

# Estimation of the influence of hydrothermal conditions on the carbon isotope composition in Sphagnum mosses of bogs of Western Siberia

Yu I Preis<sup>1</sup>, G V Simonova<sup>1</sup>, N N Voropay<sup>1,2</sup>, and E A Dyukarev<sup>1</sup>

<sup>1</sup>Institute of Monitoring of Climatic and Ecological Systems SB RAS, Tomsk, Russia

<sup>2</sup>V.B. Sochava Institute of Geography SB RAS, Irkutsk, Russia

**Abstract.** For the first time in Western Siberia, a large-scale study of  $\delta^{13}\text{C}$  in oligotrophic Sphagnum mosses is carried out. It is found that mosses of the *Sphagnum balticum* group and the *Shagnum fuscum* group have different type of isotopic composition along the meridional gradient. The response of mosses of typical and nontypical habitats to changes in hydrothermal conditions is estimated using correlation and multiple regression analysis. The values of  $\delta^{13}\text{C}$  of the *Sphagnum balticum* mosses group have strong negative correlations with summer temperature characteristics of nontypical habitats and positive correlations with the precipitation regime and hydrothermal coefficient of all habitats. Significant positive correlations of the isotopic composition of *Sphagnum fuscum* group mosses are found only for a complex hydrothermal coefficient of typical habitats. A multiple regression model taking into account the sum of temperatures above 10 °C, the Selyaninov hydrothermal coefficient, and winter precipitation explains from 26 to 58% of the observed variability of  $\delta^{13}\text{C}$  variations for all mosses and all habitats, with the exception of mosses of the *Sphagnum fuscum* group in all and typical habitats. This confirms the possibility of using Sphagnum mosses for monitoring climate change impacts, the functional state of bogs, as well as for paleoecological and paleoclimatic reconstructions.

## 1. Introduction

Oligotrophic peatlands are one of the main landscapes of the Holarctic. Information on their functional status in the past and present are particularly relevant as a basis for predictions for the near future. The development of high-resolution forecasts and search for highly sensitive bio-indicators are under way around the world. Often the isotopic composition of peat carbon ( $\delta^{13}\text{C}$ ) is considered as one of the informative indicators. Despite numerous studies of  $\delta^{13}\text{C}$  in peat and peat cellulose, the question of the significance of this indicator remains open. It is caused by different mechanisms of fractionation of stable isotopes by vascular plants and mosses and the specificity of the fractionation process in different species and in different parts of Sphagnum mosses. A significant influence on the carbon fractionation in plants is exerted by external factors: the air temperature, the partial pressure of  $\text{CO}_2$ , the water and osmotic stress, and the availability of mineral nutrition elements.

Mosses use the C3 cycle during the fixation of carbon from the atmosphere that facilitates the binding of the lighter  $^{12}\text{C}$  isotope and the accumulation of  $^{13}\text{C}$  isotope under unfavorable environmental conditions. Sphagnum mosses have relatively simple biomechanical pathways to cellulose synthesis compared to vascular plants [1]. Sphagnums do not have stomata and are unable to physiologically regulate the absorption of atmospheric  $\text{CO}_2$  from the atmosphere. The degree of filling



of the hyaline cells with water is the main mechanism governing the diffusion of CO<sub>2</sub> into the photosynthetic cells of chlorophyll [2, 3]. Consequently, the fractionation of stable carbon isotopes in Sphagnum mosses and, therefore, discrimination against the heavy <sup>13</sup>C isotope, depends on the availability of water. Lower values of the δ<sup>13</sup>C content are associated with dry conditions and vice versa. Additional discrimination contributing to a lower value of the δ<sup>13</sup>C content occurs when cellulose and other organic substances are produced from leaf sugars.

Numerous studies have revealed correlations between the isotope composition of carbon in the cellulose of Sphagnum mosses and the modern gradient of surface moisture [4–6], and by independent reconstructions of the paleohydrological conditions [7–11].

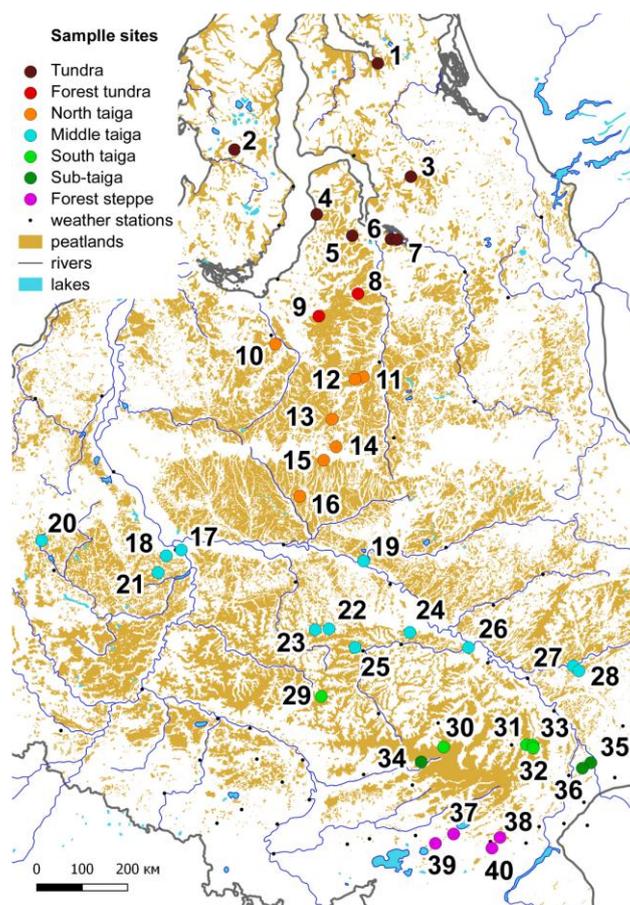
The issues of the effect of temperature on the fractionation of carbon isotopes are more complex. The temperature variation has a direct impact on the kinetics of reactions such as photosynthesis [12]. Since an increased rate of photosynthesis leads to depletion of the intracellular concentration of CO<sub>2</sub> and, thereby, a decreased carboxylation discrimination of <sup>13</sup>C, high air temperatures can indirectly lead to increasing δ<sup>13</sup>C values in trees [13]. However, different C3 plants have shown large variations in δ<sup>13</sup>C responses to temperature in laboratory and field studies [14].

A positive relationship was found in an isotope study of *S. fuscum* peat from subarctic west central Canada [15, 16] and from the north-east of the European part of Russia [17], where the temperature may be the main limiting factor controlling the growth of this species [15]. A negative correlation of δ<sup>13</sup>C and temperature was found for the Sphagnum mosses from altitudinal transect studies [18].

The difference in the set of influencing factors and the limiting factor in various natural climatic zones, regions, and ecosystems creates difficulties in studying the isotopic composition of mosses. Thus, in global studies of Sphagnum mosses in the peatlands of North America and Eurasia, only a negative correlation between δ<sup>13</sup>C in *S. magellanicum* and the groundwater level and a positive correlation between the isotope composition and the net primary production (NPP) of *S. magellanicum* and *S. fuscum* [19] were revealed.

## 2. Objects and methods

Sphagnum moss samples were taken from 40 oligotrophic bogs of Western Siberia. Totally 176 samples were collected along a meridian transect from the tundra, through the forest-tundra and taiga zones to the forest-steppe zone (Figure 1).



**Figure 1.** Map of Western Siberia with sampling sites of *Sphagnum* mosses.

The moss samples were analyzed in the Tomsk Center for Collective Use, Siberian Branch of the Russian Academy of Sciences (IMCES SB RAS). Parts of the moss stems (5 mm) below the capitula were treated with 3% HCl to remove carbonates, and then washed with deionized water in an ultrasonic bath. Isotope analysis was carried out in a continuous flow of helium using a Delta V Advantage isotope ratio mass spectrometer (Thermo Fisher Scientific, Germany) coupled with a Flash 2000 Elemental Analyzer furnace heated to 1020°C. The Elemental Analyzer was used to transform the sample organic carbon to CO<sub>2</sub>. The samples (weight: 500 µg) were weighted by Mettler Toledo XR6 scales with an accuracy of up to 1 µg and packed into tin capsules. The sample combustion was made by the flash method when oxygen is injected into the helium flow. The combustion gases – N<sub>2</sub>, N<sub>x</sub>O<sub>y</sub>, CO<sub>2</sub> and H<sub>2</sub>O – sequentially pass through the columns with oxidizing (CuO) and reducing (Cu) reagents. A trap with a magnesium perchlorate absorber was used to remove water from the helium flow. CO<sub>2</sub> was passed to the mass spectrometer using the ConFlow IV interface to determine the carbon isotope ratios and is defined as

$$\delta^{13}\text{C} = \left[ \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \right] \times 1000, \text{ [‰]}$$

where  $R_{\text{sample}}$  is <sup>13</sup>C/<sup>12</sup>C ratio in a sample of mosses; and  $R_{\text{standard}}$  is <sup>13</sup>C/<sup>12</sup>C ratio in a standard V-PDB (Vienna Pee Dee Belemnite). The isotope mass spectrometer was calibrated according to standard IAEA-600 (caffeine). The reproducibility of the results of the studied samples was ±0.09‰ for δ<sup>13</sup>C.

All samples in relation to moss species to the moistening conditions were divided into *Sphagnum balticum* group mosses (*S. majus*, *S. balticum*, *S. fallax*, *S. riparium*, *S. girgensonii*, *S. squarrosum*) and *S. fuscum* group mosses (*S. fuscum*, *S. rubellum*, *S. capillifolium*, *S. fimbriatum*), and then into

subgroups with favorable (typical habitats) and unfavorable water level regimes (nontypical habitats). Sites with unfavorable water regimes are related with extremely dry or excessive moisture habitats with an abruptly variable moisture regime disturbed by land reclamation or fires.

To estimate the influence of the temperature and moisture conditions on the isotopic composition of Sphagnum mosses, a correlation analysis of the mean  $\delta^{13}\text{C}$  values and the mean long-term air temperature and precipitation values, the hydrothermal coefficients for the observation periods for each group and the subgroup of Sphagnum mosses was performed. The analysis was carried out for a set of samples from sites selected near a specific weather station. Meteorological data were used for 14 weather stations from Western Siberia: Antipayuta, Tazovskoye, Nyda, Nadym, Tarko-Sale, Khalesova, Khanty-Mansiysk, Middle Vasyugan, Kolpashevo, Pudino, Severnoe, Bakchar, Tomsk, and Barabinsk [20].

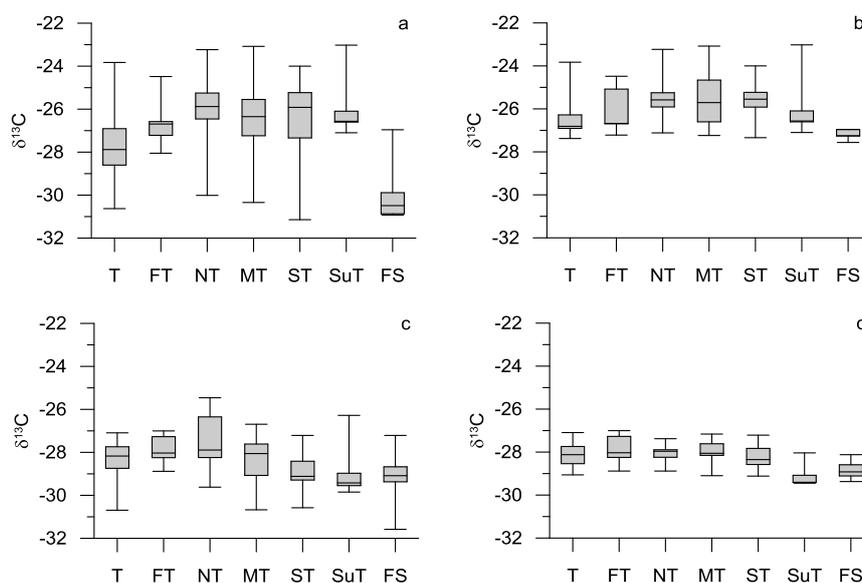
The Pearson correlation coefficients were calculated for the mean  $\delta^{13}\text{C}$  values and the following meteorological parameters: Tyr - the annual average air temperature, Tveg - the average temperature from May to September, Tsum - the average temperature from June to August, Ts10 - the sum of temperatures above  $10^{\circ}\text{C}$ , Ps10 - the sum of precipitation at an air temperature above  $10^{\circ}\text{C}$ , Pyr - the annual precipitation, Pwin - the amount of precipitation from December to February, and HTC - the Selyaninov's hydrothermal coefficient ( $\text{HTC} = 10 \cdot \text{Ps10} / \text{Ts10}$ ) [21]. These characteristics were averaged for the following observation periods: 2010-2013, 2011-2014, 2012-2015, 2013-2016, 2000-2016, and 1985-2016.

To identify the set of factors simultaneously affecting the isotope composition of mosses, a regression model was proposed that includes the characteristics of both the warm and cold periods of the year, namely, the sum of the temperatures above  $10^{\circ}\text{C}$ , the hydrothermal coefficient, and the amount of precipitation over the winter.

### 3. Results and discussion

#### 3.1. Sphagnum mosses $\delta^{13}\text{C}$ values

A significant variation of  $\delta^{13}\text{C}$  within the moss groups has been revealed within the entire study area (from -23.1 to -31.57‰ for the *Sphagnum balticum* group and from -25.5 to -31.6‰ for the *Sphagnum fuscum* group). High variations in the isotopic composition were observed for each bioclimatic zone. The amplitude of variations for the *Sphagnum balticum* group changes from 3.0 to 7.7‰, and for the *Sphagnum fuscum* group the variation amplitude is a bit lower (from 1.9 to 4.2‰) (Figure 2). In typical habitats the *Sphagnum balticum* group has heavier values of  $\delta^{13}\text{C}$  (-23.02 to -27.7‰) than the *Sphagnum fuscum* group (from -27 to -29.6‰). It indicates a significant sensitivity of the  $\delta^{13}\text{C}$  Sphagnum mosses to changes in the environmental conditions of their habitats.



**Figure 2.** Mean values (horizontal line), standard deviations (filled boxes) and maximal/minimal values (whiskers) of  $\delta^{13}\text{C}$  of mosses of *Sphagnum balticum* group (a, b) and *Sphagnum fuscum* group (c, d) from all (left) and typical habitats (right) in different bioclimatic zones of Western Siberia. T-tundra, FT – forest tundra, NT – north taiga, MT – middle taiga, ST – south taiga, SuT – sub-taiga, FS – forest-steppe.

A significant variation of  $\delta^{13}\text{C}$  in *Sphagnum* mosses from bogs of Western Siberia is a regional feature that reflects the diversity of the hydrothermal regimes of the mire ecosystems under continental climate conditions. This diversity is due to the refraction of the climate by multiscale elements of the mire surface and different response of the mire ecosystems to sharp seasonal and annual changes in the continental climate regimes.

As a result, in addition to typical habitats with favorable temperature and water regimes, habitats with unfavorable regimes are widely represented in Western Siberia. Therefore, the  $\delta^{13}\text{C}$  values for *Sphagnum* mosses can vary considerably even in a small area of a mire. On the flat-palsa bog in the northern taiga, the  $\delta^{13}\text{C}$  of 10 moss samples from the *Sphagnum fuscum* group varied from -27.1 to -27.8‰ and of 7 moss samples of the *Sphagnum balticum* group, from -25.3 to -29.4‰. In the forest-tundra on the flat-palsa bog, respectively, the  $\delta^{13}\text{C}$  for 7 *Sphagnum fuscum* samples varies from -27 to -28.9‰ and for 5 moss samples from the *Sphagnum balticum* group it varies from -26.7 to -27.7‰.

The maximum variation of  $\delta^{13}\text{C}$  is typical for the *Sphagnum balticum* group, which indicates their more responsive response to changes in the environmental conditions, especially to lower bog water level. A smaller effect of the bog drying on the change in the isotope composition of carbon in the *Sphagnum fuscum* group was observed due to a greater ability of the *Sphagnum* top sod to retain moisture due to a well-developed capillary network and the presence of additional self-regulation mechanisms for the conservation of moisture in the *Sphagnum* top sod [22].

In typical habitats, mosses from the *Sphagnum balticum* group have heavier values of  $\delta^{13}\text{C}$  (from -23.02 to -27.7‰) than the *Sphagnum fuscum* group (from -27 to -29.6‰), which corresponds to the moisture conditions of the habitats (Figure 2). In more humid conditions, the gas exchange between the plants and atmosphere changes, leading to a change in the biochemical fractionation with enrichment of mosses by  $^{13}\text{C}$  [23].

In typical habitats, the change in  $\delta^{13}\text{C}$  mosses from the *Sphagnum balticum* group along the meridional transect generally corresponds to the zonal character of the distribution of precipitation in the study area. At the same time, the zonal type of change in  $\delta^{13}\text{C}$  values of the *Sphagnum fuscum* group and the absence of heavy  $\delta^{13}\text{C}$  values (from -27 to -28‰) due to the arid climate is manifested only in the south and is practically not expressed to the north of the taiga zone. The slight variation of

the  $\delta^{13}\text{C}$  values for the *Sphagnum fuscum* group from typical habitats above the entire study area, except for the south of Western Siberia, testifies to a weak influence of zonality, in particular, the temperature factor, on the isotopic composition. Moreover, the heterogeneity of the distribution of precipitation within the zones and the local differences in the water regimes of wetland habitats exert a more significant influence.

The zonal features of distribution of  $\delta^{13}\text{C}$  in Sphagnum mosses are manifested in nontypical habitats. A considerable alleviation of the isotope composition in the *Sphagnum balticum* group in the tundra and forest-tundra is caused by a significant drying of peatlands in extremely warm years occurring even in typical habitats (hollows and drawdowns at flat-palsa bogs and peat plateau bogs, concave polygons at low-centered polygon mires), and drained khasyrei lakes.

In the middle taiga zone and on the top plateaus of the early Holocene peatlands of the sub-taiga zone the alleviation of the isotope composition is caused by active methane emission due to the widespread occurrence of regressive phenomena due to high bog water levels.

In the forest-steppe zone the  $\delta^{13}\text{C}$  values decrease due to a sharply variable character of moistening at shallow margins of bogs where the Sphagnum mosses of this group are located. Some alleviation of the  $\delta^{13}\text{C}$  values for all mosses in sub-taiga and forest-steppe is probably connected with a more arid climate, but in anthropogenically disturbed habitats it is related to the impact of reclamation and fires. All zones are characterized by the alleviation of the  $\delta^{13}\text{C}$  values for mosses from the *Sphagnum fuscum* group under conditions of less stable water regime.

### 3.2. Correlation of $\delta^{13}\text{C}$ of *Sphagnum* mosses with meteorological characteristics

The  $\delta^{13}\text{C}$  values of the *Sphagnum balticum* group in all and nontypical habitats correlate with the air temperature and precipitation (Table 1) for the whole study area. For samples from all habitats,  $\delta^{13}\text{C}$  correlates with the precipitation of the warm period ( $r = 0.52-0.65$ ), the sum of annual precipitation ( $r = 0.50-0.55$ ), and the precipitation of the previous winter period ( $r = 0.40$ ). It confirms a significant influence of the moisture regime on the  $\delta^{13}\text{C}$  values of the *Sphagnum balticum* group. A negative correlation of the  $\delta^{13}\text{C}$  values with the air temperature of the warm period ( $r = 0.5-0.51$ ) was found for samples from non-typical habitats. There were no significant relationships between the  $\delta^{13}\text{C}$  values and the meteorological characteristics for the *Sphagnum balticum* group from typical habitats.

**Table 1.** Correlation coefficients between  $\delta^{13}\text{C}$  of Sphagnum mosses and meteorological characteristics averaged over 2010-2013. Significant correlations (at  $p > 0.05$ ) are shown in bold.

Meteorological characteristics	<i>Sphagnum balticum</i> group			<i>Sphagnum fuscum</i> group		
	All	Typical	Nontypical	All	Typical	Nontypical
Tveg	0.00	0.01	<b>-0.50</b>	-	-0.18	-0.16
Ts10	-	-0.01	<b>-0.51</b>	-	-0.19	-0.21
Pyr	<b>0.55</b>	0.12	0.48	0.30	0.36	0.28
Pveg	<b>0.65</b>	0.39	0.41	0.21	0.25	0.20
Pwin	0.40	-0.08	0.10	0.21	0.38	-0.22
HTC	<b>0.58</b>	0.27	<b>0.79</b>	0.45	<b>0.53</b>	0.21

Significant correlations of the  $\delta^{13}\text{C}$  values with all temperature and precipitation characteristics are absent for the *Sphagnum fuscum* group. Positive correlations were found with the HTC values averaged over 2010-2013: for the *Sphagnum balticum* group from all and from nontypical habitats, and also for the *Sphagnum fuscum* group from typical habitats (Table 1).

The complex climate characteristic (hydrothermal coefficient) have stronger correlations with mosses isotopic composition. Linear correlations also exist in the *Sphagnum fuscum* group from typical habitats. The isotopic composition of mosses in this group is alleviation at decreasing the amount of precipitation and / or increasing the air temperature.

Analysis of linear relationships between hydrothermal coefficient and value of  $\delta^{13}\text{C}$  of mosses show weak correlation for typical or nontypical habitats separately both for *Sphagnum balticum* and *S. fuscum* groups, but for composition from all habitats the correlation coefficient increases. Mosses from nontypical habitats have lighter isotopic composition than mosses from typical ones.

### 3.3. Spatial structure of correlations

The correlation of the isotopic composition of Sphagnum mosses with the weather parameters are not uniform over the study area. Within individual bioclimatic zones the  $\delta^{13}\text{C}$  of the mosses differ in the value and sign. The correlation coefficients between the  $\delta^{13}\text{C}$  of Sphagnum mosses and the meteorological characteristics averaged over 2010-2013 for selected bioclimatic zones are shown in Table 2. Columns 2-4 contain correlation coefficients calculated for the tundra and forest-tundra zones, columns 5-7 have values obtained for the north, middle, and south taiga zones, and columns 8-10 have values for the sub-taiga and forest-steppe zones.

According to the studied cross-section, the influence of climatic characteristics on the isotopic composition of mosses from the *Sphagnum balticum* group changes in space. In the north of Western Siberia the correlations of the  $\delta^{13}\text{C}$  values for samples from all habitats are positive, in the middle the linear correlation is absent, and in the south of Western Siberia the correlation is negative. Positive correlations with precipitation characteristics exist not only for samples from all habitats (see Table 1), but also for typical and non-typical habitats in the middle and south areas.

The carbon isotopic composition of mosses from the *Sphagnum fuscum* group for the isolated bioclimatic zones has stronger relations with the weather than for the whole territory of Western Siberia. Positive linear correlations were found with temperature characteristics for all and typical habitats in the tundra and taiga zones, but in the sub-taiga and forest-steppe the correlations are negative. Strong bonds with the precipitation characteristics (annual, warm and cold period) was found in the sub-taiga and forest-steppe zone. In the south of Western Siberia the air temperature and precipitation separately or in combination (HTC) have the strongest influence on the isotopic composition of mosses. A number of significant correlations were revealed between the  $\delta^{13}\text{C}$  values and the hydrothermal coefficient, except for the taiga zone (Table 2).

**Table 2.** Correlation coefficients between  $\delta^{13}\text{C}$  of Sphagnum mosses and meteorological characteristics averaged over 2010-2013 for selected bioclimatic zones. Significant correlations (at  $p>0.05$ ) are shown in bold. T- tundra, FT – forest tundra, NT – north taiga, MT – middle taiga, ST – south taiga, SuT – sub-taiga, FS – forest-steppe.

Weather parameters	T – FT			NT – MT – ST			SuT – FS		
	All	Typical	Non-typical	All	Typical	Non-typical	All	Typical	Non-typical
<i>Sphagnum balticum</i> group									
Tveg	<b>0.69</b>	0.32	0.14	-0.15	-0.16	0.17	<b>-0.84</b>	<b>-0.74</b>	<b>-0.78</b>
Ts10	<b>0.69</b>	0.30	0.18	-0.13	-0.13	0.24	<b>-0.85</b>	<b>-0.76</b>	<b>-0.81</b>
Pyr	0.37	-0.04	0.31	<b>0.47</b>	<b>0.47</b>	-0.15	<b>0.80</b>	0.39	<b>0.93</b>
Pveg	<b>0.54</b>	0.15	0.20	0.37	<b>0.51</b>	<b>0.64</b>	<b>0.87</b>	<b>0.82</b>	<b>0.89</b>
Pwin	0.03	-0.26	0.31	0.05	-0.14	<b>-0.50</b>	0.44	-0.21	<b>0.98</b>
HTC	0.29	-0.20	<b>0.78</b>	<b>0.59</b>	<b>0.59</b>	0.07	<b>0.80</b>	<b>0.68</b>	<b>0.71</b>

<i>Sphagnum fuscum</i> group									
Tveg	<b>0.44</b>	0.17	<b>0.45</b>	0.16	<b>0.45</b>	0.13	<b>-0.84</b>	<b>-0.82</b>	<b>-0.86</b>
Ts10	<b>0.45</b>	0.18	<b>0.42</b>	0.16	-0.41	0.16	<b>-0.80</b>	<b>-0.85</b>	<b>-0.89</b>
Pyr	0.39	0.26	-0.34	<b>-0.41</b>	-0.29	<b>-0.51</b>	<b>0.55</b>	<b>0.98</b>	<b>0.99</b>
Pveg	<b>0.51</b>	0.29	0.07	0.14	-0.21	<b>0.67</b>	<b>0.66</b>	<b>0.94</b>	<b>0.96</b>
Pwin	0.19	0.18	<b>-0.75</b>	<b>-0.56</b>	0.22	<b>-0.88</b>	0.02	<b>0.93</b>	<b>0.91</b>
HTC	<b>0.72</b>	<b>0.46</b>	<b>-0.87</b>	0.29	0.17	0.20	<b>0.87</b>	<b>0.78</b>	<b>0.82</b>

### 3.4. Multiple regression model

A series of regression models proposed that includes the characteristics of both the warm and cold periods of the year was proposed to identify a set of factors simultaneously affecting the isotope composition of mosses. It was found that the best results for explaining the variability of  $\delta^{13}\text{C}$  of mosses were obtained by the model including, as predictors, the following parameters: the sum of the temperatures above 10 °C (Ts10), the Selyaninov hydrothermal coefficient (HTC), and the winter precipitation (Pwin).

The model  $\delta^{13}\text{C} = a_0 + a_1 \text{Ts10} + a_2 \text{HTC} + a_3 \text{Pwin}$  shows significant correlation coefficients from 0.51 to 0.76 for all combinations of moss habitats from the *Sphagnum balticum* group: all, typical and nontypical (see Table 2). For mosses from the *Sphagnum fuscum* group the correlation coefficients are high, but significant correlations were obtained for mosses from nontypical habitats only ( $r = 0.64$ ). The proposed model explains from 26 to 58% ( $r = 0.51 \div 0.76$ ) of the observed variability of  $\delta^{13}\text{C}$  for all mosses and all habitats, with the exception of mosses from the *Sphagnum fuscum* group from all and typical habitats.

**Table 3.** Multiple regression model parameters ( $a_0, a_1, a_2, a_3$ ), standard model error (Err), and correlation coefficient between modelled and observed data ( $r$ ).

	<i>Sphagnum balticum</i> group			<i>Sphagnum fuscum</i> group		
	Habitats					
	All	Typical	Nontypical	All	Typical	Nontypical
$a_0, \text{‰}$	-25.56	-23.14	-28.81	-28.80	-28.30	-28.70
$a_1, \text{‰/°C}$	-	-0.0026	-0.0024	-	-0.0011	-0.024
$a_2, \text{‰}$	0.0065	0.0234	0.0142	0.0013	0.0083	0.0185
$a_3, \text{‰/mm}$	-	-0.0900	0.0205	0.0154	0.0099	-0.0301
Err, ‰	0.0618	1.38	1.11	0.85	0.83	0.49
$r$	<b>0.76</b>	<b>0.51</b>	<b>0.68</b>	0.33	0.43	<b>0.64</b>

The negative values of the coefficient indicate  $a_1$  a decrease of  $\delta^{13}\text{C}$  with increasing sum of temperatures. The coefficients  $a_2$  are positive, and so  $\delta^{13}\text{C}$  increases with rising hydrothermal coefficient, but for the *Sphagnum fuscum* group from all and typical habitats the HTC does not play a significant role. The precipitation of the winter period (coefficient  $a_3$ ) significantly affects the values of  $\delta^{13}\text{C}$  only in samples of *S. balticum* group from all and typical habitats and in samples of the *S. fuscum* group from nontypical habitats. The coefficient values are negative and  $\delta^{13}\text{C}$  decreases with the growth of snow storages and spring moisture reserves.

## 4. Conclusions

For the first time in Western Siberia, a large-scale study of the isotopic composition of carbon of oligotrophic Sphagnum mosses has been performed. The median values of  $\delta^{13}\text{C}$  and limits of  $\delta^{13}\text{C}$  variation in Sphagnum moss samples in various bioclimatic zones were determined.

The presence of correlations of the  $\delta^{13}\text{C}$  values with precipitation confirms the fact that there is a significant influence of the moisture regime on the mosses of the *Sphagnum balticum* group. The isotopic composition of mosses of the *Sphagnum fuscum* group depends on a combined influence of temperature and precipitation. A more sensitive response of the mosses of the *Sphagnum balticum* group to changes in the hydrothermal conditions of the habitat is caused by both climatic and local factors. The mosses of the *Sphagnum fuscum* group have an extremely sensitive response to changes in the local growth conditions. All this confirms the possibility of using  $\delta^{13}\text{C}$  of oligotrophic sphagnum mosses of Western Siberia for monitoring climate change impacts, the functional state of bogs, as well as for paleoecological and paleoclimatic reconstructions.

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