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ON THE GROWTH OF *PLEUROZIUM SCHREBERI* (BRYOPHYTA) IN MOSCOW PROVINCE

О РОСТЕ *PLEUROZIUM SCHREBERI* (BRYOPHYTA) В МОСКОВСКОЙ ОБЛАСТИ

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Abstract

Four-year observation on growth of *Pleurozium schreberi* in Moscow Province and nearby are summarized. The species is characterized by explosive growth in the periods of continuous rains, whereas dew and even short-term strong rains do not affect its growth. In rainy periods within 3-5 days the increment sometimes exceeds 10 mm. Obtained data of annual increment of 16-75 mm are much higher than previously reported values for this species. Autumn growth is continuous before the temperature drops below +5°Ñ, whereas in spring the growth delays up to and during late May and June. Growth in different habitats differs in its values, but the overall pattern of increment dynamics is the same.

Резюме

По данным четырехлетних наблюдений *Pleurozium schreberi* в Московской области характеризуется быстрым ростом, который происходит в периоды продолжительных дождей, в то время как роса и кратковременные дожди существенно не отражаются на росте вида. В дождливые периоды за 3-5 дней линейный прирост стебля может составить более 10 мм. Полученные нами величины годичных приростов этого вида составляют 16-75 мм в год, что значительно превышает таковые, полученные предыдущими исследователями. Осенью рост мха продолжается до тех пор, пока температура не опустится ниже 5°С, но начало роста после стаивания снега весной начинается только после значительной паузы, в самом конце мая или июне. Освещенность и влажность местообитаний влияют на величины приростов, но общий характер их динамики в разных биотопах следует общим закономерностям.

KEYWORDS: *Pleurozium schreberi,* annual increment, drought tolerance, Moscow Province

INTRODUCTION

Mosses are drought-tolerant plants, with water content strongly varying following the environmental condition. In dry state their metabolism is strongly reduced and growth is almost stopped. The data on these dynamics, however, are not satisfactorily known, as most publications characterize moss growth mainly by the annual increment.

Pleurozium schreberi (Brid.) Mitt. is one of the most common pleurocarpous mosses in conifer and mixed forest in the central European Russia, often developing extensive carpets on soil in conifer forests, occasionally occurring also on rotten logs and tree bases (Ignatov & Ignatova, 2004). Ermolaeva & Shmakova (2013) demonstrated that the species is loosing up to 42% of its water content. Annual increment of *Pleurozium schreberi* has been studied in Russia by a number of authors, mostly in the northern regions, including the subarctic (Korchagin,1960; Tarkhova, 1969; Borisova & Mirin, 2007; Shpak & Shmakova, 2010; Ermolaeva, 2012).

The aim of the present study was to correlate the growth of *Pleurozium schreberi* with temperature and precipitation in Moscow Province, in the hemiboreal zone where summer weather is variable, and some years have long dry periods. The precipitation distribution within the year is often quite uneven.

Another motivation of the study was understanding the age of the plant from its structure (Fig. 1). Having a number of visually different zones, it is an intriguing question how many of them appear within one year. The closely related *Hylocomium splendens* is well-known to form a single "floor" per year, but for of *Pleurozium* this is obviously not the case, as most shoots have up to six zones, *i.e.* apparently more than the longevity of moss body survival in the forest environment.

MATERIAL AND METHODS

The main block of the increment measurements throughout the whole vegetation season has been done in Shchelkovo Distr. of Moscow Prov. (55°53'00.17"N; 38°05'17.57"E). Supplementary observations were

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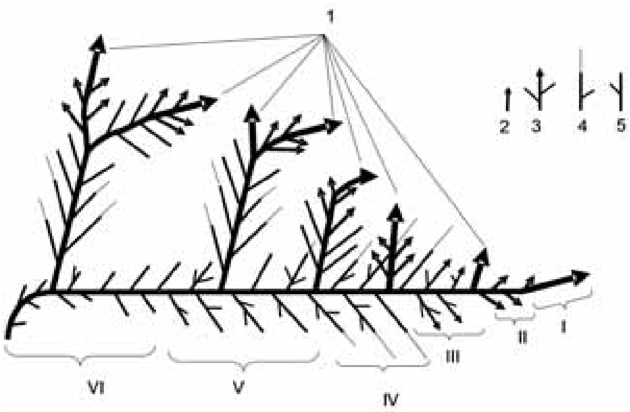


Fig. 1. Scheme of *Pleurozium schreberi* shoot system; the following zones can be recognized (in Roman numerals below them): I – distal unbranched part; II – zone of young growing and unbranched branches that have not reached their average length; III – zone of full length branches, mainly terminated their growth, often with singular branches of secondary order; IV – zone of bracnhes with attenuate apices; V – zone of bracnhes with broken off apices; VI – zone of decaying brownish branches. 1 – primary modules that arose from the main stem, showing different stages; 2 – young growing branches; 3 – branched branches; 4 – branches with attenuate apices; 5 – branches with broken apices.

done in Konakovo in neighboring Tver Prov. (56°34’40.83"N; 36°43’00.33"E) and Kaluga Prov. (54°13’36.92"N; 34°13’13.49"E), and in Zelenograd in another district of Moscow Prov. (55°59’53.32"N 37°10’27.46"E) (Table 1).

The first observation of increment dynamics in 2010 showed that dry periods result in no linear increment at all during about two months. Subsequently, in dry periods measurements were less frequent, but in rainy weather they were done at 3-5 day intervals. On average 3-5 measurements were done every month by ruler with the accuracy of 1 mm.

Two to four contrasting habitats were explored in Shchelkovo in 2011-2013, and two ecologically different places were in the focus of the study in Konakovo, Tver Province (see details in Table 1).

The increment has been measured using the method of bending with colored plastic “threads,” ca. 2 mm wide, obtained by a splitted material used for bending flowers by florists doing bouquets. Marks were put on shoots in spring, before the growth starts, at 2 mm from the shoot apex. Multi-colored threads allow the increment measuring for each individual shoot (Fig. 2). Up to 15 shoots per one tuft can be marked this way.

Day and night temperatures were taken from http://www.gismeteo.ru for Shchelkovo (with partial checking, *in situ*, which, however, showed no difference) and precipitation was recorded by ourselves, and for the present analysis days were simply sorted between rainy and not rainy (cf. Fig. 3).

To evaluate habitat effect on moss, 25 shoots from each of four habitats in Shchelkovo, and 17 shoots from each of four habitats in Konakovo were studied for: (1) number and length of branches; (2) number of branched branches; (3) number of primary module axes arising from the stems. These counts were done on the interval 2 cm long at 1.0-1.5 cm from the shoot apex.

Stem leaf measurements were done in water slides for 382 leaves from shoots from contrasting environments: 15 shoots from four contrasting habitats; in each shoot 5-8 leaves from ca. 2 cm from apex were measured using Keyence Digital Miscoscope in water slides with the accuracy 0.01 mm. The data analysis was performed in STATISTICA 8.0.

Fig. 2. Annual increments in *Pleurozium schreberi*. 1 – branches; 2 – unbranched distal part of primary module that arose from the main stem; 3 – variously developed primary module that arose from the main stem; parts above white strips are increments of 2012. Plants collected in late October 2012.

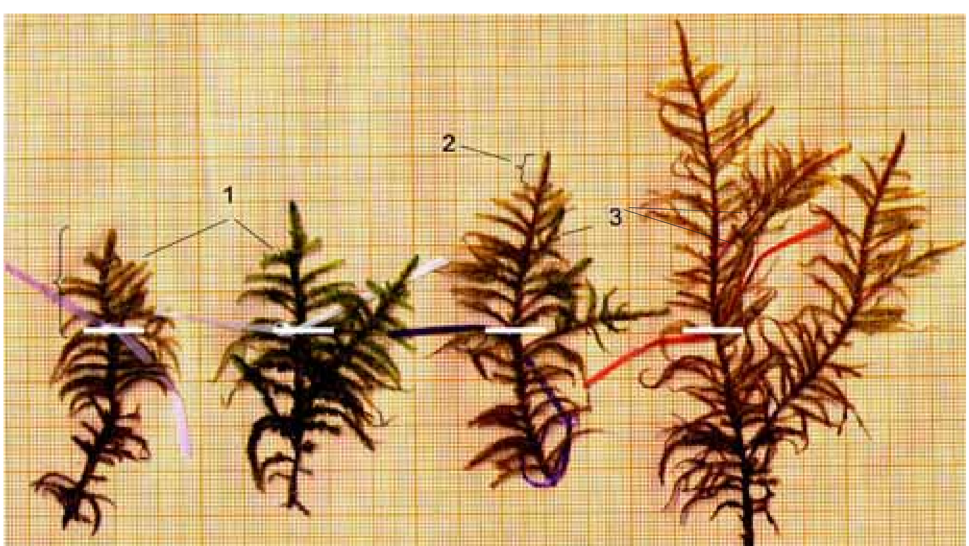


Table 1. Localities, habitats, years of observations, number of measured shoots for various datasets and annual increment (mean ±sigma / min–max, mm).

Locality	Forest type	Habitat	Year(s)	Number of shoots studied for:			Annual increment	
				Annual increment	Increment dynamics	Shoot morpho	2012	2013
Shchelkovo1	*Pinus+Picea*	Under pine on sandy hill	2010	25	15	—		
		with *Festuca ovina, Antennaria*	2011	25	15	—		
		dioica, sunny, very dry	2013	25	15	—		20.6±0.5/17-25
Shchelkovo2	*Pinus+Picea*	Under pine on sandy slope	2012	25	15	25	24.0±0.7/16-31	
		partial shade, rather dry	2013	25	15	25		23.7±0.9/20-31
Shchelkovo3	*Pinus+Picea*	Under spruce, with *Vaccinium*	2011	25	15	25		
		myrtillus, shady, rather moist	2012	25	15	25	32.6±0.8/25-40	
			2013	25	15	25		34.5±0.8/28-43
Shchelkovo4	*Pinus+Picea*	Under pine and *Sorbus*, with						
		Vaccinium myrtillus, half-	2012	25	15	25	48.1 ± 0.8/40- 55	
		shady and moderately moist	2013	25	15	25		46.2±1.0/41-56
Shchelkovo5	*Pinus+Picea*	Under *Rubus idaeus,* among	2012	25	—	25	58.9 ± 1.4/45-71	
		grasses, sunny, quite moist	2013	25	—	25		64.4±1.8/55-75
Konakovo1	*Betula* swamp	*Betula* stump, wet	2012	17	—	17	33.9 ± 1.5/25-50	
Konakovo2	*Betula+Picea*	*Betula* stump, dry sunny side	2012	17	—	17	23.1 ± 0.7/18-26	
Konakovo3	*Betula*, wet	*Betula* stump, sunny side	2012	17	—	17	34.8 ± 0.8/30-41	
Konakovo4	*Betula*, wet	same stump, shady side	2012	17	—	17	28.4 ± 0.6/24-32	
Zelenograd	*Picea*	*Picea* stump, rather wet	2012	17	—	17	30.9±0.6/27-34	

Results

Annual increment

Our measurement revealed that the annual increments of *Pleurozium schreberi* range from 16 to 75 mm a year, depending on habitat and being the largest on a relatively wet, rather well lighted place under *Rubus idaeus* canopy. The data obtained in 2012-2013 are summarized in Table 1. Somewhat incomplete data from other years and partly from other places, for whole year or only shorter periods, are as follow: 8-10 mm (up to August) on rather xeric sandy hill in 2010; 10-14 in the same place in 2011 (up to mid-September); 25-30 mm near that place under spruce canopy; 45 mm also nearby on strongly rotten log. In the beginning of June 2009, in the Kaluga locality the first start of growth results in 4-7 mm increment during five rainy days only; interestingly, in the subsequent seven days with the same weather conditions, the growth was stopped totally.

Dynamics of increment within the vegetation period

Year 2010

May of 2010 was rather warm, with rains in its beginning and up to mid June. From late June, the anomalous dry and hot weather continued two month, up to third ten-day period of August.

Plants of *P. schreberi* on sandy hill, in the dry and sunny habitat, grew in late May and early June, and then having no increment up to rainy end of August.

Year 2011

The spring weather was warm and rather dry, without several days' rains. Summer was hot, with abundant rains in the second half of June. After that was a rather dry period, with a number of short-time rains, associated with high air temperature, abundant continuous rains started in the third ten-day period of August. The temperature remained rather high up to mid-September and it was also quite rainy.

Pleurozium schreberi started its growth in 2011 only in the middle of June. In July and up to mid-August no linear increment was detected, likely because of rather short-time rains. Interestingly, abundant dew in the morning also did not affect any growth, neither on sandy dry and sunny hill, nor under spruce canopy. The drying in hot condition of that period seemed to be too fast.

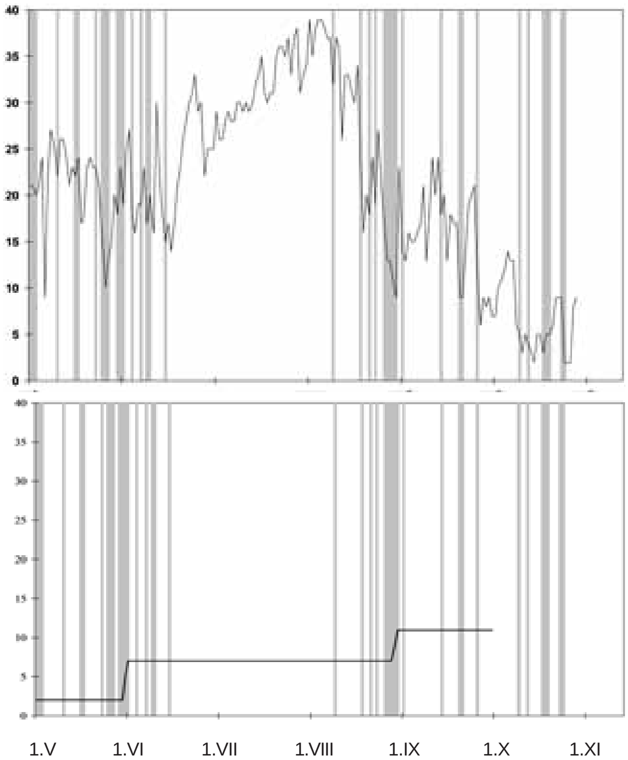
Rainy weather since mid-August caused shoot growth under the spruce canopy, while the sandy hill' population remained in a lag-phase, probably due to faster drying in the latter place comparatived to the habitat under spruce canopy.

Rainy weather in the second ten-day period of September resulted in the growth in both populations, under spruce and on the sandy hill.

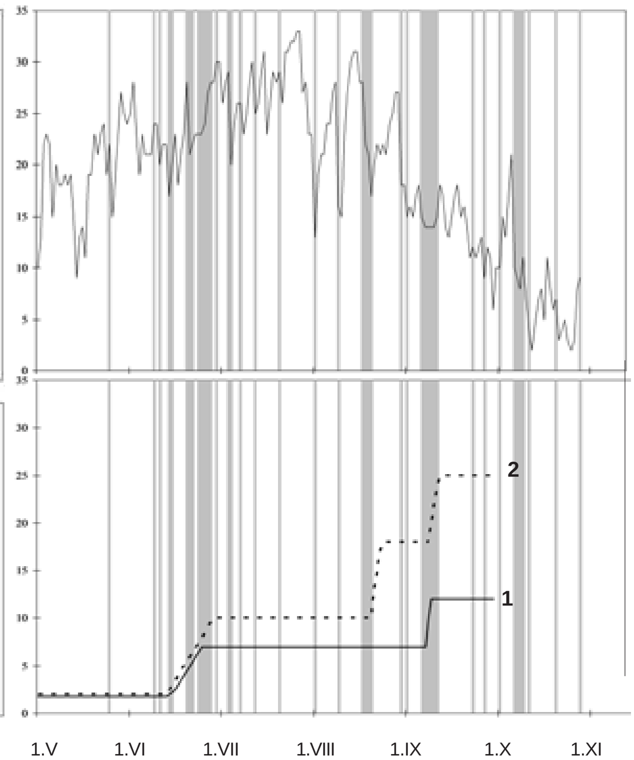
Year 2012

The end of May and summer were in general warm and rainy. Rain fell in early May, late May to early June, and with a short break then to mid June. The period from mid-June to mid July was dry, and then after mid-July rains, another dry period up to mid-August took place. Infrequent short-time rains within dry periods did not change the overall dry condition, with fast plant drying from the morning dew. After mid-August, rains were numerous, with rather short interruptions.

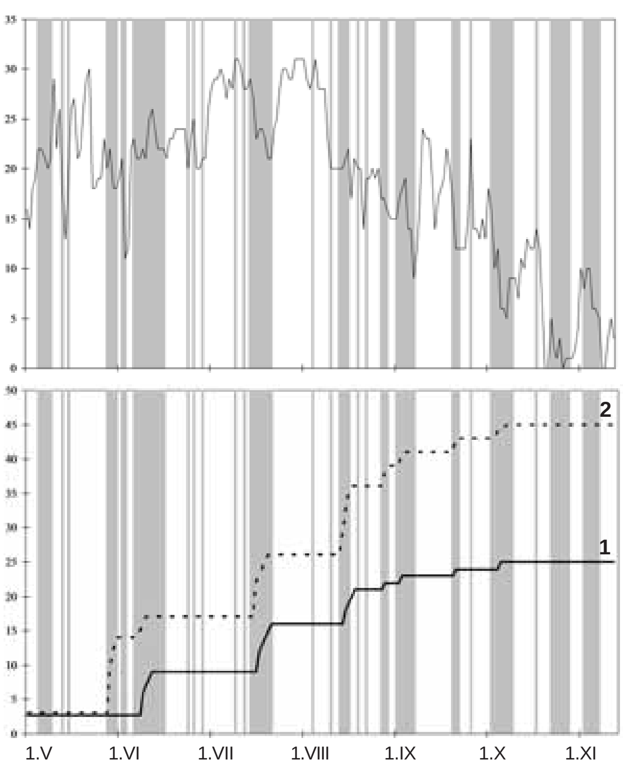
In rainy early May 2012 day temperatures were rather high and night temperatures did not drop below +10°Ñ; nevertheless, no growth was detected in the two studied populations. Shoot growth started in pine-blueberry forest in rainy late May, resulting in a 10 mm increment



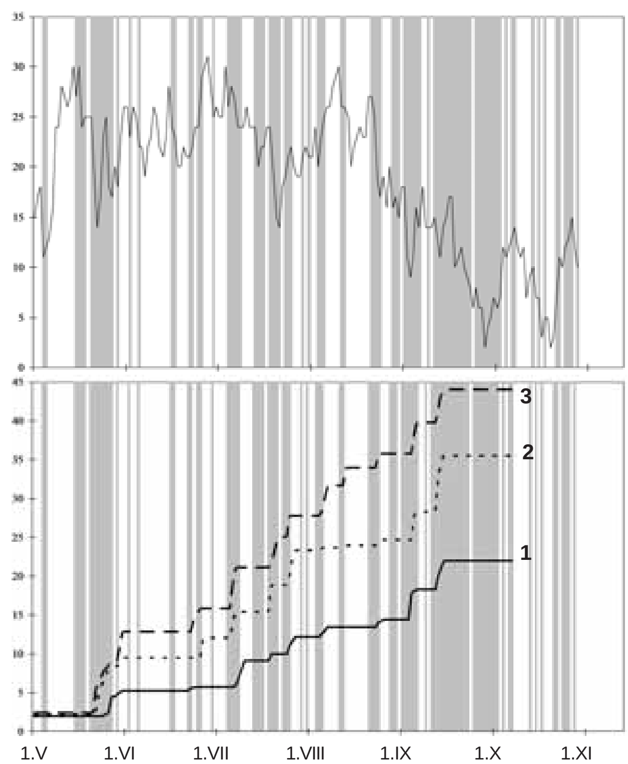
Year 2010. Growth on dry sandy hill.



Year 2011. Growth on dry sandy soil under pine (1) and under spruce canopy, shady and moderately dry (2).



Year 2012. Growth on dry sandy soil under pine (1) and under pine and *Sorbus* canopy, moderately shady and moist (2).



Year 2013. Growth on dry sandy soil under pine (1), under spruce canopy, shady and moderately dry (2) and under pine and *Sorbus* canopy, moderately shady and moist (3).

Fig. 3. Four-year observation on *Pleurozium* growth. Line in upper graphs shows temperature, °C (values at axis Y) and rainy days (shaded in all graphs). Lines in lower graphs show *Pleurozium* growth, mm (values at axis Y).

Table 2. Localities, habitats, years of observations, number of measured shoots for various datasets and annual increment (mean ±sigma / min–max, mm); n=25 in Shchelkovo localities, n=17 in Konakovo.

Locality	Habitat	Annual increment,mm	New branches, N	Branch length,mm	Branched branch, N	New primary modules, N
Shchelkovo2	partial shade, dry	24.0±0.7/16-31	14±0.4/8-18	11.6±0.3/3-23	4.6±0.6/1-9	1.2±0.1/0-3
Shchelkovo3	sunny, rather dry	32.6±0.8/25-40	11.7±0.4/8-15	10.2±0.2/3-21	1.4±0.3/0-5	0.6±0.2/0-3
Shchelkovo4	shady, rather dry	48±0.8/40-55	13.8±0.3/12-20	14.6±0.3/3-26	5.3±0.5/2-13	1.1±0.2/0-3
Shchelkovo5	moderately shady and moist	58.9±1.4/45-71	13.8±0.5/10-22	12.8±0.2/4-20	7.7±0.5/5-16	0.4±0.1/0-2
Konakovo3	shady, rather dry	34.8±0.9/30-41	13.5±0.3/11-16	13.5±0.4/3-28	7.1±0.6/3-12	0.2±0.1/0-1
Konakovo4	moderately shady and moist	28.4±0.6/24-32	12.8±0.4/10-17	12.5±0.3/3-29	3.6±0.5/1-7	0.5±0.1/0-1

within a few days. Later their growth continued, but much less intensely. More active growth re-appeared in a mid-July rainy period, as well as in a mid-August rainy period. Later on, slow growth continued up to September and a small increment took place even in the first half of October, when night temperatures remained above zero.

There was a small difference in the sandy hill population. Its plants started to grow later, in early June. The remaining profile (Fig. 3) was essentially the same as for the spruce forest' population, being different mainly in a proportionally smaller increment.

Year 2013

Late spring, middle and late summer and early autumn of 2013 were very rainy. However, in late June rain showers were mostly short, whereas in July short rain alternated with longer storms, lasting usually a whole day or a few days. A relatively dry beginning of August changed in the end of the month to cool and wet weather, which continued in September.

Pleurozium schreberi shoots started to grow in the last days of May. In five days, up to May 30, their increment was 3-5 mm on the sandy hill, 7-8 mm in the spruce forest with *Vaccinium myrtillus*, and 8-11 mm in the pine forest with *Vaccinium myrtillus*. As June rains were rather short and mosses dried up quite quickly, their growth was limited in wetter forests with blueberries, while totally stopped on dry the sandy hill. More extensive July rains resulted in greater growth; subsequent equally strong rains in mid and late July also supported *Pleurozium* growth, but it was not that intensive as in the beginning of July. In the main part of August the growth continued, but still slower than in July, but starting in late August intensive growth occurred, with one interruption in mid-September after a dry period of a few days.

Winters

No growth was detected in the period from the end of October 2011 until the end of May 2012. In 2012 the growth stopped in mid-October, after day temperatures dropped to 5°Ñ. After that, no growth occurred up to the end of May 2013.

Supplementary observation

In addition to linear increment in 2013, four populations from different environments were studied for the several branch parameters (Table 2).

The branch number was minimal in the population #2 in dark and mesic habitat. Three other populations in sunny to diffusely lightened and mesic to xeric habitats have approximately the same number of branches (Table 3). Mesic and diffusely lightened population, #3, had the longest branches, up to 2.6 cm. However this elongation correlated with branch tip attenuation, associated with thinning of distal part of branch and decrease of leaf length, especially near its tip.

Long branches have been developed also in population #4, in wet and sunny places, however in this case distal part of branches often were broken off, thus the overall branch length has been not longer than in #3, although this comparison based on non-intact branches can not be assumed as comprehensive. The maximal number of sympodially growing “primary modules” were detected in population #1, (dry, diffusely lightened), which had, at the same time, the minimal annual increment (Table 2).

The smallest increments, 16-31 mm, were found in dry and moderately shaded places, whereas the maximal values were in wet and sunny habitats, under *Rubus idaeus* canopy (Tables 1-2). The latter site also was characterized by the maximal number of branched branches, whereas the least branching was observed in dark and moderately wet places (cf. Table 2).

Ecological conditions may affect growth parameters even in very closely situated samples. Table 2 (Konakovo sites) shows data from two sides, exposed and shady, of the same stump in mesic to wet *Betula* forest. Plants from the sunny side have longer annual increments and a higher number of branched branches, but a lower number of new primary modules. At the same time the branch number and branch length do not differ.

Preliminary observation showed that the leaf length and width may vary in different environments. The typical case is that inside the dense tuft, the plant develops longer and narrower axes with smaller leaves. To avoid this effect, the plants for leaf measurements were selected from similar conditions in respect to inner/outer part of the tuft. In this case the obtained difference (cf. Fig. 4) more likely performs the effects of general ecological

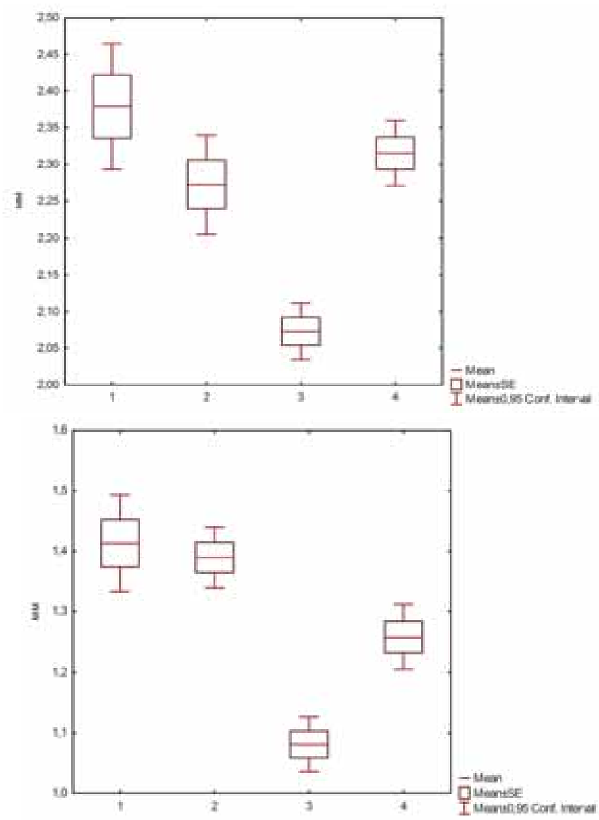


Fig. 4. Length (above) and width (below) of *P. schreberi* leaves (n=382) from Shchelkovo localities №1 (dry, moderate shade); №2 (dark, moderately wet); №3 (sunny, wet), №4 (half-shade, moderately wet).

conditions. The plants from well lighted and humid environments are contrastingly different in having smaller leaves, both in their length and width. Interestingly, the largest leaf size has been found in moderate shady and relatively dry habitat (population #1).

In addition, the population #3, with smallest leaf size, differs from others in more remotely arranged leaves, with the lower number of leaves in the interval between two branches (Fig. 5), although this fact was not considered to be studied from the beginning, and the available data are scarce and cannot support this statistically.

The overall green 'living' part of shoots in *Pleurozium schreberi* is 3-6(-7) cm in the study area. In our samples, the slowly growing population #1 in the autumn still has 'living appearance' for the whole previous year of growth and some of the year-before-previous' parts. However, in intensively growing population #4, the previous year portion to the autumn got partly or even totally brownish.

DISCUSSION

Our data illustrate that annual increment in *Pleurozium* is higher than previously reported. We found it to be 24-59 mm a year in 2012-2013, whereas it has been previously reported to be 5-7 mm in Leningrad Province (Tarkhova, 1969), 15-17 mm in forest belt of Khibiny Mts. in Kola Peninsula (Shpak & Shmakova, 2010), 13-18 mm for the North Ural foothills in Pechoro-Ilych State Nature Reserve (Korchagin, 1960), 16-19 mm for Moscow Province (Borisova & Mirin, 2007). Although the increment may vary among years, which is especially well demonstrated for Sphagna (Boch & Mazing, 1979; Ilomets, 1981; Maksimov, 1982; Knorre & Vaganov, 2005; Knorre *et al.*, 2007; Spak & Shmakova, 2010), none of the published values approaches what was found in the present study.

The present observations agree with published data on different moss species that the day temperature close to 0°C inhibits moss growth (Grabovik, 1994, 2002; Knorre & Vaganov, 2005; Spak & Smakova, 2010). Also, the late start of *Pleurozium* growth agrees with Raeymaekers & Glime (1986) data in Michigan, where delay up to July is explained by the recovering ability for photosynthesis after the long winter. Ermolaeva (2012) found that *Pleurozium* starts to grow in the forest belt of Khibiny Mountains of Kola Peninsula in June, although very slowly. In the Moscow area the growth starts in late May or first half of June, always after about 1.5-2 month delay after the snow melts, when daytime temperature is approaching the summer value.

The fact of explosive growth in *Pleurozium schreberi* was noted by Grime *et al.* (1990). We also observed explosive growth. It has been especially pronounced in rainy periods after many days of hot and dry weather. This species tolerates long dry periods, like the 2010 summer, when after two-month-long anabiosis in dry and exposed habitats, its shoots gave increments comparable with those found in these plants in much more rainy 2011, and about only half as much as in 2012 and 2013.

In the Moscow region long rains are the most important factor for promoting growth of *P. shcreberi*, but in the case of long-lasting rains, explosive growth at the beginning of the rainy period decreases after several days up to a complete stop. Short rains and abundant dew provide almost no contribution to the apparent length increment, although these periods may be also important for preparation for explosive elongation.

Literature presents controversial data on dependence of moss growth on precipitation. Ilomets (1981) indicates that Sphagna do not depend on it, whereas according to Grabovik (1994, 2002) maximal growth of *Sphagna* correlate with the annual rainfall; however, Boch & Kuzmina (1994) and Spak & Shmakova (2010) found this is not true for all peat-moss species. Goncharova & Ben'kov (2005) and Knorre & Vaganov (2005) reported that the linear increment in hollows is not necessarily higher than in hummocks, as overflooding (waterlogging) may decrease the growth as well. Our results indicate considerable difference among the studied habitats (Tables 1-2, Fig. 3), whereas in all cases the general pattern of increment within each year has been ruled by weather in principally parallel ways. However, limited growth in some shorter period may be small in unfavorable conditions, causing a

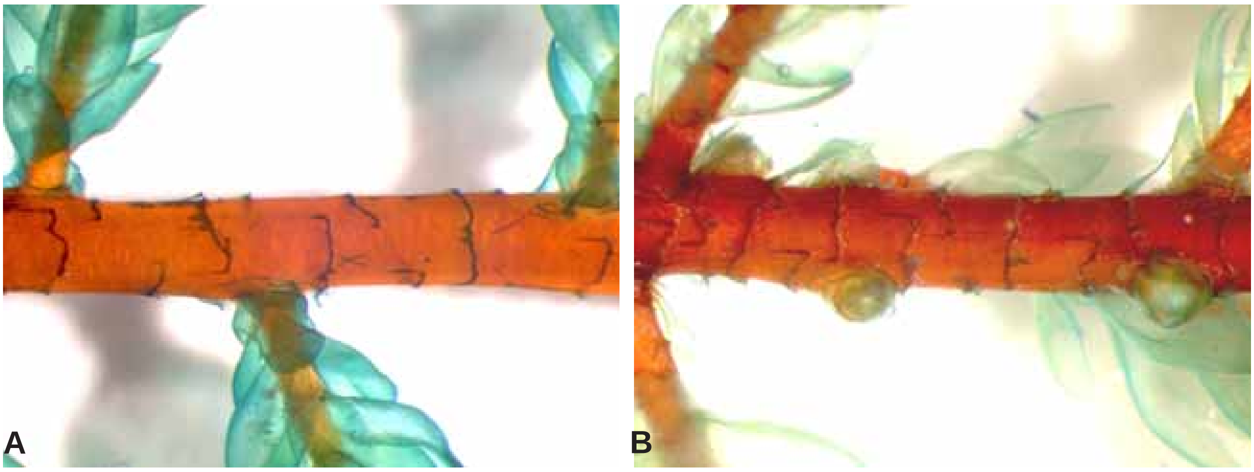


Fig. 5. Lines of leaf bases after leaf detaching, showing their more distant position in mesic and rather sunny environment (A, under *Rubus idaeus* canopy) than on a rather dry and sunny sandy hill (B, open pine forest).

smaller number of zones of visible growth. For example, in 2013 plants from the sandy hill had three such zones, not four as under spruce and shrub canopy (Fig. 3).

The moss growth dependence from the environmental parameters was discussed in several studies (Boch & Mazing, 1979; Ilomets, 1981; Knorre & Vaganov, 2005; Goncharova & Ben'kov, 2005; Goncharova, 2006). Maximal increment of *Pleurozium schreberi* in the forest belt of Khibiny in Kola Peninsula has been found in 2nd and 3rd ten-day periods of July, characterized by warm and humid weather (Ermolaeva, 2012). Contrary to that in the oceanic climate of British Columbia Asadaa et al. (2003) reported growth of *Pleurozium* in winter-time and dependence on precipitation in summer-time, the latter being similar to our results while colder ca. 8-9 months provide almost no contribution.

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