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ON THE GROWTH OF *POLYTRICHUM, PLEUROZIUM* AND *HYLOCOMIUM* IN THE FOREST BELT OF THE KHIBINY MOUNTAINS

О РОСТЕ МХОВ *POLYTRICHUM, PLEUROZIUM* И *HYLOCOMIUM* В ЛЕСНОМ ПОЯСЕ ХИБИН

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Abstract

Growth of three moss species (*Polytrichum commune, Hylocomium splendens, Pleurozium schreberi*) in the forest belt of the Khibiny mountains is examined in detail. Data on the annual linear increment and its dynamics within two years, growth rate, their dependence on habitat conditions and main environmental factors are presented. The linear increments are found to be almost the same in two years with different weather conditions, being 28-33 mm/year in *P. commune*, 20-35 mm/year in *H. splendens* and 8-14 mm/year in *P. schreberi*. *Pleurozium* started growth later than the two other species, whereas in the autumn *Polytrichum* was the first of the three species stopping its growth. The maximum growth rate was observed in the periods of sufficient moisture with air temperature 11-17°C. The growth rates in the autumn decreased ceasing when the air temperature was 6°C and lower. The growth of endohydric *P. commune* is maximal in open areas in forest meadows, whereas for ectohydric mosses *H. splendens* and *P. schreberi* the most favorable conditions were openings between trees.

Резюме

Детально исследован рост трех видов мхов *(Polytrichum commune, Hylocomium splendens, Pleurozium schreberi)* в лесном поясе Хибин. Получены данные о сезонных изменениях длины годичных приростов, скорости роста, их зависимости от условий обитания и основных факторов окружающей среды среды. Линейные приросты мхов, растущих в схожих условиях в разные годы, оказались близкими. В конце вегетации длина прироста у *P. commune* составила 28-33 мм, у *H. splendens* – 20-35 мм, у *P. schreberi* – 8-14 мм. Осенью *P. commune* прекращает рост раньше, чем *H. splendens* и *P. schreberi*. Максимальную скорость роста наблюдали в условиях достаточного увлажнения при температурах воздуха 11-17°C. При температуре воздуха 6°C и ниже, скорость роста составляла всего 0.1-0.2 мм в сутки или рост прекращался. Максимальные показатели роста эндогидрильного мха (*P. commune*) наблюдали на открытых участках лесного пояса, эктогидрильных мхов (*H. splendens* и *Pl. schreberi*) - в просветах крон деревьев.

KEYWORDS: *Polytrichum commune, Hylocomium splendens, Pleurozium schreberi*, mosses, annual increment, growth rate

Introduction

The studies of moss growth patterns are difficult due to small plant size and lack of obvious annual increment markers. At the same time, the significant role of mosses in the productivity of plant communities of mountain-tundra of Khibiny (Shmakova *et al.*, 2008) identifies the need for detailed study of the growth of the dominant species, depending on environmental factors and habitat conditions. Measurement of linear growth in the opinion of some authors can give a true picture of moss productivity (Rincon & Grime, 1989; Zechmeister, 1995; Stark *et al*., 2001). The first data on the values of the moss linear growth in the Khibiny Mountains were published earlier (Shpak *et al.*, 2008, 2010).

Summarizing the extensive literature of moss ecology, Glime (2007) believes that the growth of most bryophytes is limited by availability of water, light, nutrients, whereas the temperature is less important. The most intensive growth occurs at temperatures below 25°C. At higher temperatures plants stop any growth. In the temperate zone, the most growth occurred in the spring and in the autumn, but the author admits that it occurs in winter in warm climates and during summer in the Arctic and Subarctic regions. For many bryophytes the days accompanied by the melting of snow are the best time of year for growth when there are no cover plants, it is warm but not hot. The importance of microclimatic temperatures for growth rate of forest bryophytes was shown by

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Gabriel (2000). Plants often respond to the influence of temperatures, known as the sum of positive temperatures. However, the temperature requirements in mosses are not sufficiently investigated. Despite the large number of studies of these processes in mosses, data are controversial.

The aim of our study was a detailed study of the growth characteristics of the three moss species in different habitats of the forest belt in Khibiny mountains.

Material and Methods

The study was conducted in 2009 and 2012 in rather open birch and spruce forest, about 300 m above sea level, in the Polar-Alpine Botanical Garden in the Khibiny mountains (67°39'N – 33°40'E). The natural conditions of this territory are described in detail by Kostina *et al.* (2001). Three moss species common in the study area (Belkina & Likhachev, 2001) were selected.

Polytrichum commune Hedw. Mesohygrophyte, growing on soil. It is an endohydric moss, keeping absorbed water and minerals in internal gametophyte tissue (Schofield, 1985; Proctor, 2000). Its growth is orthotrophous, and stem is not branching. Annual increment is apparent from the leaf size pattern, as leaves appearing in spring are markedly smaller than those developing in summer, as well as by bending of the stem.

Hylocomium splendens (Hedw.) Bruch et al. grows on soil and decomposing wood. The stem develops steplike innovations once a year, clearly marking the annual increments.

Pleurozium schreberi (Bird.) Mitt. grows mainly on soil, more rarely on stumps and fallen trunks, in habitats drier than the previous species. Linear growth over the main stem, from thread, tied in the beginning of season, was measured.

Both latter species are mesophytes and ectohydric mosses, absorbing substances all over the surface of the gametophyte.

Mosses were selected in the following habitats:

1. Forest meadow, on soil (*P. commune, H. splendens, P. schreberi*).
2. Forest meadow, on stump (*H. splendens, P. schreberi*).
3. Under the spruce canopy (*P. commune*).
4. Opening between trees (*P. commune, H. splendens, P. schreberi*).

The annual length increments were measured according to Korchagin (1960) during the vegetation periods from spring (June, snow melting) to autumn (September-October, up to first snow). 20-50 shoots were measured in each habitat, at the interval of 5 to 15 days. At the date of measurement the length of increments (mm) and the growth rate (mm/day) over a period between measurements were determined. Analytical data processing and construction of charts by the program STATISTICA 8.0 were executed; the parametric coefficient of pair correlation of Brave-Pearson was applied.

The air temperature was measured with the help complexes (model iBDLR-3-U-X) installed at a height of about 1 m above the level of the moss cover. Precipitations with the help of rain-gauges were measured. For each period between the growth measurements the average daily air temperature and precipitations were assumed. The temperature and amount of precipitations during the vegetation periods are presented in the Table 1.

For the vegetation period the time with the air temperature above 5°C was determined. The duration of the growing season in 2009 amounted to 111 days (June 10 to September 28), in 2012 to 110 days (June 5 to September 22). In 2009 the first air temperature above 10°C was established on June 23, and in 2012 for 2 weeks earlier. The temperature below 10°C started in 2009 on September 11, and in 2012 already on August 18. The sum of effective and active temperatures for the years of observations were the same and have no different from long-term data for the territory of the Botanical Garden, 1100° and 746°, respectively (Semko, 1989). However, precipitation during the growing season was not the same, being twice higher in 2009 than in 2012.

In general, 2009 had a relatively cool spring and warm autumn, with an uneven distribution of precipitations during the vegetation period; in 2012 the spring was warm, autumn was cold and started early, and there were no long dry periods.

Results

Linear growth

Fig. 1 shows the changes of the moss linear increments by years in different habitats. The average values (Table 2) for each point on the curves of moss linear growth with representative selection (n = 20-50) was used. The relative error of the mean linear increments for the date of measurement at each point by *P. commune* in 2009 were in the range of 3-10%, in 2012 – 3-5%, by *H. splendens* – 3-13% and 2-6%, by *P. schreberi* – 4-18% and 7-17%, respectively. The value of the relative error above 10% was a characteristic of moss growth in early spring.

In all moss species the curves of annual growth have an *S*-shaped pattern with three apparent periods (spring and early summer moderate growth, the active summer growth and autumn slowing down up to complete growth cessation). The dates and duration vary during the years of observations (Fig. 1). The relative dynamics of increments within the growth season is shown also in Table 3. Measuring of the increment length had begun in the spring of the current season at time of total snow melting, on June 17. However, already at this time *P. commune* had an obvious fresh increment of 4-5 mm (13-18% of its annual increment) and *H. splendens* had 2-5 mm (8-16% respectively), cf. Fig. 1 A, B and Table 3. *Pleurozium* did not grow in this period of the year.

The period of active growth by all three species of mosses begins in the second half of July (Table 3). Growth slowed down in dry and cold periods, recovering in more favorable conditions.

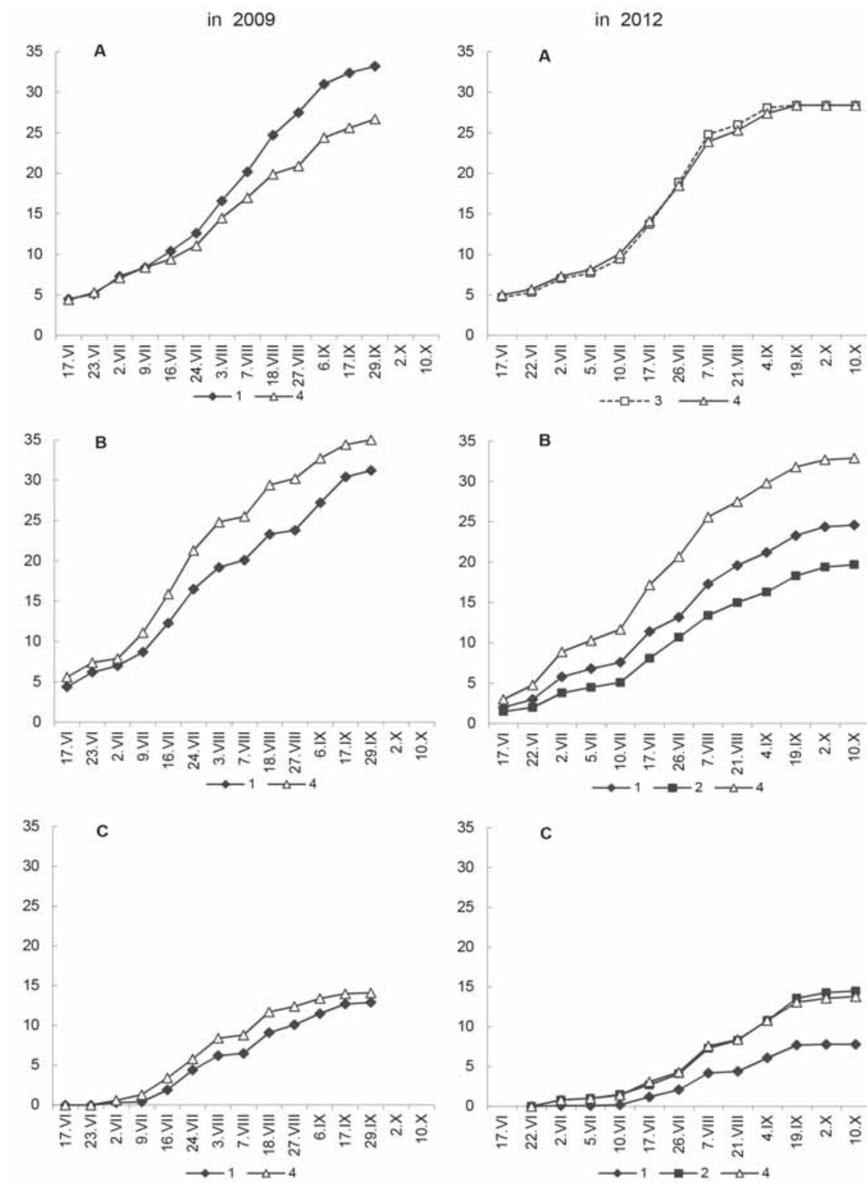

Fig. 1. Dynamics of linear increments in different habitats: A – *Polytrichum commune*; B – *Hylocomium splendens*; C – *Pleurozium schreberi*. X axis: dates of measurements; Y axis: length, mm: habitats: 1 – forest meadow on soil; 2 – forest meadow on stump; 3 – under spruce canopy; 4 – opening between trees.

Active growth in September was resumed only in *P. schreberi* when the air temperature was below 8°C. Growth of the endohydric moss *P. commune* in mild autumn of 2012 stopped when the temperature dropped below 6°C, in the third ten-day period of September 2012, while both ectohydric mosses continued their growth up to snowfall (Table 3).

The annual linear increments in *Polytrichum commune* reached 27-33 mm (Table 2), being maximal in individuals from the forest meadow, in 2009. In the opening between the trees the length of increments was the same (28 mm) in both years of observations. In 2012 there was no difference between plants in this opening and under the spruce canopy. The variation coefficient of linear increments in different habitats was slightly different. In 2009 the value of the variation coefficient in the opening between trees and on soil in the forest meadow was 17.4% and 18.1%, respectively. In 2012, the coefficient of variation was higher than in 2009 (23.4% under spruce canopy, 27.2% in the opening between trees).

The annual linear increments in *Hylocomium splendens* was 19-35 mm. The maximum length in individuals was observed on soil both in the opening between trees and in the forest meadow, while the minimal values were on the stump in the meadow. The variation coefficient of length increments by *H. splendens* moss was 14-17%. The variation was lower in the opening site than on the forest meadow on both soil and stump.

Pleurozium schreberi started growth later than *Polytrichum commune* and *Hylocomium splendens,* and its annual increment reached the lowest value among studied mosses, 8-14 mm. The maximum values were recorded on the stump and in the opening. The increments on soil in the forest meadow differed between the years of observations significantly (7.8 ± 0.6 in 2009 and 12.8 ± 1.2 mm in 2012, $p<0.01$). The variation coefficient in the

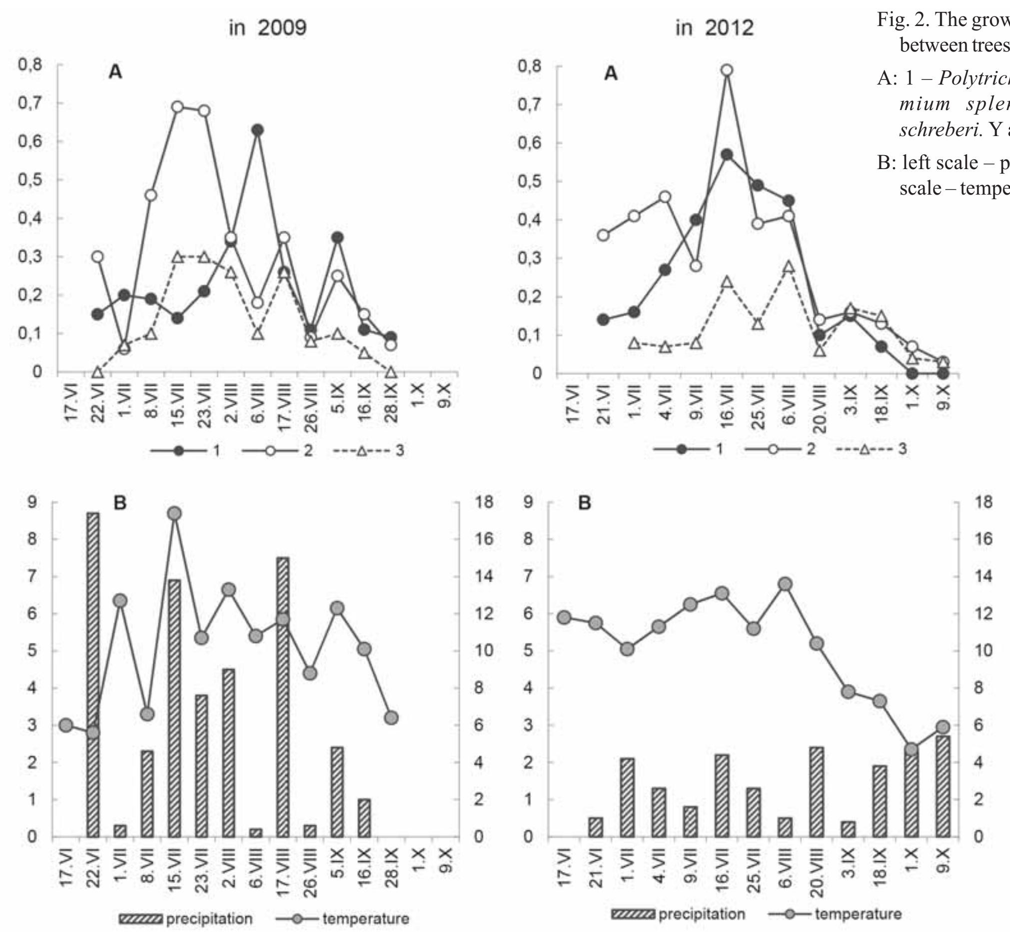

Fig. 2. The growth rate of mosses in opening between trees.

A: 1 – *Polytrichum commune*; 2 – *Hylocomium splendens;* 3 – *Pleurozium schreberi.* Y axis – growth rate, mm/day.

B: left scale – precipitations, mm/day; right scale – temperature, °C.

forest meadow on both soil and stump was quite high (32-44%), being lower in the opening between trees (16-22%). The linear increment dynamics was found to be principally the same in timing of growth periods in various habitats, but the amount of growth was different.

Growth rate

The moss growth rate and the relationship with environmental factors were studied in more detail in the opening between trees (Fig. 2). Data from other habitats showed similar patterns to growth rate curves, being different in maximal values.

Polytrichum commune (Fig. 2, A1). The growth rate in 2009 was low (less than 0.2 mm/day) up to the middle of July. In 2012 already from the beginning of July the growth rate increased noticeably. The maximum growth rate in 2009 (0.6 mm/day) was at the beginning of August after the rainy period with favorable temperature conditions (11°C), but in 2012 from mid-July to early August, the growth rate was 0.4-0.5 mm/day. Autumn peak of the growth rate in the beginning of September 2009 was half as much as in summer. In 2012 at the end of August, despite the significant amount of precipitation, temperature drop led to a decline of the growth rate. It seems that for *P. commune* growth the more important is the stability of the favorable temperatures. Small amount of precipitation or its absence does not lead to a reduction of the growth rate, which is especially clearly seen in 2009. For endohydric moss moisture accumulated in the previous period and the morphological features (tough stem, hard and thick leaves) ensure the stability of the water regime. Earlier we have shown that a loss of moisture in individuals of *P. commune* for 8 days without precipitation during the 15-24°C days amounted to only 14% of the initial quantity of water (Shpak, 2008). Diffusion resistance of moisture from the leaf of *P. commune* is several times higher than that of the vascular plants; heavy rainfall at a favorable temperature may on the contrary lead to reduction of growth rate, as this blocked CO_2 absorption and high internal water content obstructs the process of photosynthesis (Thomas *et al*., 1996).

Hylocomium splendens. Changes in the growth rate of this species are presented in Fig. 2, A2. In spring, in the time of snow melting, when moisture was unlimited, the active growth of stems, ca. 0.3 mm per day (about half of maximal value), was observed even at low temperatures (about 6°C). The maximum growth rate, 0.7-0.8 mm/day, occurred in the second ten-day period of July both in 2009 and 2012, although lack of precipitation strongly reduced it. The ectohydric moss *H. splendens* stems lost up to 44% of the initial amount of water during 8 days without precipitation at 15-24°C (Shpak, 2008). In September, at a temperature 8°C and below even with

Table 1. Air temperature and precipitations in year of investigations.

Year	Sum of effective temperatures (above +5°C)	Sum of active temperatures (above +10°C)	Daily mean temperature,°C	Precipitation, mm
		2009		
June	152	85	8.6	55
July	325	287	12.9	140
Aug	322	234	10.8	110
Sept	234	139	8.7	11
VI–IX	1033	745	10.3	316
		2012		
June	241	195	11.5	32
July	381	340	12.3	39
Aug	310	189	10.3	39
Sept	144	—	7.6	56
VI-IX	1076	724	10.4	166

the large amount of precipitations, the growth rate decreased to 0.1 mm per day.

Pleurozium schreberi in spring had a low growth rate (less than 0.1 mm/day), which continued until the beginning of July (Fig. 2, A3). The growth rate had several more or less equal peaks during the summer and early autumn. The maximum growth rate was only 40-50% that of the previous species, never exceeding 0.3 mm/day. The first maximum observed in the middle of July, the second in August. In the autumn from the end of August until mid-September the growth rate by *P. schreberi* was reduced to only half in comparison with the maximum. The sharp decline in the growth rate of *P. schreberi* has been observed in the days when there were no precipitation events or the number of them was minimal. Earlier we found that the loss of moisture in stems of this moss in 8 days without precipitation and at 15-24°C amounted to 42% of its initial quantity (Shpak, 2008). Shpak & Shmakova (2010) have shown also that turfs of *P. schreberi* are 3-4 times denser than the previous species. Probably due to this fact, *Pleurozium* turfs are able to retain moisture and thus maintain a high growth rate with little precipitation (e.g. 0.5 mm/day, cf. 6.VIII.2012 in Figs. 2, 3).

Growth rate correlation with temperature and precipitation

In order to determine the connection of the growth rate with environmental factors, we combined data of both years. The scatter plots of moss growth rate against the temperature and precipitation are presented in Fig. 3.

There is a positive correlation in grow rate of *Polytrichum commune* with the temperature and almost no correlation with precipitations (r = 0.54 and r = -0.15, respectively). The scatter plots shows a limited number of days and rather narrow range of temperatures and precipitation when growth rate is highest in the period between 16 July and 5 September. The active growth of *P. commune* occurs at temperature 11-14° C and precipitations 0.5-2.5 mm per day.

In *Hylocomium splendens,* the growth rate correlation with the temperature and precipitations was positive and average (r = 0.56 and 0.41, respectively). All values of higher growth rate were found in the period from 4 July to 23 July, being the maximal at the temperature 11-

Table 2. The mean length (mm), standard error (SE) and it's coefficient of variation (V) of moss annual linear increments in different habitats: 1 – forest meadow on soil; 2 – forest meadow on stump; 3 – under spruce canopy; 4 – opening between trees.

Species	Year	№ hab	n	Mean length, mm	SE, mm	V, %
Polytrichum commune	2009	1	20	32.4	1.8	18.1
	2009	4	29	26.8	0.9	17.4
	2012	3	47	28.4	1.0	23.4
	2012	4	50	28.4	1.1	27.2
Hylocomium splendens	2009	1	20	31.3	1.6	15.5
	2009	4	28	34.9	1.0	14.6
	2012	1	48	24.6	0.6	17.3
	2012	2	30	19.7	0.6	15.7
	2012	4	50	32.9	0.7	14.2
Pleurozium schreberi	2009	1	20	12.8	1.2	32.1
	2009	4	32	14.1	0.5	22.1
	2012	1	30	7.8	0.6	43.7
	2012	2	30	14.5	1.1	39.5
	2012	4	20	13.8	0.5	16.6

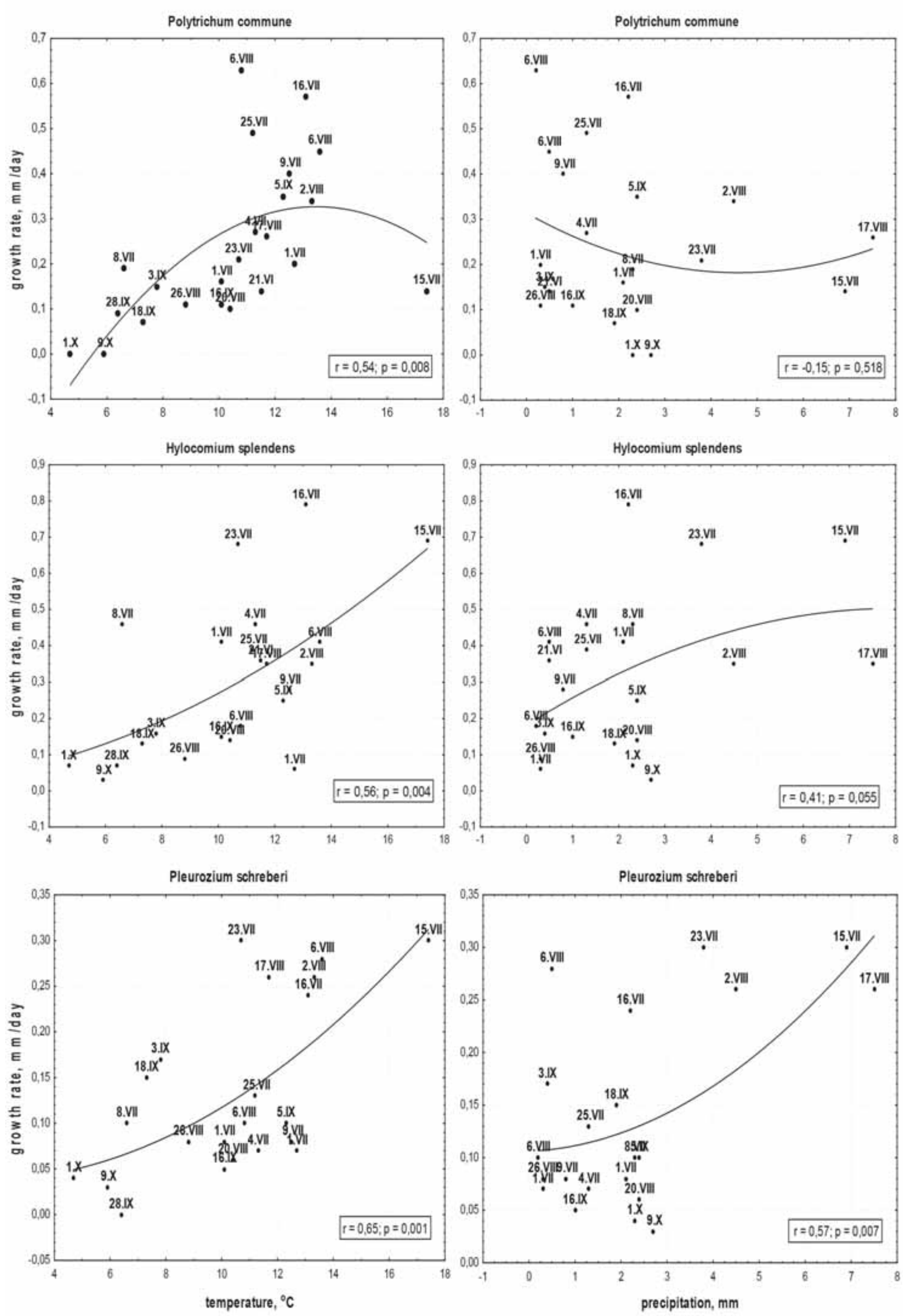

Fig. 3. Scatterplot of moss growth correlation with temperature (n =23) and precipitations (n = 22). r - coefficient of correlation, p - p-level.

13°C and precipitations of 2-4 mm per day. However the active growth was observed also on 15 July at 17°C and precipitations ca. 7 mm per day (Fig. 3).

The growth rate positive correlation with the temperature and precipitations was highest in *Pleurozium schreberi* (r = 0.65 and 0.57, respectively). The high growth rate was observed in the period since 15 July to 17 August, at the temperature 11-14°C and precipitations in a very broad range, from 0.5 to 7.5 mm per day (Fig. 3). An equally high growth rate once observed at higher air temperature of 17°C, in the period of sufficient amount of precipitations, 7 mm per day.

Discussion

Previously we have shown that in the forest zone of Khibiny already in the beginning of May the snow cover is reduced to 10-20 cm and "small hotbeds" are formed, the temperature in the turf was set from 0 to 0.5°C and not changed until the disappearance of snow (Shpak & Shmakova, 2009). The solar radiation accounted to 200-300 lux on the surface of the mosses in naturally formed "hotbeds", under snow "roof", while at the same time the light conditions above the snow come to 15000-25000 lux. Such conditions provide for mosses the level of CO_2-exchange of not more than 1 mg CO_2/g dry weight per

Table 3. The moss linear increments (percentage from annual) in the periods between the measurements. Habitats: 1 – forest meadow on soil; 2 – forest meadow, on stump; 3 – under spruce canopy; 4 – opening between trees. Consider a certain growth occured in *P. commune* and *H. splendens* before total snow melting on 17 June.

2009

Species	№ hab	17.VI	23.VI	2.VII	9.VII	16.VII	24.VII	3.VIII	7.VIII	18.VIII	27.VIII	6.IX	17.IX	29.IX	2.X	10.X
Polytrichum commune	1	First measurements	2	7	3	6	7	13	11	14	8	10	4	2	Snowfall	
	4		3	7	5	4	6	13	9	12	4	13	4	4		
Hylocomium splendens	1		6	3	5	12	13	9	3	10	2	11	10	2		
	4		5	1	9	14	15	10	3	11	2	7	5	2		
Pleurozium schreberi	1		0	2	1	12	19	14	2	20	8	11	9	2		
	4		0	4	5	15	17	18	3	21	5	7	4	1		

2012

Species	№ hab	17.VI	22.VI	2.VII	5.VII	10.VII	17.VII	26.VII	7.VIII	21.VIII	4.IX	19.IX	2.X	10.X	
Polytrichum commune	3	First measurements	2	6	2	6	15	18	21	5	7	1	0	0	Snowfall
	4		2	6	3	7	14	16	19	5	7	3	0	0	
Hylocomium splendens	1		4	11	4	3	15	8	17	9	7	9	4	1	
	2		3	9	4	3	15	13	14	8	7	10	5	1	
	4		5	12	4	4	17	11	15	6	7	6	3	1	
Pleurozium schreberi	1		0	1	0	1	13	12	26	3	22	21	1	0	
	2		0	6	1	3	8	10	22	7	18	19	5	1	
	4		0	6	1	3	12	9	24	6	17	17	4	1	

hour (our unpublished data). On this basis we can assume that the moss growth begins under the snow. This agrees with the current data for *P. commune* and *H. splendens,* showing certain growth already at the time of end of snow melting. However, these two species are likely somewhat different in "winter" growth, as *P. commune* stops growth early in autumn after the temperature drops below 6°C, whereas *H. splendens* is slowly growing up to snowfall and develops annual innovations in the second half of September, although at this time it is only 1.5-2 mm long.

The ability of mosses (for example, *Polytrichum strictum*) to increase the length of the annual segments even at negative temperatures was observed by Vitt (1990). *Sanionia uncinata* at the temperature of about 3°C had a photosynthesis rate up to 70% of the maximum (Uchida et al., 2002).

The start of linear growth in *P. schreberi* coincides with the air temperature above 10°C (Table 1) and only in the second ten-day period of July the growth increment was 1-3 mm (1-6% of the maximum). This late development has been reported for this species also by Raeymaekers & Glime (1986) in Michigan in U.S.A., and somewhat similar results were found also by Kostina et al. (2013) for Moscow Province in Russia.

Explosive growth alternating with long dormant periods with almost no growth reported for *Pleurozium* by Sofronova & Kostina (2012) was not observed by us in the Khibiny Mountains: decrease in the growth rate between maximums was moderate and not so long. Probably in the generally more humid climate of Kola Peninsula the potential tolerance to long dry periods is not so apparent.

The present data well support the subdivision of mosses into endohydric and ectohydric groups: the representative of the former, *P. commune*, strongly differs from ectohydric *Pleurozium* and *Hylocomium* by correlation between growth rate and precipitation (Fig. 3). At the same time, all three species show statistically well supported dependence of their growth on temperature, which importance for moss growth seems to be underevaluated, at least in the northern territories. Interestingly, all three studied species express individual patterns in their relation to temperature, which would be interesting to check with additional observations.

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