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Variations in the length of Scots pine (*Pinus sylvestris* L.) needles under the influence of climatic factors and solar activity in different conditions of northern taiga

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Abstract: The aim of the study was to assess the influence of climatic factors on the growth of pine needles in different conditions of the water regime of soil. Studies were conducted in lichen pine forests, cowberry pine forests, blueberry pine forests, shrub-sphagnum pine forest and pine on swamp in the Arkhangelsk forestry regions (northern taiga). The needle length is influenced by solar activity (the Wolf number). The effect of solar activity on increasing the needle length is greatest in optimal growing conditions. In northern taiga conditions, air temperature is the main climatic factor affecting the growth of needles. In the blueberry, cowberry and lichen pine forests, an inverse high correlation of the needle length with the night air temperature of August of the current year was revealed. The pine on swamp revealed a high correlation between the needle length and the air temperature at the end of July of the current year of needle development. In the year preceding the needle development, a high inverse correlation was found between the needle length and the temperature of mid-September in the cowberry and blueberry pine forests. In the current year, high correlations of the lengths of needles and precipitation were observed in extreme growing conditions.

Keywords: needle length; air temperature; precipitation; Wolf number

Pine plantations have an important environmental function and operational value. The length of the needles is an indicator of the state of a tree, its reaction to changing conditions (López et al. 2008; Feklistov, Tyukavina 2014; Eimil-Fraga et al. 2015; Grossiord et al. 2017; Fan et al. 2019; Tyukavina et al. 2019). Studying the needle length dynamics will reveal the pine response to environmental change and assess the pine adaptation potential to climate change (Grossiord et al. 2017; Fan et al. 2019) as the growth of individual organs can be estimated by changes in the growth of the entire tree (Schiestl-Aalto, Mäkelä 2017).

According to Pravdin (1964), the size of needles reflects the conditions of the environment in which the root system is located. Improvement of growing conditions leads to a decrease in the needle length due to the fact that adverse climatic factors (cold, frost, dryness) are more pronounced in adverse growing conditions (Kondratyev 1961; Kamenetskaya 1973; Kishchenko 1978). However, a number of authors (Listov 1972; Feklistov et al. 1997) believe that the deterioration of growth conditions leads to a decrease in the parameters of needles. According to Lopez et al. (2008) needles of the shortest length are formed in dry growing con-

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Table 1. Key characteristics: values (means) of the sampled stands

Sample plots	Forest type	Stand composition	Mean		Age (year)	Stand density (No. of stems per ha)
			DBH (cm)	height (m)		
1	Pine on swamp	10P	4.6	4.5	62	-
2	Shrub-sphagnum pine forest	10P+B	9.8	10.4	61	3,770
3	Blueberry pine forest	9P1B	16.5	16.3	70	1,113
4	Cowberry pine forest	10P	13	15	65	2,338
5	Lichen pine forest	10P	10.3	11.2	68	3,025

B – birch-tree, P – pine-tree

ditions. The decisive climatic factor determining the needle length is the air temperature of the current growing season (Junttila, Heide 1981; Tukavina, Feklistov 2001; Veretennikov 2002).

The aim of this study was to assess the influence of climatic factors on the growth of pine needles in various types of forests in the northern taiga subzone of European Russia.

MATERIAL AND METHODS

The research was carried out in lichen pine forests, cowberry pine forests, blueberry pine forests, shrub-sphagnum pine forests and pine on swamp in the Arkhangelsk forestry region in the northern taiga subzone (Table 1, Fig. 1). The type of forest was established according to the classification of Sukachev (1931). The studies were carried out in 1996–1999 and 2016–2018. The meteodata for Arkhangelsk for the period 1996–1999 was taken from the base of the All-Russian Research Institute of Hydrometeorological Information; for the period 2016–2018, the data of the meteorological station WRM 918H (HUGER GmbH, Germany) was used. Data on solar activity were taken from the Geoinformation System of the Russian Federation GIS "METEO DV". On the trial area, 5 to10 model trees were chosen in proportion to the representation of trees in the stand for the level of the crown development and the intensity of growth. Needles of different ages were selected in July from the middle branch of the crown, with the exception

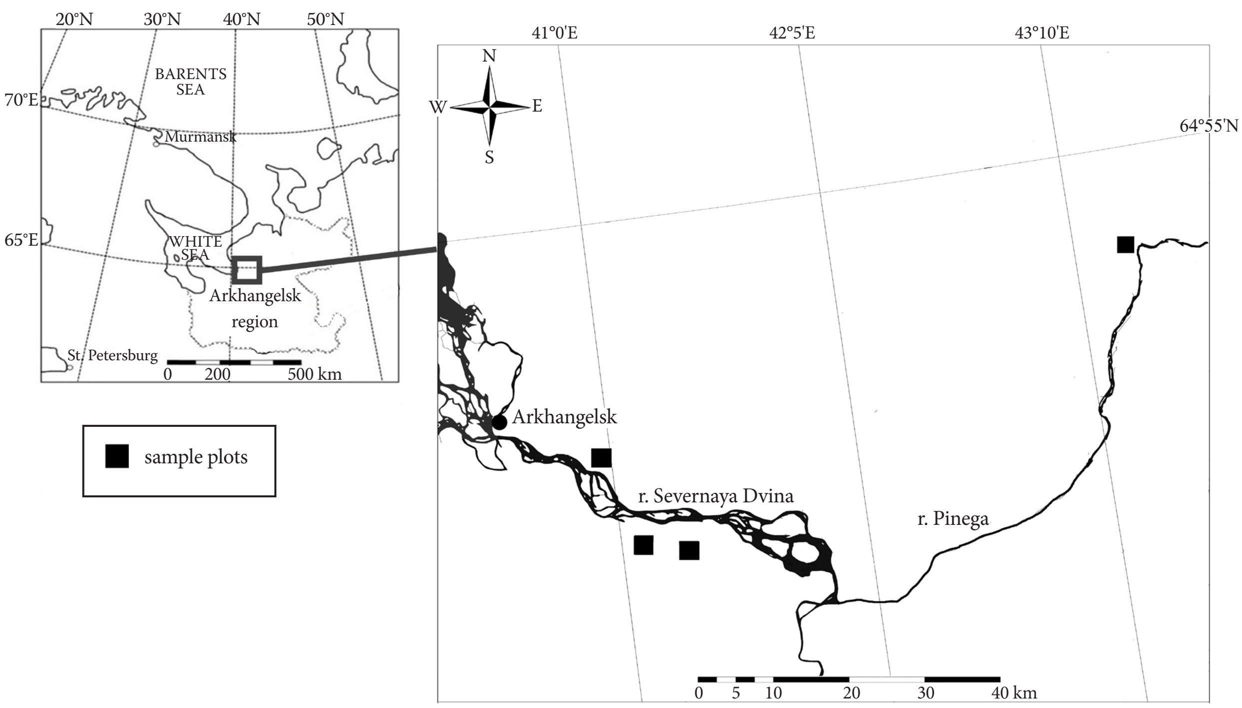

Fig. 1. Outline map of the location of sample plots

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of the first and second order, in two replications. From each tree 16–24 needles were selected. The needle length was measured with a calliper (Krasnyy instrumental'shchik, USSR) to the nearest 0.05 mm.

In the cowberry pine forest there are medium sandy Podzols developing on the moraine sand; in the blueberry pine forest there are thin sandy Podzols developing on the moraine light loam; in the lichen pine forest there are thin sandy Podzols developing on the moraine light loam; in the shrub-sphagnum pine forest there are peat soils. According to Viktorov and Remezova (1988), the depth of groundwater is more than 10 m in the lichen pine forest, the depth is 3–5 m in the cowberry pine forest, the depth is up to 2 m in the blueberry pine forest, the depth is 0–0.2 m in the shrub-sphagnum pine forest. Therefore, dry growing conditions include lichen and cowberry pine forests, normal growing conditions include blueberry pine forest, too moist growing conditions include shrub-sphagnum pine forest and pine on swamp.

The lichen pine forests occupy the top part of the slopes of the high sandy ridges. Decomposition of organic residues under these conditions is slowed down by lack of moisture. The cowberry pine forests are confined to high areas of the wavy terrain, blueberry pine forests to an even higher plateau. Shrub-sphagnum pine forest and pine on swamp are swampy closed depressions. Soil groundwater here often comes to the soil surface (Pobedinsky 1979). One of the main reasons for the poor growth of wetlands and wetlands is the extremely low or complete lack of oxygen in the root layer of the soil (Veretennikov1968). With excessive moisture, the root system of trees is located in the upper layers of peat, so the batteries are not practically available to trees (Pobedinsky 1979).

Statistical processing of the results was performed using STATISTICA (Version 10, 2011) and Python software (Version 2.7.12, 2016), SciPy package (Version 0.18.1, 2016).

RESULTS AND DISCUSSION

From 2012 to 2016, in the new growing conditions, a simultaneous change in the needle length was noted over the years (Fig. 2). In the shrub-sphagnum pine forest, the opposite, above-mentioned growing conditions, synchronous changes in the needle lengths by years were observed. In this period in the blueberry pine forest, there were the best conditions for the growth of pine relative to the needle length. In extreme growth conditions on the soil water regime (lichen pine forests, shrub-sphagnum pine forests) the smallest needle lengths were observed. The difference in the needle length between prosperous and dysfunctional growing conditions was 1.7 to 2 times. From 1993 to 1997, no simultaneous change in the needle lengths over the years was observed. The needle length in different growing conditions is practically at the same level. There is a tendency to increase the needle length in the blueberry and cowberry pine forest. The greatest difference of 1.3 times between the blueberry pine and shrub-sphagnum pine forest was observed in 1995. Therefore, in the period 2011–2016 conditions have developed that allow trees growing on the best soil and water regime to realize their life potential. Among the main factors influencing the growth of trees and the parameters of needles are precipitation and air temperature (Veretennikov 2002; Sobolev, Feklistov 2016; Grossiord et al. 2017).

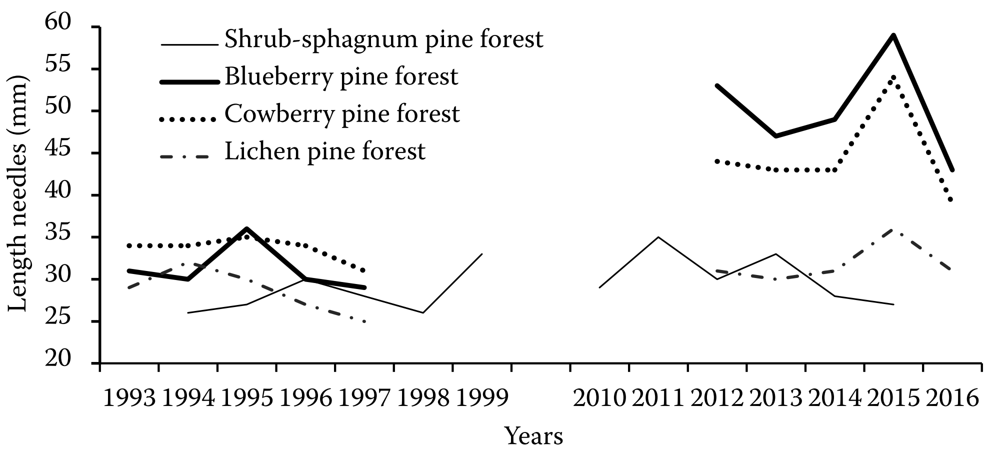

Fig. 2. The dynamics of the lengths of pine needles in different growing conditions

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Table 2. Characteristics of climate indicators by period (mean)

Year	Per year			During the growing season		
	Temperature (C°)	Precipitation (mm)	Solar activity (Wolf number)	Temperature (C°)	Precipitation (mm)	Solar activity (Wolf number)
1994–1997	1.3 ± 0.4	646 ± 55.7	30.4 ± 6.3	11.7 ± 0.3	279.6 ± 64.8	27.6 ± 5.3
2012–2015	2.5 ± 0.4	642.6 ± 50.2	92.8 ±11.1	13.3 ± 0.4	270.0 ± 51.2	93.3 ± 7.9
The significance of the difference (r) at t_{st} = 2.4	2.1	0.05	4.9	0.3	0.1	6.9

Comparing 1994–1997 and 2012–2015, no significant difference was found in the average air temperature and in the amount of precipitation per year and during the growing season (Table 2). However, for the period 2012–2015 the average solar activity (the Wolf number) was 3–3.4 times longer than in the period 1994–1997. The influence of solar activity on the extreme lengths and the synchronicity of their peaks, regardless of growing conditions, were identified by a number of authors (Tyukavina et al. 2017). According to their data, in the years of the formation of abnormally large needle lengths in the series, the values of the Wolf number exceed the average 1.7 times. According to our data, the influence of solar activity on increasing the needle length is greatest in optimal growing conditions. Thus, the needle length in the period from 2012 to 2015 compared with the period from 1994 to 1997 in the blueberry pine forest increased 1.5–1.6 times. In the cowberry pine forest the needle length increased 1.3–1.5 times. In the lichen pine forest the needle length increased 1.1–1.2 times. In the shrub-sphagnum pine forest the needle length increased 1.04–1.06 times.

Consequently, solar activity is a global factor, of which periodicity is characteristic and on which changes in the average lengths of the needles for certain periods will depend.

At the level of one-year periodicity, high significant correlations of the needle length with air temperature, precipitation of the previous and current year of needle development (Figs 2–4) were revealed. The correlation is significant when the correlation coefficient is higher than 0.7 or –0.7. But the correlation coefficient approaching 0.9 and higher indicates a steady dependence of these indicators.

Consideration of the influence of precipitation and temperature of the previous year is necessary for the development of needles. According to Schiestl-Aalto, Mäkelä (2017), a tree should be prepared in advance for the growth period. Growth of needles depends on weather conditions during budding (Bobkova 1981). The buds are set after the end of intensive growth of shoots (Sergeeva 1971) and this happens in July (Kishchenko et al. 1981). According to Owens (1986) primordium inception begins in the first half of July and actively continues for 6 weeks. According to our data, correlations of needle lengths with air temperatures of the growing season of the previous year do not exceed 0.8 and –0.8. There are high correlations in certain types of forests.

So in blueberry and cowberry pine forests lower daily temperatures in September of the previous year contribute to the formation of longer needles. During this period, the trees go to a state of rest. Elevated air temperatures during this period can lead to the consumption of spare carbohydrates, which can ensure the active work of the cambium in early spring. So, for the needles in spring there is a latent period of growth when it is still hidden by the bud scales of the kidneys, with the establishment of average daily temperatures above 0°C (Gabeev 1982). Intense growth occurs at favourable temperatures in late May and early July. The higher the temperature during this period, the longer the needles will be formed in the blueberry and cowberry pine forests. Favourable conditions for growth in this period are due to the fact that the root system injects a significant amount of water, and transpiration is still relatively small (Veretennikov 2002). Pine on swamp has an inverse high correlation of the needle length with the air temperature. In late May and early July, under these conditions, elevated groundwater levels limit the physiological processes of pine (photosynthesis, transpiration), and elevated air temperatures will lead to intensive respiration of tree organs. As a result, non-compensable waste of organic substances will occur. In this regard, lower air temperatures at

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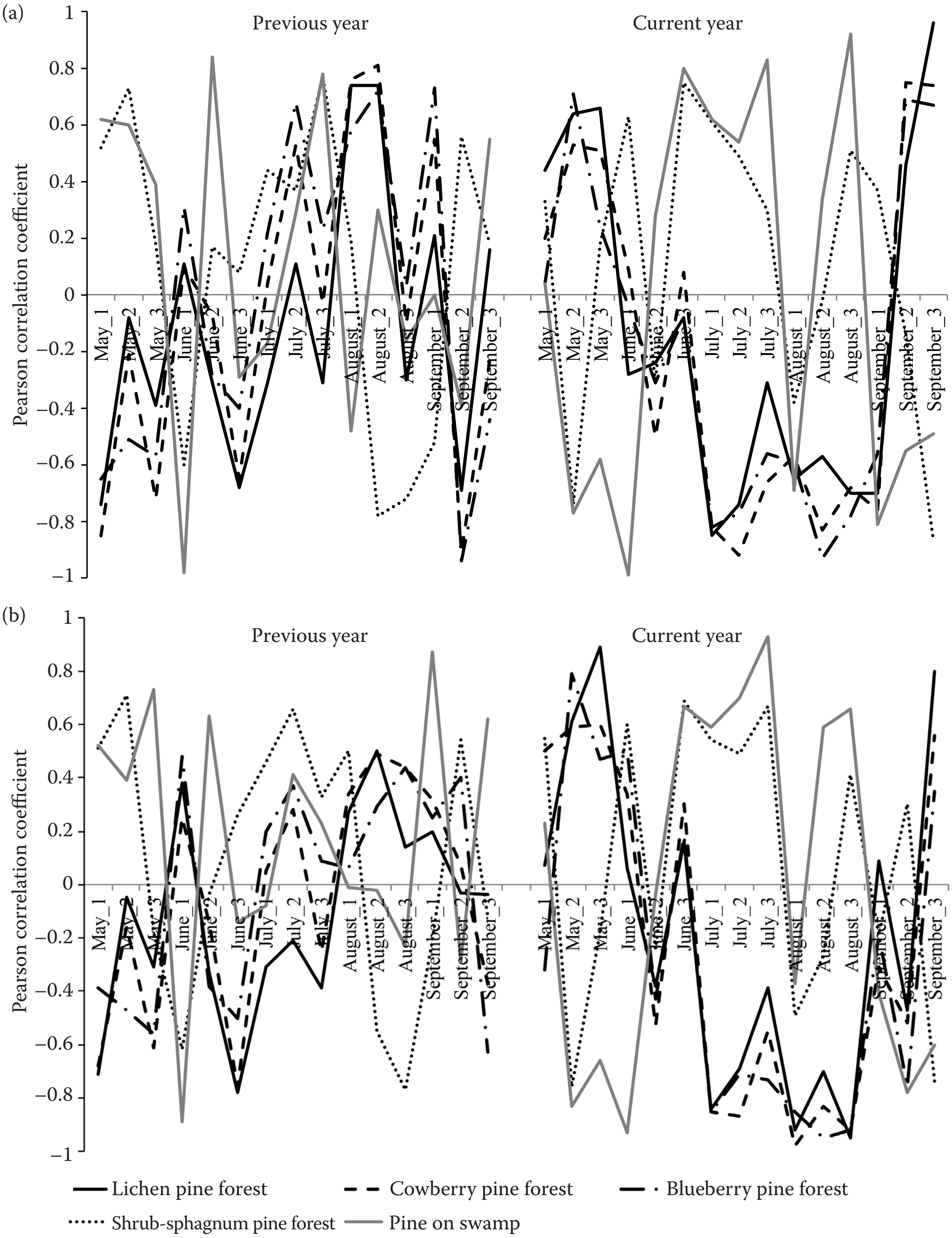

Fig. 3. The Pearson correlation coefficient of needle length with daily (a) and night (b) temperature

the end of May and in the first half of June will allow waiting for the growth processes of the tree in the swamp conditions of a more favourable air regime in the area of its roots. But already from the end of June and in the following months, increased summer temperatures are required, which will allow the soil to lose water intensively and create the most favourable conditions for growth under these conditions. In fresh growing conditions from the beginning of July, lower temperatures are required to form the greatest length of needles (Fig. 3). This is due to the establishment of a dry period in July and lower air temperatures will compensate for the lack of precipitation. The growth of needles in sum-

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mer can be mediated through their photosynthesis (Zagirova 2000). So, according to Malkina et al. (1983), when reaching 25% of the final length, the growing needles begin to use their assimilants, and when they reach 50%, they fully provide themselves with carbohydrates. According to Deligöz et al. (2018), the total carbohydrate content is the lowest in June, July, and from August to October it becomes the same as in the needles of older age. Therefore, in July-August, when the processes of growth of annual needles in length continue, the processes of assimilate synthesis used in it for its growth may also depend on the weather conditions of this period (Zagirova 2000). The greatest correlations of the needle length with temperature occur in the swamp at the end of July, and in fresh growing conditions at the beginning of August. Moreover, in the blueberry, cowberry and lichen

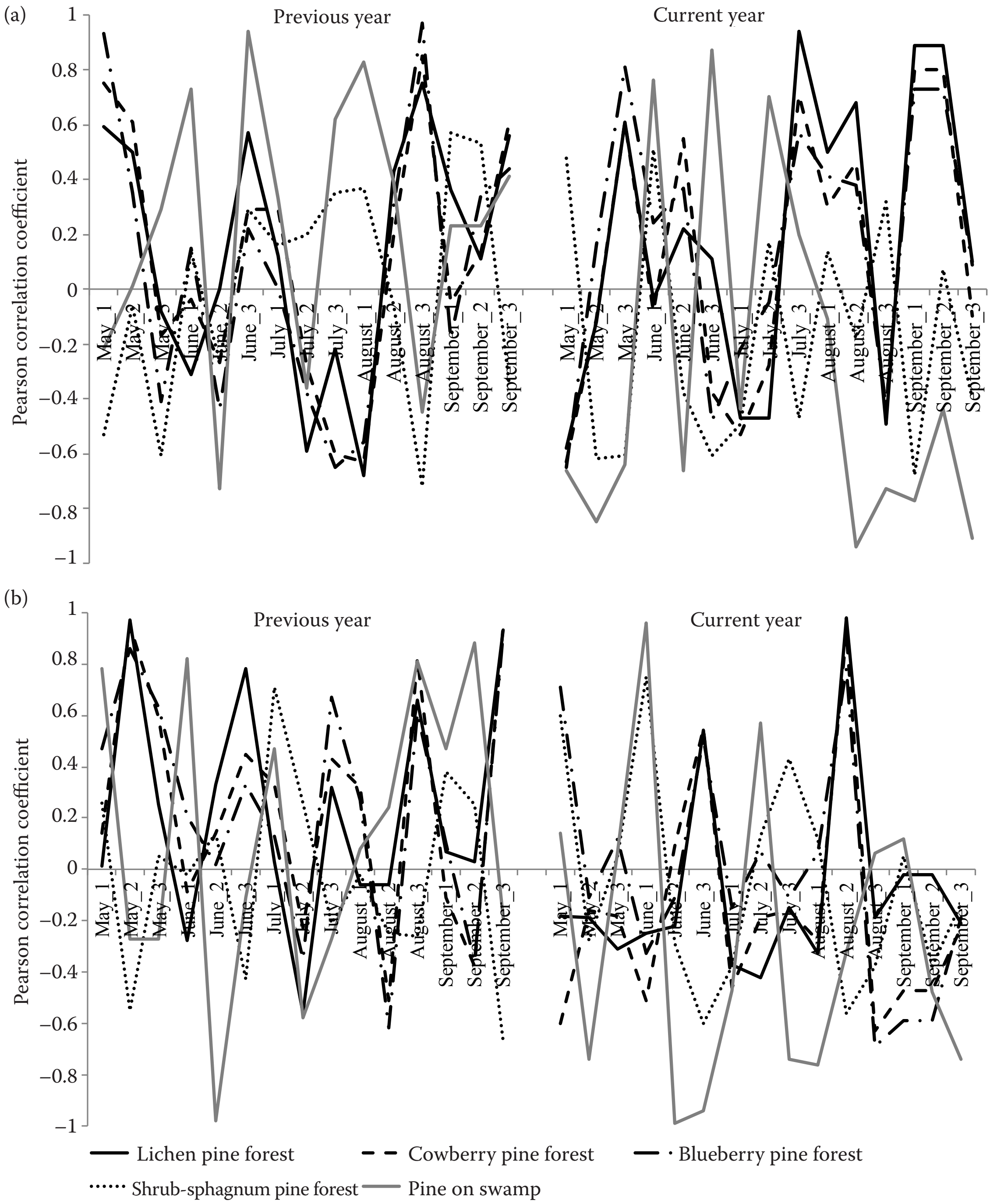

Fig. 4. The Pearson correlation coefficient of needle length with daily (a) and night (b) precipitation

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pine forests there is the greatest dependence of the length of the needles with night temperatures. In fresh conditions in August, due to lower night temperatures, respiration intensity will be limited, while in July and June in white nights the process of photosynthesis occurs both day and night (Shvetsova, Voznesensky 1970; Tuzhilkina 1984) and spending on breathing already in the overall balance is not significant.

In the year preceding the growth of needles, the correlation of precipitation during the growing season with the needle length does not exceed 0.7 and –0.7 in most cases (Fig. 4). A high inverse correlation of the needle length with precipitation of mid-June and a high direct correlation with the precipitation of the end of June were revealed. Blueberry pine forests revealed a high correlation between the needle length and rainfall at the end of August of the previous year's development. In the current year, high correlations of the needle lengths and precipitation are observed in extreme growing conditions. So the pine on swamp revealed a high inverse correlation between the needle length and the precipitation in mid-May and mid-June. In lichen pine forests there is a high correlation between the needle length and the precipitation at the end of July and mid-August. There are quite synchronous changes in the closeness of the relationship between the needle length and the amount of precipitation in different types of forest. In this connection, it can be argued that the air temperature is a determining factor affecting the needle length, compared with the amount of precipitation.

CONCLUSIONS

The needle length in chronology is due to solar activity (the Wolf number). The effect of solar activity on increasing the needle length is greatest in optimal growing conditions. In northern taiga conditions, the main climatic factor affecting the growth of needles is air temperature. In the blueberry, cowberry and lichen pine forests, an inverse high correlation of the needle length with the night air temperature of August of the current year was found (r = –0.92 to –0.98 at t = 13–41). The pine on swamp revealed a high correlation between the needle length and the air temperature at the end of July of the current year of the needle development (r = 0.83–0.93 at t = 6–16). In the year preceding the needle development, a high inverse correlation was found between the needle length and the temperature of mid-September in the cowberry and blueberry pine forests (r = –0.91 to –0.94 at t = 16–27, respectively). In the current year, high correlations of the needle length and precipitation were observed in extreme growing conditions. The pine on swamp revealed a high inverse correlation between the needle length and rainfall in mid-May (r = –0.85 at t = 7) and mid-June (r = –0.95 at t = 154). In lichen pine forests there is a high correlation between the needle length and the precipitation at the end of July (r = 0.94 at t = 19) and in mid-August (r = 0.98 at t = 53).

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