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Modern Gas-Exchange Processes in Forest-Steppe Sphagnum Bogs in the Baraba (West Siberia)

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Abstract—Peculiarities of forming emission flows of carbon dioxide and methane in forest-steppe raised Sphagnum bogs have been studied in view of coenotic structure and damage to the vegetation as a result of fire. The reasons of relatively low rate of methane emission in pine-dwarf shrub Sphagnum bogs under the marginal conditions have been analyzed. The concentrations of CH_4 and CO_2 in bog waters have been presented.

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Investigation of gas-exchange processes in surface ecosystems is a priority trend in biosphere programs. Accumulation of greenhouse gas in atmosphere and change of climatic system needs scientific explanation and analysis of regional peculiarities and global regularities. In the solution to the problem of carbon balance in the biosphere an important role is played by the studies of northern bogs of boreal belt [1 - 6]. Bog ecosystems are considered as global surface source of methane and store of carbon supplied from atmosphere. Optimal conditions for peat accumulation are formed in the places of excessive damping of ground surface. However this is bogs of the marginal zone with unstable atmosphere damping that deserve special attention.

So forest-steppe raised Sphagnum bogs at present have no sufficient resources for progressive growth. They do not form masses with substantial area and are presented in the landscape with separate small islands. Climate change, human's economic activities (reclamation measures, peat development) as well as frequent fires appear to be the risk factors for unique natural objects.

Forest-steppe raised peat-bogs are interesting as model objects for evaluation of the range of changes of main parameters of carbon cycle (primary products, peat accumulation, CO_2-gas-exchange, mineralization of vegetable residues, peat, etc.). Unstable character of atmosphere damping may cause deep changes of the process cyclic recurrence and recession development. During preliminary route observations in 2006–2008 general ecological state of forest-steppe raised Sphagnum bogs has been estimated. It was found out that many of these objects have been exposed to fires. This resulted in significant disorders in vegetation of the bog complexes: degradation of Sphagnum cover (patchiness, projective cover of no less than 3–5%), spread out of bushes and dwarf shrubs [7].

Main objective of this work was to study peculiarities of forming emission flows of carbonic gas and methane of forest-steppe Sphagnum bogs in view of coenotic structure and damage to vegetation cover as a result of fire.

OBJECTS AND METHODS

Research was carried out in the Baraba steppe in the years 2009 and 2010. Flows of carbonic gas and methane were mainly observed in summer, in the end of June, beginning of July and in Autumn, in September and October in the raised Sphagnum bog (RB1) with the area of about 4 km^2 (55°14′ N 79°05′ E). The bog was formed in a small roundish surface valley. The central part of peat-bog raising above the elements of the surrounding landscape is well pronounced. Maximal depth of the peat bed is 4.5 m. About 80% of the bog area is occupied with pine-dwarf Sphagnum association (PDS, riam). In the moss cover Spagnum fuscum (Schimp.) Klinggr prevails. In the northwestern part of the bog in the local lowering a small lake was formed. 50–60 m wide band from riam to the lake is occupied with sedge-Sphagnum association (SS, bog). The bog complex is bordered with highly-productive sedge-reed and reed associations.

To measure the rate of carbonic gas and methane emission 2 and 60 l volume exposure chambers were used. Internal air circulation was provided with the use of the built-in ventilator. Steel non-corrosive bases of the chambers were in advance embedded at 10 cm in the upper layer of peat. During exposition (15–30 min) the chambers were covered with light-proof case with reflecting layer from aluminum foil.

Calculation of CH_4 and CO_2 flows is based on a linear regression model of gas concentration change inside the chamber during exposition. Analysis of gas samples was performed at the laboratory conditions

with Crystal 5000 chromatographer. During the field experiments we performed automated registration of carbonic gas concentration, air temperature and relative humidity inside the chambers with gas-analyzer Testo-435 (Germany), peat temperature at the depth of 140 cm and air in the surface layer at Sphagnum surface (T-175). Evaluations of carbonic gas flows obtained with the use of gas analyzer and gas chromatographer differed insignificantly ($F_{ga} = 0.99 \times F_{gc}$; $R^2 = 0.86$; $n = 23$) that proves reliability of the obtained results.

For comparison analogous measurements of CH_4 and CO_2 emission were performed at the raised peat-bog (RB2) recovering after 10–15 years ago fire and located 30 km to the north from RB1. The bog complex of an oval shape and the area of about 2.5 km^2 was formed in local lowering at the low ridge foot. The well pronounced is the coenotic structure of the bog with raised central part (riam) and periphery (reed, sedge-reed and small-reed associations). Maximal depth of peat bed is 3.5 m. Vegetation cover in the central part of riam is strongly transformed. The rarefied wood stage consists of *Pinus sylvestris* L. with the height up to 10–12 m and birch under-bush *Betula pubescences* Ehrh. Among dwarf-shrub the prevailing are *Ledum palustre* L. and *Chamaedaphne calyculata* (L.) Moench. forming thick beds. Both bog complexes are in one bioclimatic zone and comparatively close to each other. This allowed excluding influence of climatic factors from consideration.

Bog water samples from different depths were selected with the use of metal tube and syringe. The first portion of water filling the tube was not used. At the laboratory conditions the syringe with bog water was fully filled with argon (20 ml). After the equilibrium setting gas phase was analyzed with chromatographer according to the standard method [8]. Access of atmosphere air at selection of bog water and preparation of samples to analysis was excluded due to the use of the three-way cock. The level of bog water (LBW) and depth of sample selection was counted from the surface of the moss layer.

RESULTS AND DISCUSSION

Temperature conditions and atmospheric precipitates for the years of research quite complied with the figures characterizing weather and climatic conditions of the forest-steppe zone (Fig. 1). Annual amount of precipitates varied from 350 to 390 mm. Average monthly temperature in July in 2009–2010 was 17–18°C. Warmer and more humid conditions were set in July of 2008. Distribution of summer precipitates over the months in different years has an unstable character. In 2009 from May to October the level of precipitation was 206 mm. Maximal amount (79 mm) fell to July. For the same period of 2010 the amount of precipitations was 179 mm from which 90 mm fell in June. Lack of atmospheric damping in summer-Autumn period contributed to lowering of bog water level in the

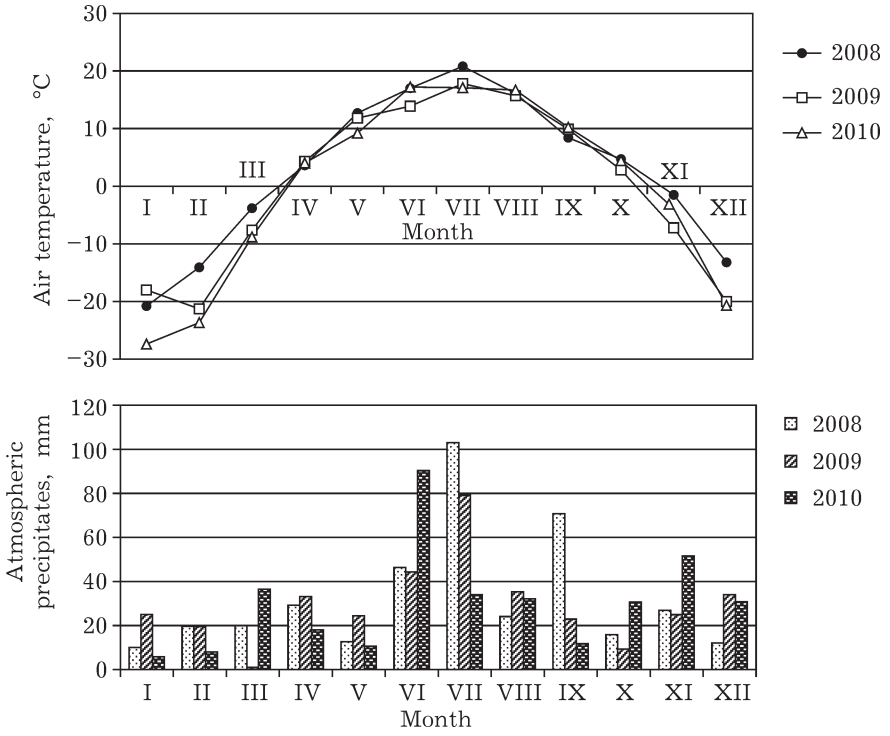

Fig. 1. Air temperature and atmospheric precipitates in the area of research. Weather station "Barabinsk" (the data were provided at the web-site "Weather time-table" http://rp5.ru/).

Emission of carbonic gas and methane at control (RB1) and (RB2) raised bog recovering after fire, mg/(m^2 · h)

Object	CO_2 ($\bar{E} \pm \sigma$)	CH_4 ($\bar{E} \pm \sigma$)	*n*
RB1	Sedge-Sphagnum association (lakeside band)		
	142.4 ± 42.5	0.89 ± 0.70	10
	Sedge-reed association (periphery of bog complex)		
	370.6 ± 210.5	15.67 ± 13.72	11
	Pine-dwarf-Sphagnum association (central part)		
	279.0 ± 161.3	0.08 ± 0.12	14
RB2	Reed-sedge association (periphery of bog complex)		
	620.9 ± 145.1	4.47 ± 2.90	2
	Pine-dwarf association with Sphagnum spots (central part)		
	426.5 ± 190.1	0.06 ± 0.06	8

central part of the bog complex RB1 (to 50–60 cm) and complete drying up of its peripheral part occupied by sedge-reed association.

As observations showed pyrogenic factor plays a key role in forest-steppe raised bog development (Sphagnum burnout, cessation of peat accumulation, spread out of bushes and dwarf-shrubs, change of forest structure). Breach of vegetation cover causes changes in water regime for the entire bog complex. An evidence of frequent fires (with 15–20 years periodicity) is thin strata of coaly particles in the vertical section of peat-bog RB2. In the table we may see values of carbonic gas and methane flows in the selected objects average for the entire period of observation. Despite absence of sphagnum (projective cover 3%) the overall emission of carbonic gas in the central part of the burnt peat-bog turned out to be somewhat higher than in the inviolate bog. Methane emission in riam associations was insignificant. Marsh ecosystems located in the periphery of bog complexes were characterized by higher rate of carbonic gas and methane emission. Intermediate values of greenhouse gas flows were obtained for sedge-Sphagnum association formed under the influence of in-bog lake.

Difficult recovery of Sphagnum cover after the fire is apparently bound with insufficient amount of atmospheric precipitates at forest-steppe conditions. Lack of moss layer in the structure of vegetation cover could cause the shift of water balance in the entire bog complex. At least at almost equal conditions of the atmospheric damping in Autumn of 2009 the level of bog water in the periphery part of the studied objects differed by 30–50 cm. High rate of carbonic gas emission, the lowest possible projective cover with Sphagna, and lack of signs of raised peat accumulation result from pyrogenic factor impact.

Besides evaluation of the content of gases dissolved in bog water revealed the difference between main types of bog complex ecosystems (Fig. 2). Concentration of methane dissolved in water of sedge-Sphagnum bog formed in forest-steppe conditions is higher than in ecosystems of middle and northern taiga of the same type [8]. Its values 2–6 mg/l more agreed with the concentration range fixed in the bogs of southern taiga [9–11]. In relation to the content of dissolved carbonic gas the analogous trend was observed.

The general regularity of the increase of the dissolved CH_4 and CO_2 content with depth is confirmed for the raised Sphagnum bog of the forest-steppe zone. The rate of methane emission to atmosphere was higher at the higher level of its content in the bog water SS compared with PDS. The calculations have shown that the diffusion flow of methane in liquid phase could

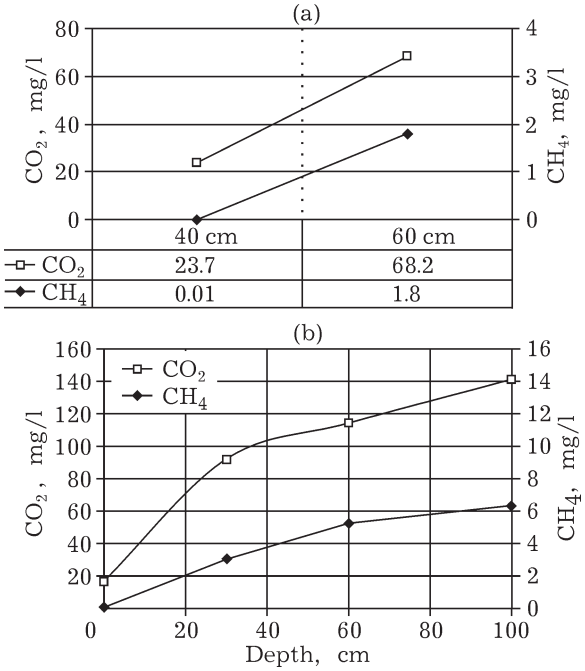

Fig. 2. Content of dissolved gases in bog water of pine-dwarf-Sphagnum (a) and sedge-Sphagnum (b) ecosystems (2.07.2010).

make up to approximately 30% of overall emission to atmosphere registered with the use of exposition chambers in sedge-Sphagnum phytocenosis.

At the same time significant share of the dissolved carbonic gas and methane in water of the central part of the raised complex bog RB1 (PDS phytocenosis) is an indicator of mineralization and methanogenesis activeness in the peat bed. Consider possible reasons for the low rate of methane emission in such bog ecosystem. In our opinion the major factors influencing methane emission from the peat thickness to atmosphere is low temperatures of water and peat, formation of condensed layer, and oxidation of methane with microorganisms. Imperfect procedure of exposition chambers installation, complex character of bog nano-relief, and loose structure of the upper layer of peat-bog add uncertainty in the estimates of the considered indicator.

Despite the comparatively high air temperature at Sphagnum surface (Fig. 3) peat at the depth of 10–15 cm warmed up weakly in the beginning of July. Depending on nano-relief temperature of the upper 10 cm layer of peat changed within the limits 0.3–4.3°C. In some places locally there were icy formations. Minimal daily temperatures of air in the ground layer at that time fall on the early morning hours. In the depth of the peat bed (140 cm) daily variations of temperature are practically absent. During warm period of the year the temperature regime of low horizons changes slightly. Early autumn frost along with bog water level (BWL) decrease contributes to permeation of low temperatures in the zone of intense gas exchange.

Formation of condensed horizon at the depth of about 80 cm was found at the upper dead-layer boring. At the depth 100–120 cm intense emission of marsh gas enriched by methane was observed. Decrease of dissolved CH4 concentration to minimal value 0.01 mg/l at the depth of 40 cm (at average value of BWL of 24 cm) may also prove its consumption by microorganisms. Thus, imperfection of the method in combination with peculiarities of the bog surface nano-relief is the major reason of uncertainty in evaluations of emission flows in the given locality.

CONCLUSIONS

Investigation of the major functional characteristics of the raised Sphagnum bogs of the forest-steppe zone is topical in relation to modern dynamics in the global climatic system and changes in the natural environment. The obtained estimates of major parameters of CO_2- and CH_4-gas exchange compared to analogous characteristics of bog eco-systems of taiga zone allow

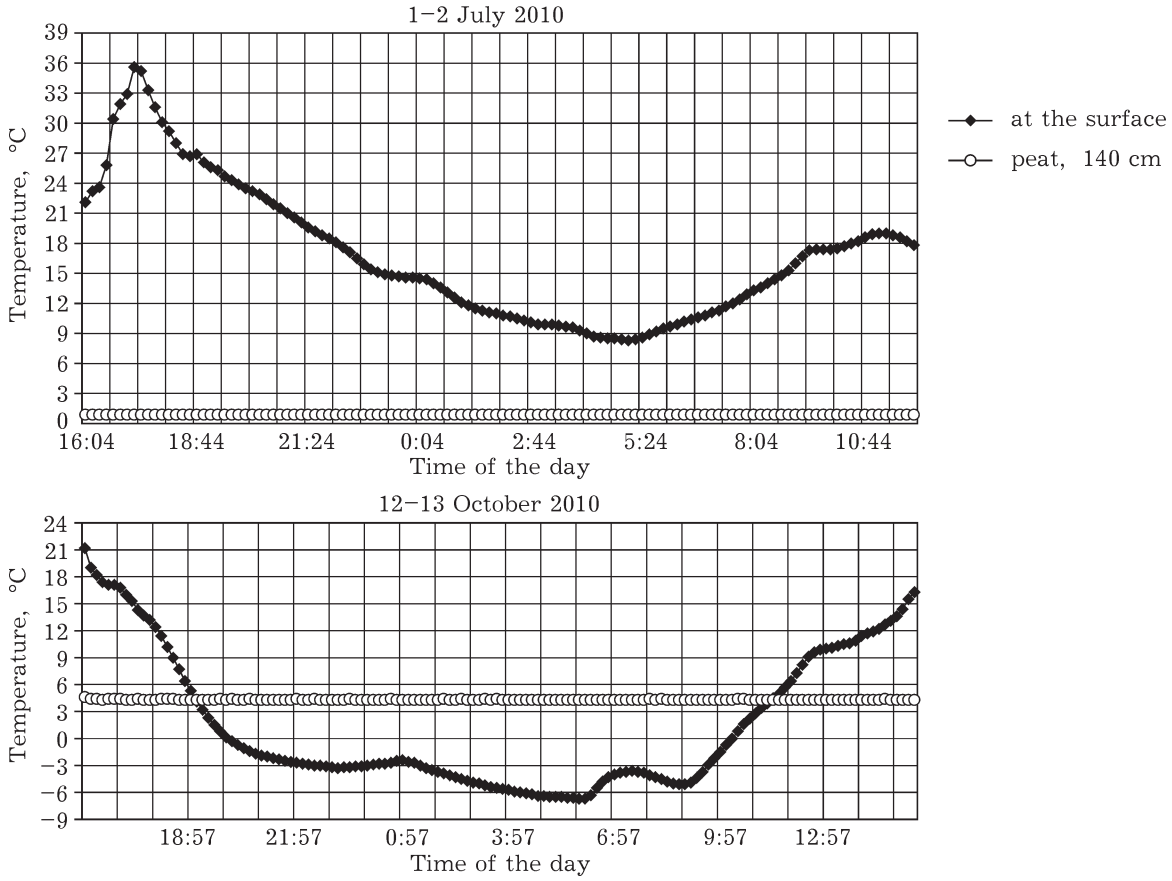

Fig. 3. Temperature conditions of emission flow formation in pine-dwarf-Sphagnum association (riam peak).

enlarging the information base. Data on modern processes in the peat-Sphagnum bogs may serve a starting point for organization of ecological monitoring and development of the forecast of forest-steppe landscape dynamics. The fact that these objects lose the function of atmospheric CO_2 binding and regulation of water-carbon balance of the territory as a result of pyrogeneous factor and economic activities of a human being make us consider them as structural elements of landscape with higher ecological risk.

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