascular plants and bryophytes of calcareous mires in the Mesyagutovo forest-steppe region have been published (Kulikov & Filippov 1997, Mirkin 2011, Baisheva *et al*. 2018). Nevertheless, the vegetation and total plant diversity of calcareous fens in the Republic of Bashkortostan is still insufficiently understood.

Schoenus ferrugineus is one of the diagnostic species of calcareous fens. The importance of habitats for this species to the flora of the Urals is underlined by its rare occurrence in Russia, and promoted by the research interest in phytogeography. *Schoenus ferrugineus* in Bashkortostan is distant from the main area of the European distribution and located at the eastern edge of its Eurasian range.

The present study aimed to record the vascular plant and bryophyte diversity of the Arkaulovskoe mire massif, to characterise the spatial structure of the mire massif and its vegetation complexes, to obtain information about spatial and temporal variation of the chemical and physical environment in relation to the seasonality of weather, and to compare plant growth conditions between the relict plant communities dominated by *Schoenus ferrugineus* at Arkaulovskoe and similar calcareous fen communities occurring in Scandinavia, within the main European range of this species.

METHODS

Study site

The natural monument "Arkaulovskoye Mire" was established in 2005. It is situated within Salavat District, Republic of Bashkortostan in the Bashkir Fore-Urals (the south-eastern part of the East European Plain bordering the western foothills of the Southern Urals). Mean annual temperature is 1–1.5 °C and mean annual rainfall is 600–650 mm (Yaparov 2005).

Arkaulovskoye Mire covers an area of 150 ha at 55.413611–55.425556 °N, 57.925278–57.947222 °E and altitude 280–300 m a.s.l. (Muldashev *et al*. 2016). It lies between two streams (Mukle and Solyenyi Klyuch) on the slope of a hill in the valley of the Yuryuzan' River, and all mire waters drain into those two streams. The maximum thickness of the peat deposit reported by Bradis (1951) is about 4 m. The mire is fed by several springs with highly mineralised water and deposits of raw sulphur, iron oxides and carbonates are found both within and outside the boundaries of the mire. The temperature of the spring water is lower than, or the same as, the temperature of the surroundings.

Vegetation and floristics study

The study area was visited several times in 1993, 2000, 2005, 2009, 2012 and 2017. Sketch-level mapping of the mire microlandscapes (Masing 1974) was carried out in 2009 by the transect method combined with vegetation survey, and visualised using a Landsat 5 satellite image. In total, 60 geobotanical relevés were recorded in 2009 and 2012, using sample plots of different sizes ranging from 2 m² on hummocks to 400 m² at homogeneous forest sites. Additional data were obtained in other years by conducting a random floristic survey of the entire study area, aiming to record all species present.

Within each sample plot, all plant species were recorded and their cover was estimated using the Braun-Blanquet cover-abundance scale (Braun-Blanquet 1964). Specimens of bryophytes and some vascular plant species that could not be identified in the field were collected and identified at the UFA Herbarium. The bryophyte specimens were identified by the traditional anatomical-morphological method using Olympus CX31 and Al'tami SPM 0880 microscopes. The nomenclature of species follows Hill *et al*. (2006), The Plant List (2013) and Söderström *et al*. (2016).

The geographical distribution of species was analysed according to the botanical-geographical method, and floristic analysis was undertaken in line with the Russian botanical school. Species presence was rated on the basis of relevance to the ecological-coenotical plant species groups (Nitsenko 1969, Smirnov *et al*. 2006) and the ecological groups of species in relation to water regime, as well as in terms of species fidelity with mires (Botch & Smagin 1993), with regional amendments. The assessment of species groups and ecological amplitudes was based on expert knowledge of the habitat preferences of each species in the Southern Urals region.

Mire water and peat study

Some physical and chemical characteristics of mire water were measured in order to obtain indicative information about the habitats of plant species and communities. No regular monitoring data are available, only single measurements at the locations of the geobotanical relevés, and the number of observation points was insufficient to support a statistically robust comparison of the habitats. Water table depth was measured from the surface in temporary boreholes cored simultaneously with the geobotanical study. Portable instruments (Hanna HI 98129 Combo PH/EC/TDS/T) were used to measure the pH, electrical conductivity (EC) and temperature of mire water in situ at the water table in the boreholes (WT), in water samples squeezed from surface plant material (S), and at the surfaces of pools (P) and streams (R). EC and pH values were standardised to 25 °C.

Weather conditions differed significantly between the two measurement sessions (at the beginning of July 2009 and in August 2012). According to data from the Duvan meteorological station (http://aisori-m.meteo.ru/waisori), the summer of 2009 was typical for the region with monthly average temperatures of +17.4, +16.2 and +14.7 °C and monthly precipitation sums of 39.2, 74.4 and 74.8 mm in June, July and August, respectively; whereas the corresponding figures for the same months in 2012 were +18.9, +21.1 and +18.1°C, and 47.2, 14.9 and 31.9 mm. During the survey in 2012, day-time air temperature reached 31.2 °C although it was cooler (11.9–19 °C) at night.

Peat depth and structure were studied using an "Instorf" peat corer ("Russian peat sampler"; Belokopytov & Beresnovich 1955). The depth of the peat deposit was measured from the ground surface to the underlying solid travertine deposit. A preliminary field assessment of macrofossil composition in the north-western part of the mire massif was undertaken by examining two deep cores.

Seasonal changes in vegetation structure

As the study area is located within the forest-steppe region, most of the boreal species growing here are close to the southern borders of their ranges and can survive only in mire ecosystems, whose microclimatic conditions can mitigate negative effects of the continental climate. To reveal the differences in microclimatic conditions between the habitats of the mire and its surroundings, we carried out a retrospective comparison of seasonal vegetation development and land surface temperature at different locations between years with different weather conditions, using remote sensing data and the Normalized Difference Vegetation Index (NDVI). The NDVI was derived from cloudless Landsat 5, Landsat 7 and Landsat 8 images for the period 01 April to 30 October in 2010 and 2016. Image processing started with radiometric and atmospheric correction of the images (Neteler & Mitasova 2008). Morning temperature (between 8 a.m. and 10 a.m.) was extracted from the thermal satellite channels in the spectral range 10.4–12.5 microns. Thermal Infrared Sensor data were converted from spectral radiance to brightness temperature, which is the effective temperature viewed by the satellite (USGS 2016). All of the calculations were carried out in QGIS with GRASS GIS Integration; the Zonal Statistics Plugin was used to calculate the mean values of NDVI and temperature for each site. Five plots were used for ground truthing, of which three were within the mire massif (sedge - reed birch forested mire, sparse pine and birch forested mire and *Schoenus ferrugineus* - small sedges - brown mosses open mire) and two were on the surrounding non-waterlogged mineral land in birch forest (55.40743 °N, 57.93981 °E) and grass pasture (55.40403 °N, 57.91673 °E), 650 m and 1650 m distant from the mire, respectively.

Comparison of climatic conditions with those at a *Schoenus ferrugineus* site in Sweden

The Nätsjöbäcken Mire (61.651396 °N, 15.186416 °E) is a calcareous fen located about 12 km from Hamra in Hälsingland, Sweden. It was chosen, as a site where *Schoenus ferrugineus* grows within the main range of its geographical distribution, for comparison of its growth conditions with those at the Arkaulovskoye Mire. The climatic characteristics of the two sites were assessed on the basis of data from the nearest weather stations, i.e. N 35127 (http://aisori-m.meteo.ru/waisori) situated in the Duvan settlement about 35 km from Arkaulovskoye Mire and Darn Meteorological Station No. 02329 (http://www.pogodaiklimat.ru/msummary.php?m=5ety=alletid=02329) in Hamra.

RESULTS

Vegetation cover and habitat characteristics of the Arkaulovskoye Mire

According to the floristic zonation of Bashkortostan (Gorchakovsky 1988), the study area belongs to the Mesyagutovo forest-steppe district located in the undulating plain between the rivers Yuryuzan' and Ai. Terrigenous and terrigenous-carbonate formations of the Early Permian with calcium bicarbonate enriched groundwater are typical (Abdrakhmanov *et al*. 2002). Several other larger mires of this type have been reported from this area (Bradis 1946).

The mire massif has two flat domes. The smaller dome to the north-west is sparsely forested and has numerous pools connected by brooks draining into the Mukle stream. The larger dome in the eastern part of mire massif has an irregular boundary and fewer but larger pools which drain via brooks into the Solyenyi Klyuch stream. The two domes are separated by forested mire. Although the mire massif has nature protected status, it is used by local people for illegal moss harvesting and is periodically affected by fires. Several fire scars are visible in reed-dominated locations.

The Arkaulovskoye mire massif consists of five microlandscape types (Masing 1974) (Figure 1), including flooded forests along with forested and open mires. The streams and pools are described separately. Since vegetation classification was not the aim of this study, we describe the major vegetation complexes and their phytosociological interpretation for each microlandscape type.

(1) The forested mire margins do not form real lagg, their further spread being limited by the streams. The peatland is surrounded by grey alder - bird cherry forests with humus-rich soils without peat, which are periodically flooded but otherwise well drained. The vegetation cover of this forest is characterised by a predominance of *Urtica dioica* and high constancy of *Ribes nigrum, Glehoma*

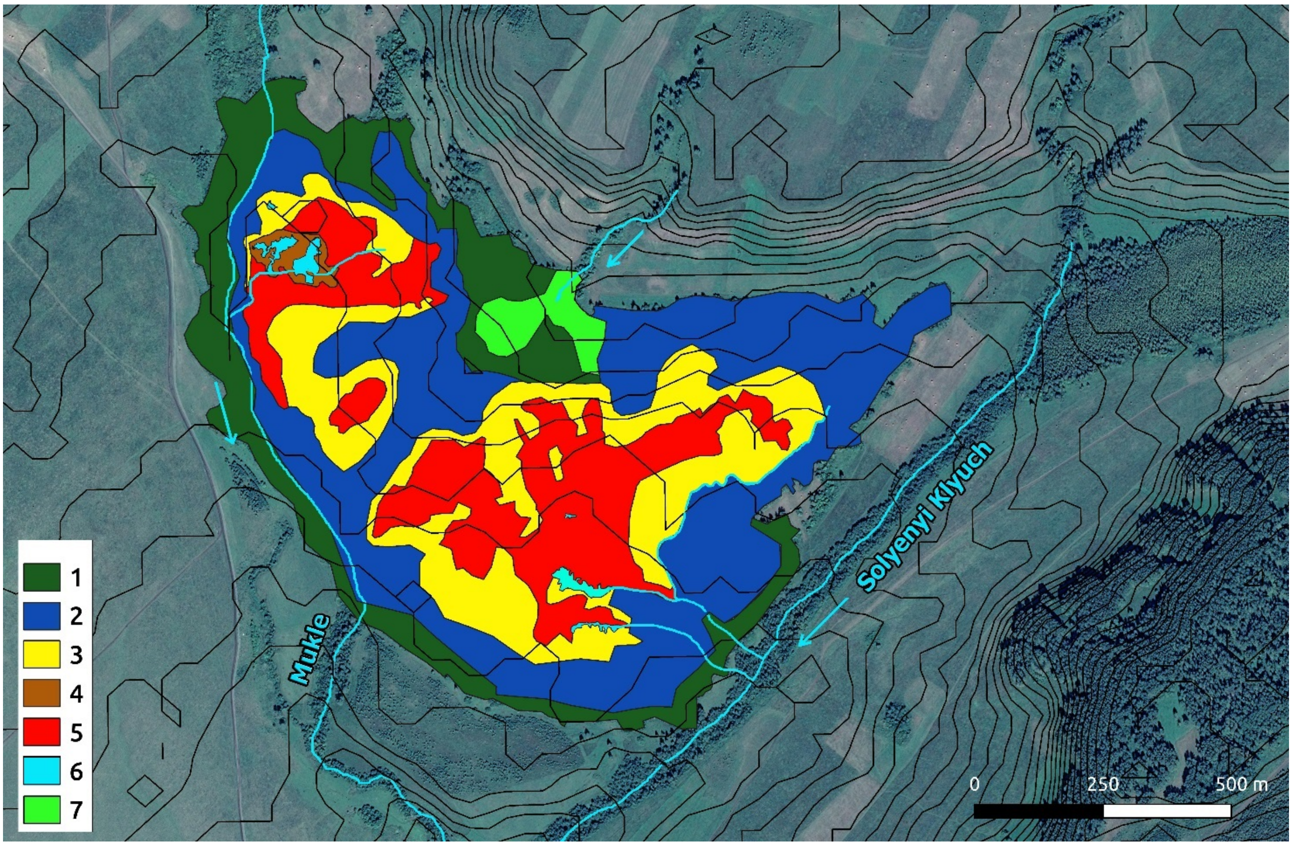

Figure 1. Plan view of the Natural Monument “Arkaulovskoye Mire” (Republic of Bashkortostan, Russia) showing the spatial structure of the mire massif. The mire microlandscape types, identified by their predominant plant community types (as described in the text) are as follows: 1 = periodically flooded grey alder - bird cherry forest; 2 = sedge - reed birch and birch - alder forested mire; 3 = sparse pine and birch forested mire; 4 = moss - shrub dwarf pine forested mire; 5 = *Schoenus ferrugineus* - small sedges - brown mosses open mire; 6 = large pools and streams; 7 = vegetation complexes of birch tree stands and hayfields on mineral soils. The contour interval is 3 m.

hederacea, Humulus lupulus, Athyrium filix-femina, Geum rivale and *Impatiens noli-tangere*. The mean tree cover is 75 % and the herb cover varies greatly (25–70 %). The bryophyte composition is similar to that of the sedge - reed birch and birch - alder forests described below. These communities belong to the alliance ***Alnion incanae*** Pawłowski *et al*. 1928. The water table level fluctuates between -50 and -30 cm.

(2) The sedge - reed birch and birch - alder forested mire microlandscapes are located on the gentle slopes surrounding both mire domes, including a 100–250 m wide north–south stripe that separates the two parts of the mire massif (Figure 2a). The cover of the tree layer is 30–70 %, the height of the trees is 12–15 m reaching 20 m in better-drained sites, and the mean diameter of their trunks is about 20 cm. The shrub layer is formed by *Frangula alnus, Viburnum opulus, Salix cinerea* and *Sorbus aucuparia*, it is relatively dense, and its cover is 15–20 %. In the herb layer *Filipendula ulmaria* and *Phragmites australis* are dominant, and *Rubus saxatilis, Carex cespitosa, Molinia caerulea, Sanguisorba officinalis, Galium uliginosum* and *Vicia cracca* have high constancy. The herb cover can vary greatly (40–80 %), depending mainly on the duration of waterlogging. The cover of bryophytes is low (1–5 %). *Climacium dendroides, Drepanocladus aduncus, Plagiomnium ellipticum* and *Brachythecium mildeanum* have relatively high constancy in the ground (moss) layer; and *Amblystegium serpens, Callicladium haldanianum, Lophocolea heterophylla, Brachythecium salebrosum* and other epixylic species are common on the bases of tree trunks and on decaying wood. In terms of phytosociological classification these communities belong to the association ***Carici cespitosae-Betuletum pubescentis*** Solomesh et

Figure 2. Plant communities and habitats described in the text. a: sedge - reed birch and birch - alder forested mire; b: sparse pine and birch forested mire; c: pool with large hummocks forming islands; d: stream; e: *Schoenus ferrugineus* - small sedges - brown mosses open mire; f: lime deposit covering the mire surface.

Grigoriev in Martynenko *et al*. 2003 from the alliance ***Betulion pubescentis*** Lohmeyer et Tx. ex Oberd. 1957. The habitats are supplied by water from the peatland domes, especially on rainy days. Peat depth is 30–60 cm and the water table level is usually below -40 cm but sometimes at the surface, pH is close to basic (around 8) and EC is quite high at 2024 µS cm^{-1} (Table 1).

(3) The sparse pine and birch forested mire microlandscapes have tree cover 10–30 % and a herb layer with dominance of *Molinia caerulea* and high constancy of *Potentilla erecta, Phragmites australis*, *Vaccinium uliginosum, Succisa pratensis*, *Rubus saxatilis*, *Schoenus ferrigineus*, *Parnassia palustris*, *Inula aspera*, etc. (Figure 2b). These communities replace the

Table 1. Summary of the measurements of physical and chemical characteristics of mire water water in the different habitats of the “Arkaulovskoye Mire” Protected Area, Republic of Bashkortostan, Russia. Habitat types: 1 = sedge - reed birch and birch - alder forested mire, 4 = moss - shrub dwarf pine forested mire, 5 = *Schoenus ferrugineus* - small sedges - brown mosses open mire, 6 = small pools, 6a = streams. Sample types: WT = at the mire water table; S = squeezed from the surface moss cover; P = at the surface of a pool; R = at the surface of a stream.

Dates	Habitat type	Water sampling	pH		EC, μS cm^{-1}		Water sample temperature, °C		Air temperature, °C		Previous days precipitation sum, mm		Previous 10 days air temperature, °C	
			min	max	min	max	min	max	min	max	min	max	min	max
06 July 2009	2	WT	8.01		2024		14.0		10.3	17.6	15.2	33.9	4.9	23.1
	5	WT	7.48	7.67	2278	2352	10.0	11.8	10.3	17.6	15.2	33.9	4.9	23.1
	6	P	7.57	7.84	1878	2202	12.0	13.7	10.3	17.6	15.2	33.9	4.9	23.1
	6a	R	7.61	7.77	2225	2231	8.4	10.8	10.3	17.6	15.2	33.9	4.9	23.1
03–06 August 2012	4	WT	7.6	7.6	1878	2256	16.1	16.3	11.9	31.2	0	4.8	10.7	29.0
	4	S	6.8	7.1	2205	> 4000	18.2	22.0	11.9	31.2	0	4.8	10.7	29.0
	5	WT	7.0	7.5	2271	2636	17.2	24.6	11.9	31.2	0	4.8	10.7	29.0
	5	S	7.6	7.8	2280	2945	22.9	25.7	11.9	31.2	0	4.8	10.7	29.0
	6	P	7.0	7.8	1126	2296	19.2	27.9	11.9	31.2	0	4.8	10.7	29.0
	6a	R	6.9	8.0	2024	2372	7.6	21.6	11.9	31.2	0	4.8	10.7	29.0

sedge - reed birch and birch - alder vegetation of the flat terraces of the mire massif where it slopes towards to the central part of the mire (Figure 1). Bryophyte cover is not high (5–7 %) and the most common species are *Campylium stellatum* and *Tomentypnum nitens.* The syntaxonomical position of these communities is not completely clear. Peat depth ranges from 80 to 200 cm and the water table level varies from -30 cm up to the surface during rainy periods.

(4) Moss-shrub dwarf pine forested mire complexes with large pools are found on the north-western flattened dome of the mire massif. Small hummocks of diameter 30–80 cm and height 15–40 cm form up to 30 % of the habitat. Larger hummocks are found in the pools where they form small islets extending up to 1 m above the water level (Figure 2c). The sparse (20 % cover) tree stand is formed by dwarf forms of pine, single birch and grey alder trees 2.5–3 m tall with trunk diameters of 4(6) cm. The shrub layer (cover 10–15 %) is formed by *Frangula alnus*. The moss layer (cover 50–90 %) consists mainly of *Sphagnum warnstorfii*, *Tomentypnum nitens, Pleurozium schreberi* and *Aulacomnium palustre*. This is the only location where *Paludella squarrosa* and *Sphagnum fuscum* are found, growing on the tallest hummocks. *Ledum palustre, Vaccinium uliginosum, V. vitis-idaea, V. microcarpum, V. oxycoccos, Rubus saxatilis, Molinia caerulea, Phragmites australis, Carex dioica* and *Epipactis palustris* have high constancy. The floristic composition of these communities includes diagnostic species of the classes ***Scheuchzerio palustris-Caricetea fuscae*** Tx. 1937 (*Sphagnum warnstorfii, S. subsecundum, Parnassia palustris*, etc.) and ***Oxycocco-Sphagnetea*** Br.-Bl. et Tx. ex Westhoff *et al*. 1946 (*Aulacomnium palustre, Vaccinium microcarpum, V. oxycoccos, Drosera rotundifolia*, etc.). The peat depth is 200–300 cm, and water table level varies from 0 to -30 cm relative to the ground surface. The pH of soil water at the mire surface is 6.8, while at 25 cm depth it is higher (7.6). The EC of water squeezed from mosses at the surface is very high (the maximum value exceeded the measuring ceiling of 4000 μS cm^{-1}). Lower in the profile (at 25 cm depth) EC is much lower (minimum 1878 μS cm^{-1}).

(5) The microlandscapes covering the two flattened domes in the north-western and south-eastern parts of the mire massif have open communities with *Schoenus ferrugineus*, small sedges and brown mosses with dominance of *Scorpidium cossoni* and *Campylium stellatum* and high constancy of *Molinia caerulea, Phragmites australis, Sanguisorba officinalis, Eriophorum angustifolium, Parnassia palustris, Potentilla erecta, Pinguicula vulgaris* and *Tomentypnum nitens*, as well as sparse small *Betula pubescens* trees (Figure 2e). The cover of bryophytes (40–85 %) and herbs (10–60 %) varies with microrelief and hydrological conditions. Whitish spots (lime deposits) formed on the surfaces of bryophytes are very frequent, especially near streams and pools (Figure 2f). The vegetation of this community type can be classified to the alliance ***Caricion davallianae*** Klika 1934. The maximum peat depth is about 4 metres, while water table level varies between zero and 15 cm below the surface. The vegetation is often covered by travertine deposits. Water pH is more basic (7.0–7.5) at the water table (-10 cm) and at surface (7.6–7.8) than in other sampled locations; and EC is very high, ranging from 2270 to 2945 μS cm^{-1} (Table 1).

(6) Within the open sites there are numerous small pools (diameter 3–8 m) and a few large pools (20–30 m wide, 60–80 m long). The pools are surrounded by communities of *Phragmites australis* and brown mosses (*Hamatocaulis vernicosus, Bryum pseudotriquetrum*, etc.) and host communities of *Chara* algae or *Utricularia vulgaris* occur in the water. The measurements of pH and EC in pool water vary widely, pH from 7.0 to 7.8 and EC from 1126 to 2296 μS cm^{-1}. Water temperatures are close to average daily air temperature (Table 1).

(6a) Communities with *Phragmites australis, Lysimachia vulgaris, Carex cespitosa, C. rostrata, Deschampsia cespitosa, Plagiomnium ellipticum, Drepanocladus aduncus*, etc. are found on the banks of streams in the forested margins of the mire massif (Figure 2d). Also, temporary watercourses connecting the pools are relatively common on the open mire. The pH of water in streams varies from 6.9 to 8.0 and EC from 2024 to 2372 μS cm^{-1} (Table 1). The streams are fed by numerous springs and water temperature is low (8–10 °C) except during periods with extremely high air temperatures (> 30 °C), when it can reach 21.6 °C (Table 1).

Peat and travertine deposition

According to our survey the soft deposits are entirely underlain at depth 3–4 m by solid travertine which could not be sampled by the peat corer. The surface deposits consist of peat or peat alternating with travertine layers (from 5 to 50 cm depth), interchanging with soft travertine layers (10 to 60 cm depth).

The upper part of the peat deposit in the sparse pine and birch forested mire (Microlandscape 3) on the slopes of the western part of the mire massif consists of 60 cm of travertine overlying 40 cm of *Sphagnum* and *Sphagnum* - reed peat mixed with travertine. From 100 cm below the surface the layers of peat and travertine are 5–10 cm thick, at 120 cm depth the peat type changes from *Sphagnum* to sedge - *Hypnum*, wood peat appears at 150 cm, while from 170 cm the *Sphagnum* and reed peat type reappears and the peat is free of travertine but mixed with charcoal.

The second deep core indicated faster accumulation in moss - shrub dwarf pine forested mire on the north-western dome (Microlandscape 4). Here the *Hypnum* - wood peat is mixed with travertine for the first half metre, then changes to *Sphagnum* peat with less travertine or to pure peat. Travertine appears again at 100 cm depth and comprises the whole of the deposit at 125–185 cm. The next 15 cm is pure *Sphagnum* peat, then there is *Sphagnum* peat with travertine from 200 to 280 cm and pure travertine from 280 cm.

The layering indicates that travertine deposition occurred during specific periods in the past. During our surveys we noticed evidence that travertine formation is also in progress at the present time, both near the springs and in the central open part of the mire where the numerous small open pools form a cascade of mineralised surface water bodies. On a hot summer day we observed that the surface water in the pools warmed up to 27.9 °C (Table 1). At higher temperatures, less carbon dioxide can be dissolved than at low temperatures, resulting in the deposition of calcium carbonate. Plants and algae can accelerate the process by using the carbon dioxide in the water as a carbon source (Grootjans *et al*. 2006). Carbonate-encrusted bryophytes, *Chara* algae and vascular plants often occur in the travertine.

Floristic analysis of Arkaulovskoye Mire

The current list of flora for the protected area “Arkaulovskoye Mire” contains 182 vascular plant species and 87 bryophyte species, including 20 liverworts and 67 mosses (Appendix). We found populations of rare and endangered species, seven from the Red Data Book of Russia (Bardunov & Novikov 2008) and 26 from the Red Data Book of Bashkortostan (Mirkin 2011).

The vascular plants: bryophytes ratio is 2.1:1. The species diversity of the study area is quite high, incorporating 59 % of the bryophytes and 42 % of the vascular plants found in the mire ecosystems of the Bashkir Fore-Urals.

The highest species richness of both bryophytes and vascular plants occurs in the periodically flooded grey alder - bird cherry forest and sedge - reed birch and birch - alder forested mire types (Types 1 and 2), which are represented mainly in marginal parts of the mire (Appendix), and the lowest number of species is found on the banks and in the water of pools and streams (Types 6 and 6a). Low species richness of bryophytes was also recorded in sparse pine and birch forested mire with tall and dense herb layer (Type 3).

Among the vascular plants recorded in the study area, the proportion of species found rarely and accidentally in mires (mire species fidelity score 1) is relatively low (~10 %) and species indifferent to mire habitats, i.e. occurring equally in mires and other habitats (score 2; ~38 %) are better represented. In contrast, the proportion of bryophytes scoring 1 is quite high (30 %); these are mostly epiphytic and epixylic species that usually grow in forests (Table 2). Indeed, the species assemblages for forest communities have high ratings for both bryophytes (~39 %) and vascular plants (25 %). About 41 % of the bryophyte and 52 % of the vascular plant species recorded at Arkaulovskoye Mire have high mire species fidelity scores (3–5) and are evaluated as ‘true’ mire species. Therefore, only about half of the total number of species are typical mire species, and the proportion of species growing only rarely and accidentally in mires is quite high. This is partly due to the high diversity of forest species growing in the periodically flooded grey alder - bird cherry forests and sedge - reed birch and birch - alder forests along the mire margins, and partly because plants from surrounding ecosystems are able to expand across the mire owing to its relatively small size.

In terms of area types (species ranges), the bryophytes recorded on the Arkaulovskoye Mire are circumpolar (67.8 %) and multiregional (32.2 %) species; and the floristic elements include multi-zonal (36.8 %), boreo-arctic montane (26.4 %), boreal (18.4 %) and boreo-temperate (18.4 %) species. Among the vascular plants, the area types represented are Euro-West Asian (31.7 %), Holarctic (22.8 %), Eurasian (21.1 %), Euro-Siberian (12.8 %), North American-Euro-West Asian (5 %), European (4.4 %), hemi-cosmopolitan (1.7 %) and North American-Euro-West Siberian (0.5 %); and the floristic elements include multi-zonal (30.6 %), boreo-temperate (26.7 %), boreal (16.1 %), boreal forest-steppe (9.4 %), forest-steppe (7.2 %), sub-Arctic boreal (3.9 %), temperate (3.3 %) and temperate-forest-steppe (2.8 %) species.

The high proportion of multi-zonal species (approximately one-third of both bryophytes and vascular plants) is typical for mire floras in different regions, and can be explained by the azonal character of mire vegetation. The substantial proportions of bryophyte species representing boreo-arctic montane, boreal and boreo-temperate floristic elements, and of boreo-temperate and boreal floristic elements among the vascular plants, is also typical for mires of the temperate and forest steppe zones (Blagoveshchensky 2006, Bakin 2014, Volkova 2018) and reflects the connection of the floristic complexes of these mires with the boreal zone.

Seasonal development of vegetation structure

The lower part of Figure 3 shows average monthly temperature and precipitation in the study area for 2010 (with a warm and extremely dry summer) and 2016 (average temperature within normal limits for the Southern Urals region). The seasonal development of vegetation and surface temperature conditions during these two years, in three different habitats of the Arkaulovskoye Mire and two non-mire habitats in the surroundings, is shown in the upper part of Figure 3.

The seasonal changes in vegetation growth and development through each year, as reflected by the NDVI, provide insights about the efficiency of photosynthesis per unit area and, thus, the microclimatic characteristics of the habitats. In 2016

Table 2. Results of the floristic analysis of “Arkaulovskoye Mire” Protected Area, Republic of Bashkortostan, Russia.

Floristic indices	Scores (%)	
	Bryophytes	Vascular plants
Species fidelity score to mire habitats		
1: species found rarely and accidentally in mires	30.0	10.3
2: species occurring equally in mires and other habitats	28.9	37.9
3: species occurring in mires and other habitats but finding better ecological conditions for growth in mires	10.0	14.9
4: species found primarily in mires, but occurring in other habitats occasionally	18.3	20.7
5: species occurring exclusively in mires	12.8	16.1
Species associated with different habitat and vegetation types		
Eurytopic species found in a wide range of habitats	6.9	0
Aquatic and riparian species	1.1	3.9
Aquatic and wetland species	2.3	7.2
Wetland species	26.4	9.4
Meadow and wetland species	11.5	17.8
Forest and wetland species	12.6	13.3
Forest species	39.1	25.0
Meadow species	0	19.4
Weeds	0	3.9
Ecological groups of species in relation to water regime		
Hydrophytes	2.3	3.3
Hygro-Hydrophytes	3.4	2.2
Hygrophytes	28.7	28.9
Hygro-Mesophytes	17.2	25.0
Mesophytes	42.5	36.1
Xero-Mesophytes	5.7	4.4

(typical year), pasture showed the highest values and steepest increase of NDVI from the beginning of the growing season, but was overtaken by forested habitats during May and June. At the end of June, NDVI began to decline in all of the plant community types sampled but most intensively on pasture, whose NDVI was eventually exceeded by all other sampled habitats in August. That month was relatively wet (precipitation exceeded the long-term monthly average value), and this caused a resumption of grass growth reflected by a slight increase of pasture NDVI in the second half of the month, but NDVI continued to decline gradually in all other communities. In 2010 there was a severe drought, accompanied by increased air temperature for almost the full duration of the growing season. The development of pasture vegetation had already ceased in June, when NDVI was below 0.3, corresponding to partially bare soil and dried vegetation. In the other community types, July NDVI values were lower than in 2016 but did not fall below 0.4. After rainfall in the first half of August, the NDVI values of mire and forest vegetation increased, whereas the NDVI value for pasture did not recover, indicating that plant growth resumed in the mire and forest but not on the pasture. These results support the hypothesis that the microclimatic conditions of mire habitats provide a buffer against the influence of high temperature and drought. The most resilient of the communities sampled was sedge - reed - birch forested mire, followed by birch forest, then the sparsely wooded and open mire habitats (sparse pine and birch forested mire, *Schoenus ferrugineus* - small sedges - brown mosses open mire).

Comparison of climatic conditions at *Schoenus ferrugineus* sites in Bashkortostan and Sweden

The comparison of average monthly temperature and precipitation data between *Schoenus ferrugineus* habitats on the Nätsjöbäcken Mire (Sweden) (within

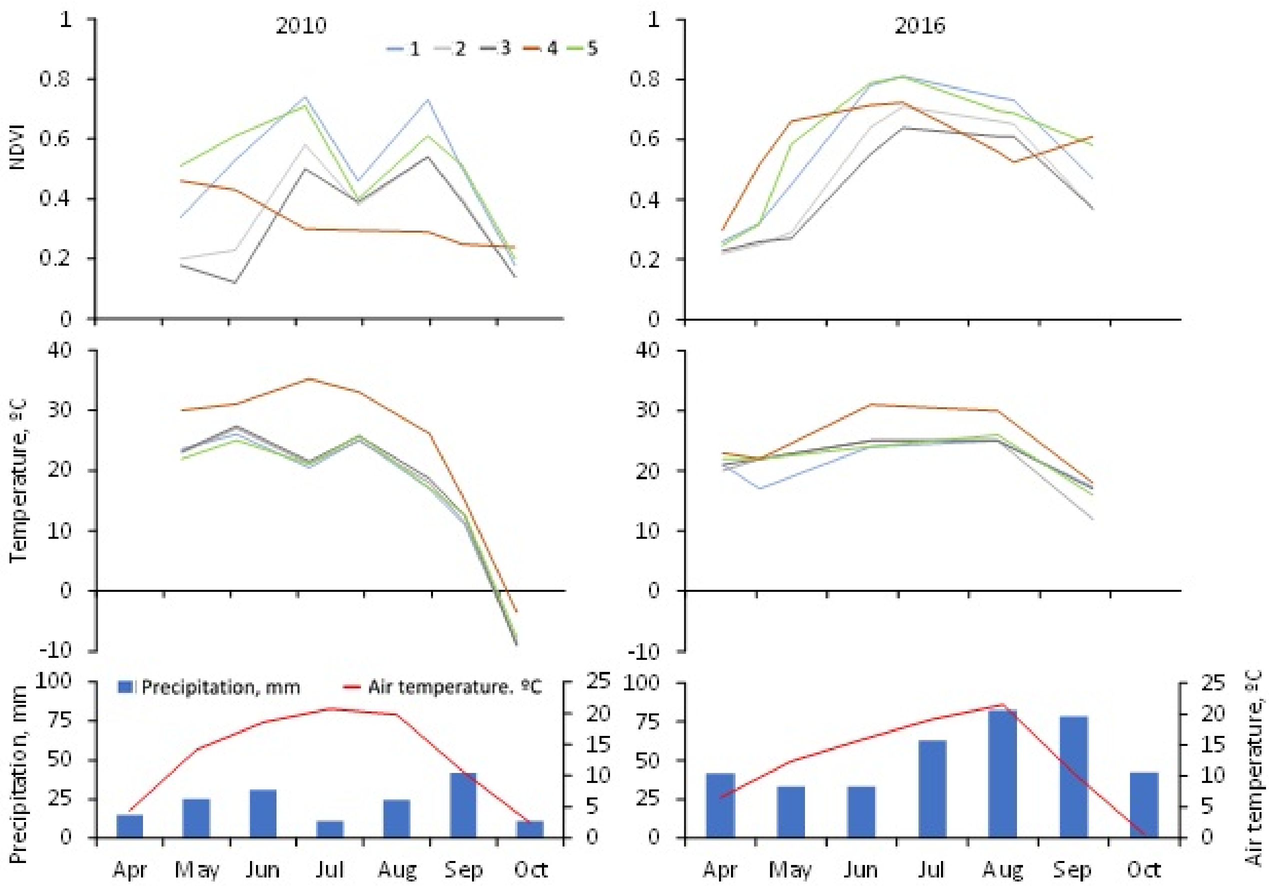

Figure 3. Seasonal changes of NDVI (top) and surface temperatures (middle) derived from Landsat earth observation data, in different habitats on the Arkaulovskoye Mire (1: sedge - reed birch forested mire; 2: sparse pine and birch forested mire; 3: *Schoenus ferrugineus* - small sedges - brown mosses open mire) and surrounding mineral land (4: pasture; 5: birch forest) during the 2010 (left) and 2016 (right) growing seasons. The bottom two graphics show monthly means of air temperature and precipitation at the Duvan weather station, approximately 35 km from Arkaulovskoye Mire, for the same period.

the main range of this species) and in our study area (where *Schoenus ferrugineus* is a relic) showed significant climatic similarities (Figure 4). In both areas, the temperature rises above zero in April. Monthly average temperatures during the growing season are lower in Nätsjöbäcken Mire (Sweden) than in Arkaulovskoye Mire (Bashkortostan) by 1.5–3.5 °C, but the significance of the differences is uncertain and the only confirmed difference is between the extreme temperature values. Mires are known generally for the mitigation of temperature extremes (Nichols 1998, Yurova *et al*. 2014, Kiselev *et al*. 2019), which means that the temperature regimes of the compared mires are similar. Average precipitation during the growing season (May to September) in the vicinity of Nätsjöbäcken Mire (288 mm) is also close to the value for our study area (305 mm).

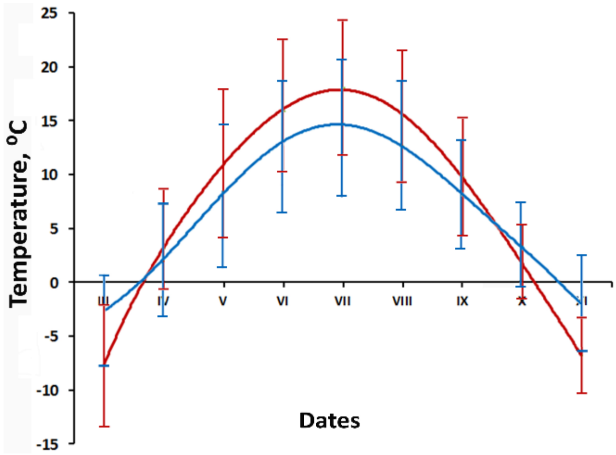

Figure 4. Average monthly air temperature at Duvan, Russia (~35 km from Arkaulovskoye Mire), 1966–2017 (red curve) and at Darn/Hamra, Sweden (~12 km from Nätsjöbäcken Mire), 2002–2018 (the flatter blue curve). Both mires have populations of *Schoenus ferrugineus*.

DISCUSSION

The mire massif of the natural monument “Arkaulovskoye Mire” has very high nature conservation value on account of its high species and ecosystem biodiversity, which is related to historical travertine deposition, as reflected by the numerous travertine layers in the peat. Travertine formation is nowadays a rather rare phenomenon in the temperate zones of Europe (Grootjans *et al*. 2006), but appears still to be in progress at this site.

The analysis of the peat deposit indicates that the development of the mire massif was controlled by a number of climate-related events which triggered changes in hydrology and intensive travertine deposition. The current vegetation structure also reflects these processes.

Even though the deposition of calcium carbonate prevents acidification and eutrophication of the topsoil (Grootjans *et al*. 2006), there are islets of meso-oligotrophic vegetation in the Arkaulovskoye Mire (Figure 1). Large through-flow fens can raise their own water levels through time, so they expand and new spring mires form on progressively higher parts of the landscape. In a late stage of peat development, the inflow of groundwater can become locally insufficient to sustain groundwater-fed fen vegetation, and patches of bog vegetation appear on the oldest parts of the fen mire massif where the depth of peat deposits is greatest (Grootjans *et al*. 2006). The surface of the mire massif is elevated due to the presence of a thick layer of peat, but its profile remains flattened due to ongoing mineralisation of peat. Thus, mesotrophic conditions persist and the mire does not develop into a bog. The combination of calcicolous and acidophilous plant species further elevates the biodiversity of the site.

A number of rare relict species for the Southern Urals (*Cladium mariscus, Gymnadenia odoratissima, Ophrys insectifera, Schoenus ferrugineus*, etc.) are associated with calcareousmires. Their main ranges are in the humid coastal and mountainous regions of Central Europe. The presence of these floristic complexes in the Urals is thought to be related to eastward migrations from Central Europe during one of the humid and less continental phases of the Holocene (probably the Atlantic period), and their disappearance from most of the East European Plain may be explained by climatic continentalisation during the sub-boreal period (Kulikov 2005). The study area still has a moderately cold and humid climate owing to the influence of the Ural Mountains on the transport of atmospheric moisture. The temperature regime during the growing season is similar to that of at least one site within the main range of *Schoenus ferrugineus*, i.e. the Nätsjöbäcken Mire (Figure 4). Moreover, we have shown that the microclimatic conditions of the mire tend to mitigate the temperature extremes of warmer continental summers and may thus be an important factor in ensuring the survival of relict floristic complexes in this region.

Although the vegetation complexes of this spring mire are quite well-preserved and have protected area status, the populations of some of Arkaulovskoye’s rare species are small and vulnerable, and some species have already become extinct. The last record of *Cladium mariscus* in this mire dates back to 1928, and the population of *Liparis loeselii* now comprises less than 100 mature individuals (Kulikov & Philippov 1997). Restoration of the populations of some of these rare species could be attempted by transplantation from larger populations that have survived in other calcareous mires located nearby (Karakulevskoye Mire). However, neither method of species population restoration (seeding or transplantation) is widely practised for *Cyperacea* and could be challenging. *Cladium mariscus* has a low capacity for reproduction due to its inefficient fruit dispersal mechanism and low seedling survival rates (Pokorný *et al.* 2010). Seasonal variation of environmental factors (e.g. groundwater and soil/peat water levels, soil moisture content, temperature) jeopardise the establishment of many other *Cyperacea* species at revegetation sites (Steed & DeWald 2003), and the reintroduction of *Cyperaceae* via rhizomes is generally more successful than using seeds in unstable environments.

The authors have experience of artificially increasing (restoring) the density of critical populations of rare red-listed species within protected areas. These field experiments are logistically complex, requiring permission from the environmental authorities and involving sowing and planting of seedlings obtained from a licensed introduction nursery (Muldashev *et al.* 2011). Also, transplantation trials for rare calcareous fen species need careful planning to avoid losses amongst both the donor populations and the transplanted propagules, for example due to extremes of climate such as summer drought in the year of transplantation, which may cause fluctuations in groundwater level with repercussions for success of the trials.

The climatic conditions at Arkaulovskoye are already more continental than in otherwise analogous west European sites, and periods of hot weather can last for months. Especially considering the progress of climate change, strategies for the conservation of rare plant species at this site should avoid reliance on any prospects for effective restoration of lost populations. Rather, the strategy should be focused on protecting the local and regional hydrological systems that maintain the mire and its vegetation, and thus on averting the risk of any further species losses occurring.

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AUTHOR CONTRIBUTIONS

AAM, VBM and IGB performed the geobotanical relevés; VBM classified the plant communities, AAM collected and identified specimens of vascular plants, EZB and IGB collected specimens of bryophytes. EZB measured the EC and pH of mire water, identified the bryophyte specimens, and performed the analyses of flora. TYuM and AAS took part in the field studies in 2009. NIF carried out the retrospective assessment of seasonal development of vegetation and surface temperature at Arkaulovskoye Mire using earth observation data and compared climatic conditions between Arkaulovskoye Mire and Nätsjöbäcken Mire in Sweden. TYuM provided information on peat deposit structure, EC and pH measurements, and helped to put the information on flora and vegetation into the context of mire science. EZB, AAM and NIF wrote different parts of the manuscript, which was compiled and edited primarily by TYuM. All authors discussed the results and contributed to the final version of the manuscript.

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Appendix

Table A1. Floristic composition of the different types of plant communities in the Natural Monument “Arkaulovskoye Mire”, Republic of Bashkortostan, Russia. Types: 1 = periodically flooded grey alder - bird cherry forest, 2 = sedge - reed birch and birch - alder forested mire, 3 = sparse pine and birch forested mire, 4 = moss - shrub dwarf pine forested mire, 5 = *Schoenus ferrugineus* - small sedges - brown mosses open mire, 6 = vegetation of pools, 6a = vegetation of streams. The indices in Columns 1–7 are average Braun-Blanquet cover-abundance scores calculated for each species per community type. Asterisks (*) indicate species that are included in the Red Data Book of Bashkortostan (Mirkin 2011), and double asterisks (**) are species that are listed in the Red Data Book of the Russian Federation (Bardunov & Novikov 2008).

Species name	Community types						
	1	2	3	4	5	6	6a
Vascular plants							
<u>Trees and shrubs</u>							
Alnus glutinosa (L.) Gaertn.	r	1					
Alnus incana (L.) Moench.		1	+	+	r		
Betula pendula Roth		4					
Betula pubescens Ehrh.		3	2				
Frangula alnus Mill.	r	2	1	+	r		
Humulus lupulus L.	2	r					
**Ledum palustre* L.			r	1	r		
Padus avium Mill.	2						
Picea obovata Ledeb.				r			
Pinus sylvestris L.			2	1	r		
Populus tremula L.		r					
Rhamnus cathartica L.	r	r					
Ribes nigrum L.	1	r					
Ribes spicatum Robson	r						
Rosa glabrifolia C. A. Mey. ex Rupr.		r					
Rosa majalis Herrm.	r	r					
Rubus idaeus L.	+						
Salix caprea L.		+					
Salix cinerea L.		+	r				
Salix rosmarinifolia L.		r	r	r	r		
Salix myrsinifolia Salisb.	+	r	r	r	r		
**Salix pyrolifolia* Ledeb.		r					
Sorbus aucuparia L.		r		r			
Viburnum opulus L.	r	+					

Species name	Community types						
	1	2	3	4	5	6	6a
<u>Herbaceous plants and dwarf shrubs</u>							
Aconitum septentrionale Koelle	r						
Aegopodium podagraria L.	1						
Agrostis gigantea Roth		r	r				
Agrostis stolonifera L.		r					r
Alisma plantago-aquatica L.							r
Angelica sylvestris L.	r	+					
Antennaria dioica (L.) Gaertn.	r						
Arctium tomentosum Mill.	r						
Artemisia absinthium L.	r						
Athyrium filix-femina (L.) Roth	1	r					
Brachypodium pinnatum (L.) P. Beauv.		1	r				
Calamagrostis arundinacea (L.) Roth		r					
Calamagrostis epigeios (L.) Roth		r	r				
Calamagrostis purpurea (Trin.) Trin.	r	r					
Cardamine amara L.	r						r
Carduus crispus Guirão ex Nyman	r						
Carex acutiformis Ehrh.							1
Carex appropinquata Schumach.	r	+					
Carex buxbaumii Wahlenb.			r	r	r		
Carex capillaris L.		r					
Carex cespitosa L.	r	1					
Carex diandra Schrank					r		
**Carex dioica* L.				+	+		
Carex juncella Th. Fries		+			r		
Carex lasiocarpa Ehrh.		r					
Carex panicea L.			+		+		
Carex pseudocyperus L.							r
Carex rhynchophysa C. A. Mey.	r	+					r
Carex rostrata Stokes							2
Catabrosa aquatica (L.) P. Beauv.							r
Catolobus pendulus (L.) Al-Shehbaz	r						
Cerastium davuricum Fisch. ex Spreng.	r						
Cirsium arvense (L.) Scop.	r	r					
Cirsium canum (L.) All.		r					
Cirsium heterophyllum (L.) Hill		+					
Cirsium oleraceum (L.) Scop.	r	+					

Species name	Community types						
	1	2	3	4	5	6	6a
***Cladium mariscus* (L.) Pohl					r		
Cuscuta europaea L.	+						
Cuscuta lupuliformis Krock.	r						
***Cypripedium calceolus* L.			r				
Dactylis glomerata L.	r	r					
Dactylorhiza fuchsii (Druce) Soó					r		
Dactylorhiza incarnata (L.) Soó			r				
**Dactylorhiza ochroleuca* (Wustnei ex Boll) Holub			r		r		
**Dactylorhiza russowii* (Klinge) Holub			r		r		
Delphinium elatum L.	r						
Deschampsia cespitosa (L.) P. Beauv.	+	r					
**Drosera anglica* Huds.				+			
Drosera rotundifolia L.				+			
Dryopteris carthusiana (Vill.) H. P. Fuchs	r	r					
Dryopteris cristata (L.) A. Gray	r						
Dryopteris filix-mas (L.) Schott	r						
Eleocharis quenqueflora (Hartmann) O. Schwarz			r		r		
Elymus caninus (L.) L.	+	r					
Empetrum hermaphroditum Hagerup				+			
Epilobium angustifolium L.		r					
Epilobium ciliatum Raf.	r						
Epilobium hirsutum L.							r
Epilobium palustre L.					+		
**Epipactis atrorubens* (Hoffm.) Besser.			r				
**Epipactis palustris* (L.) Crantz			+	1	r		
Equisetum arvense L.	r	r					
Equisetum palustre L.	r	r			r		
Eriophorum angustifolium Honck.			r		+		
Eriophorum latifolium Hoppe					r		
Eupatorium cannabinum L.							r
Euphrasia pectinata Ten.					+		
Festuca rubra L.		r					
Filipendula ulmaria (L.) Maxim.	1	2	r	r			
Galium boreale L.		+	r		r		
Galium mollugo L.		r					
Galium rivale (Sibth. et Sm.) Griseb.	+	r					
Galium uliginosum L.		+	r	+	r		

Species name	Community types						
	1	2	3	4	5	6	6a
Gentiana pneumonanthe L.		r					
Gentianopsis doluchanovii (Grossh.) Tzvelev					r		
Geranium palustre L.		r					
Geranium pratense L.		r					
Geranium sylvaticum L.		r					
Geum rivale L.	+	1					
Geum urbanum L.	+						
Glechoma hederacea L.	1						
**Gymnadenia conopsea* (L.) R. Br.			r				
***Gymnadenia odoratissima* (L.) Rich.			r				
Hedysarum alpinum L.		r		r			
**Herminium monorchis* (L.) R. Br.			r		r		
Hieracium umbellatum L.		r					
Impatiens noli-tangere L.	+						
Inula aspera Poir.			+	r	r		
Juncus articulatus L.					r		r
Kadenia dubia (Schkuhr) Lavrova et V. N. Tichom.		r					
Lathyrus palustris L.		r					
Lathyrus pratensis L.	r	r					
Lemna minor L.							r
Lemna trisulca L.							r
Leonurus quinquelobatus Gilib.	r	r					
Ligularia sibirica (L.) Cass.		+					
***Liparis loeselii* (L.) Rich.					r		
Lithospermum officinale L.	r	r					
Lycopus europaeus L.	r	r					r
Lysimachia europaea (L.) U. Manns et Anderb.		r					
Lysimachia thyrsiflora L.	r						r
Lysimachia vulgaris L.	r	+					
Lythrum salicaria L.							+
Maianthemum bifolium (L.) F. W. Schmidt		r					
Matteuccia struthiopteris (L.) Tod.	r						
Moehringia trinervia (L.) Clairv.	r						
Molinia caerulea (L.) Moench		2	3	2	2		
**Orchis militaris* L.		r					
**Ophrys insectifera* L.			r				
Parasenecio hastatus (L.) H. Koyama	r	r					

Species name	Community types						
	1	2	3	4	5	6	6a
Paris quadrifolia L.	r						
Parnassia palustris L.			+	r	r		
Pedicularis karoi Freyn				r	r		
Persicaria bistorta (L.) Samp.		r					
Phragmites australis (Cav.) Trin. ex Steud.		2	1	1	2	2	
**Pinguicula vulgaris* L.					r		
Poa nemoralis L.	r	r					
Poa palustris L.	r	r					
Poa pratensis L.		r					
Poa remota Forselles	r	r					
Poa trivialis L.	r	r					
Polemonium caeruleum L.		r					
Polygonatum odoratum (Mill.) Druce		r					
Potentilla erecta (L.) Raeusch.		+	1	1	+		
Pulmonaria mollis Wulfen ex Hornem.	r	r					
Pyrola rotundifolia L.		+	r	+			
Ranunculus repens L.	r						
Rubus saxatilis L.	r	2	1	+	r		
Sanguisorba officinalis L.		+	+	r	+		
Saussurea parviflora (Poir.) DC.		2					
Schoenoplectus tabernaemontani (C.C. Gmel.) Palla		r			r		
**Schoenus ferrugineus* L.			1		2		
Scutellaria galericulata L.		r					r
Selinum carvifolia (L.) L.		r					
Senecio nemorensis L.	r						
Silene baccifera (L.) Roth	r						
Solanum kitagawae Schonbeck-Temesy	+						
Stachys palustris L.							r
Stellaria aquatica (L.) Scop.	r	r					r
**Stuckenia filiformis* (Pers.) Börner				1		r	r
Succisa pratensis Moench		r	1		r		
Thalictrum flavum L.		r					
Triglochin maritima L.					r		
Triglochin palustris L.					r		
Tussilago farfara L.							+
Typha latifolia L.							r
Urtica dioica L.	2						r

Species name	Community types						
	1	2	3	4	5	6	6a
Utricularia intermedia Hayne				r			
**Utricularia minor* L.						+	
Utricularia vulgaris L.				1		r	
**Vaccinium microcarpum* (Turcz. ex Rupr.) Schmalh.			r	1			
Vaccinium oxycoccos L.				1	r		
Vaccinium uliginosum L.		r	1	2	r		
Vaccinium vitis-idaea L.		r	r	2			
Valeriana officinalis L.		r					
Veronica anagallis-aquatica L.							r
Vicia cracca L.		+	+	r	r		
Viola epipsila Ledeb.	+	r					
Total number of vascular plants:	69	95	42	34	45	4	24
Bryophytes							
Liverworts							
Aneura pinguis (L.) Dumort.				r	r		r
Blepharostoma trichophyllum (L.) Dumort.		+					
Cephalozia bicuspidata (L.) Dumort.				r			
Cephaloziella hampeana (Nees) Schiffner ex Loeske		r					
Cephaloziella rubella (Nees) Warnst.		r					
Chiloscyphus pallescens (Ehrh.) Dumort.	r	r					
Chiloscyphus polyanthos (L.) Corda		+					
Fuscocephaloziopsis connivens (Dicks.) Váňa et L.Söderstr.				r			
Fuscocephaloziopsis lunulifolia (Dumort.) Váňa et L.Söderstr.		r					
Fuscocephaloziopsis pleniceps (Austin) Váňa et L.Söderstr.				r			
Lepidozia reptans (L.) Dumort.		r					
Lophocolea heterophylla (Schrad.) Dumort.	+	+					
Lophocolea minor Nees		+					
Lophozia ventricosa (Dicks.) Dumort.		r					
Mylia anomala (Hook.) Gray				r			
Odontoschisma denudatum (Mart.) Dumort.		r					
Pellia endiviifolia (Dicks.) Dumort.					+		+
Ptilidium pulcherrimum (Weber) Vain		+					
Riccardia chamedryfolia (With.) Grolle				r			
Syzygiella autumnalis (DC.) K.Feldberg, Váňa, Hentschel et Heinrichs		r					

Species name	Community types						
	1	2	3	4	5	6	6a
<u>Mosses</u>							
Amblystegium serpens (Hedw.) Schimp.	+	+					
Aulacomnium palustre (Hedw.) Schwägr.		+	+	2		+	
Brachythecium capillaceum (F. Weber et D. Mohr) Giacom.	r	r			r		
Brachythecium mildeanum (Schimp.) Schimp.	+	+					
Brachythecium rivulare Schimp.		r					
Brachythecium salebrosum (Hoffm. ex F. Weber et D. Mohr) Schimp.	+	+					
Breidleria pratensis (W. D. J. Koch ex Spruce) Loeske		+					
Bryum bimum (Schreb.) Turner		r					
Bryum capillare Hedw.		r					
Bryum pseudotriquetrum (Hedw.) P. Gaertn., B. Mey. & Scherb.	+	+		+	+	+	+
Callicladium haldanianum (Grev.) H. A. Crum	+	+					
Calliergon giganteum (Schimp.) Kindb.						r	
Calliergonella cuspidata (Hedw.) Loeske	+	r					
Campyliadelphus chrysophyllus (Brid.) R. S. Chopra					r		
Campylidium sommerfeltii (Myrin) Ochyra	r	r					
Campylium stellatum (Hedw.) Lange et C. E. O. Jensen		+	+	r	4	+	r
Ceratodon purpureus (Hedw.) Brid.		+			r		
Climacium dendroides (Hedw.) F. Weber et D. Mohr	r	+					
**Conardia compacta* (Drumm. ex Müll. Hal.) H. Rob.		r					
Cratoneuron filicinum (Hedw.) Spruce	r						+
Dicranum bonjeanii De Not		r		r			
Dicranum flagellare Hedw.		r					
Dicranum montanum Hedw.		+					
Dicranum polysetum Sw. ex anon				r			
Dicranum scoparium Hedw		+					
Distichium capillaceum (Hedw.) Bruch et Schimp.		r					
Distichium inclinatum (Hedw.) Bruch et Schimp.		r					
Drepanocladus aduncus (Hedw.) Warnst.	r	+					
Drepanocladus polygamus (Schimp.) Hedenäs		r	+		+		
Fissidens adianthoides Hedw.			r		r		+
Fissidens osmundoides Hedw.					r		
Funaria hygrometrica Hedw.					r		
**Hamatocaulis vernicosus* (Mitt.) Hedenäs						r	
Helodium blandowii (F. Weber et D. Mohr) Warnst.				+			
Hygroamblystegium humile (P. Beauv.) Vanderp., Hedenäs et Goffinet	+	r					

Species name	Community types						
	1	2	3	4	5	6	6a
Hylocomium splendens (Hedw.) Schimp.				r			
Hypnum pallescens (Hedw.) P. Beauv.		+					
Leptobryum pyriforme (Hedw.) Wilson		+			r		
Leskea polycarpa Hedw.	+						
Mnium stellare Hedw.		r					
**Paludella squarrosa* (Hedw.) Brid.				+		r	
Plagiomnium cuspidatum (Hedw.) T. J. Kop.	+	+			r		
Plagiomnium ellipticum (Brid.) T. J. Kop.	+	+					
Plagiomnium rostratum (Schrad.) T. J. Kop.	r	+					
Plagiothecium denticulatum (Hedw.) Schimp.	r	+					
Plagiothecium laetum Schimp.		+					
Platygyrium repens (Brid.) Schimp.		r					
Pleurozium schreberi (Willd. ex Brid.) Mitt.		+		2			
Pohlia nutans (Hedw.) Lindb.		+	+				
Pseudoamblystegium subtile (Hedw.) Vanderp. et Hedenäs	r						
Pseudoleskeella nervosa (Brid.) Nyholm	r						
Pylaisia polyantha (Hedw.) Schimp.	+	r					
Rhytidiadelphus triquetrus (Hedw.) Warnst.		r		+			
Sanionia uncinata (Hedw.) Loeske		+					
Sciuro-hypnum curtum (Lindb.) Ignatov	r						
Sciuro-hypnum reflexum (Starke) Ignatov et Huttunen	+	r			r		
Scorpidium cossonii (Schimp.) Hedenäs				+	4	+	+
Scorpidium scorpioides (Hedw.) Limpr.					r		
Sphagnum angustifolium (Warnst.) C.E.O. Jensen				+			
Sphagnum capillifolium (Ehrh.) Hedw.		1		+			
Sphagnum fuscum (Schimp.) H. Klinggr				2			
Sphagnum subsecundum Nees				1			
Sphagnum warnstorfii Russow			+	2			
Straminergon stramineum (Dicks. ex Brid.) Hedenäs						r	
Tetraphis pellucida Hedw.		+					
Thuidium recognitum (Hedw.) Lindb.		r					
Tomentypnum nitens (Hedw.) Loeske		r	1	2	2	+	
Total number of bryophytes:	24	58	7	22	16	9	6
Total number of plant species:	93	153	49	56	61	13	30