ISSN 0096-3925, Moscow University Biological Sciences Bulletin, 2017, Vol. 72, No. 2, pp. 52–58. © Allerton Press, Inc., 2017.
Original Russian Text © V.A. Kudryavtseva, T.A. Belevich, L.S. Zhitina, 2017, published in Vestnik Moskovskogo Universiteta, Seriya 16: Biologiya, 2017, Vol. 72, No. 2, pp. 63–69.

HYDROBIOLOGY

Diatoms in the Ice of Velikaya Salma Strait, the White Sea, before the Spring Algal Bloom[1]

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Received December 7, 2016; in final form, March 2, 2017

Abstract—Diatom species composition in the ice of Velikaya Salma strait of Kandalaksha Bay of the White Sea was studied in 5 stations in March, 2013–2014—prior to the spring algal bloom. Under-ice water salinity and ice thickness did not differ significantly between the two years. In total 59 diatom taxa (47 species and 12 taxa of higher taxonomic ranks) were found in the ice of Velikaya Salma strait, which makes 61% of the number of diatom taxa found in Velikaya Salma ice during the whole ice period and 22% of all the White Sea ice species. Species *Stenoneis obtuserostrata* (Hustedt) Poulin and *Gyrosigma concilians* (Cleve) Okolodkov were identified in the White Sea ice for the first time. Szymkiewicz-Simpson similarity coefficient for pairs of stations with significant difference was 0.44–0.80.

Keywords: White Sea, diatoms, ice algae, *Stenoneis obtuserostrata*, *Gyrosigma concilians*.

DOI: 10.3103/S0096392517020080

Algae and cyanobacteria inhabiting the ice play key role in matter and energy fluxes in polar ecosystems [1, 2]. Ice photoautotrophic organisms contribute up to 57% to primary production in Central Arctic [2]. Organic matter, produced by ice algae and cyanobacteria, is used by planktonic and benthic animals [3]. Diatoms is the most versatile group of photoautotrophic organisms, inhabiting sea ice [4] and giving the major contribution to the total biomass of ice algae [5].

Warming of the Arctic in the recent decades [6] leads to reduction of ice cover, its thickness, and increasing of the first year ice surface [7]. Such changes of the ice cover may affect both composition and amount of primary production of ice autotrophs [8, 9]. Therefore, analysis of biota of first year ice, and the ice of the White Sea belongs to this type, gains more and more importance.

Ice cover of the Subarctic White Sea is seasonal, it exists for 4–5 months [10]. In December ice cover surface and thickness grow, in February and March the ice gains relative stability, in April and May it thaws.

To date, quite a large amount of data has been accumulated upon the White Sea ice inhabitants [8, 10, 11]. Previous research in Velikaya Salma strait showed, that ice algae biomass peaks in April [11]. Species composition and abundance of ice algae are subject to pronounced space and time variability, which proves the importance of annual monitoring of ice algae in different parts of the sea.

The aim of present study is to investigate the taxonomic composition of diatoms in Velikaya Salma strait of Kandalaksha Bay of the White Sea in March 2013 and 2014—time before the spring algal bloom. We also aimed to compare this diatom species composition with that of the Arctic seas.

MATERIALS AND METHODS

Research was conducted in Velikaya Salma strait in March 2013 and March 2014 at Nikolai Pertsov White Sea Biological station (WSBS) of Lomonosov MSU. Sampling was performed at five stations (Fig. 1).

At each station 1-2 ice cores were drilled using an ice corer with 15 cm internal diameter. Each core was divided into parts to reduce melting time. Parts of cores were placed in separate plastic containers and melted at room temperature; to prevent cell damage from osmotic stress no less than 1 litre of sea water, previously filtered through 2 μm pore membrane filter and sterilised, was added to each container [12]. Melted ice samples were concentrated by means of backward filtration and preserved with Lugol's solution. Diatom species were identified in concentrated samples in light microscope MICMED-1 (LOMO, Russia) at 100–400x magnification. For more precise

[1]The article was translated by the authors.

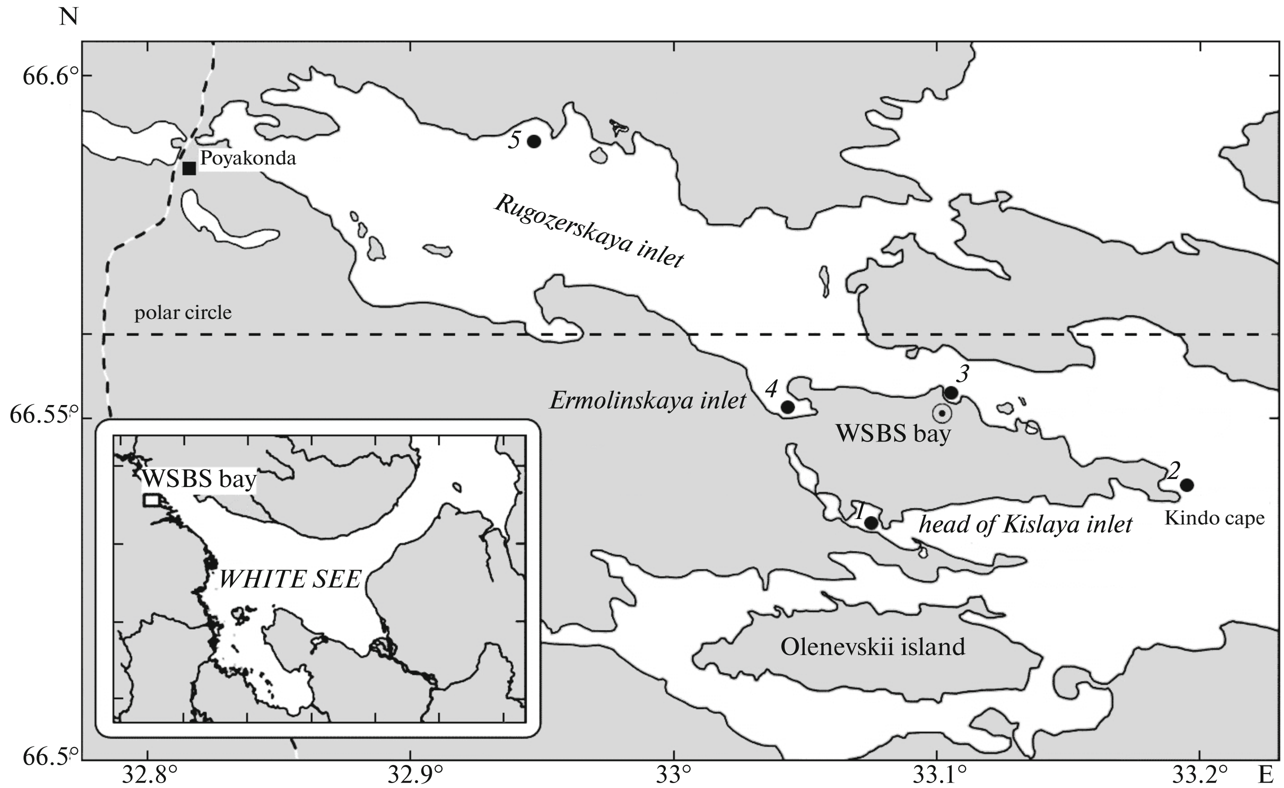

Fig. 1. Map of study area and sampling stations: *1*—head of Kislaya inlet; *2*—Kindo cape; *3*—WSBS bay; *4*—Ermolinskaya inlet; *5*—Rugozerskaya inlet.

identification permanent slides were made for light and scanning electron microscope (CAMScan, Great Britain). H_2O_2 (15%) and concentrated H_2SO_4 with $K_2Cr_2O_7$ were used to clear the cells of organic components [13].

Salinity of ice samples, melted without addition of sea water, and of under ice water samples was determined with conductometer Cond 3150i (WTW, Germany).

Species composition similarity was evaluated using Szymkiewicz-Simpson similarity coefficient (S):

$$S = a/[a + \min (b, c)],$$

where a is the number of common species for the two compared algal communities, min (b, c) is the minimal number of species, recorded from only one of those communities. Groups of species *Navicula* spp. and *Nitzschia* spp., comprising unidentified species of respective genera, were excluded from similarity analysis.

RESULTS AND DISCUSSION

Abiotic factors. According to the data of the meteorological station of WSBS, average day temperature in February and March was higher in 2014 than in 2013. However, ice cover thickness at stations did not differ significantly in 2013 and 2014 (Table 1). Sea depth varied from 2 to 6 m at stations. Under ice water salinity varied between 21.9–26.7‰. Salinity of melted ice samples varied between 0.2 and 5.2‰. The lowest layer of ice cores (1–2 cm thick) at station 4 (2013 and 2014) and station 5 (2014) had visible brown colouring, pointing to high algal biomass. According

Table 1. Ice thickness (IT, cm) and snow cover thickness (SC, cm), under-ice water salinity (Sw, ‰) at sampling stations

Station	Year	IT, cm	SC, cm	Sw, ‰
1	2013	70.5	9	24.9
	2014	58	1	25.6
2	2013	33	10	25.5
	2014	26	<1	25.5
3	2013	21.5	9	24.5
	2014	49	3	24.5
4	2013	55	25	22.0
	2014	52	0.5	21.9
5	2013	47	20	26.6
	2014	45	5	26.7

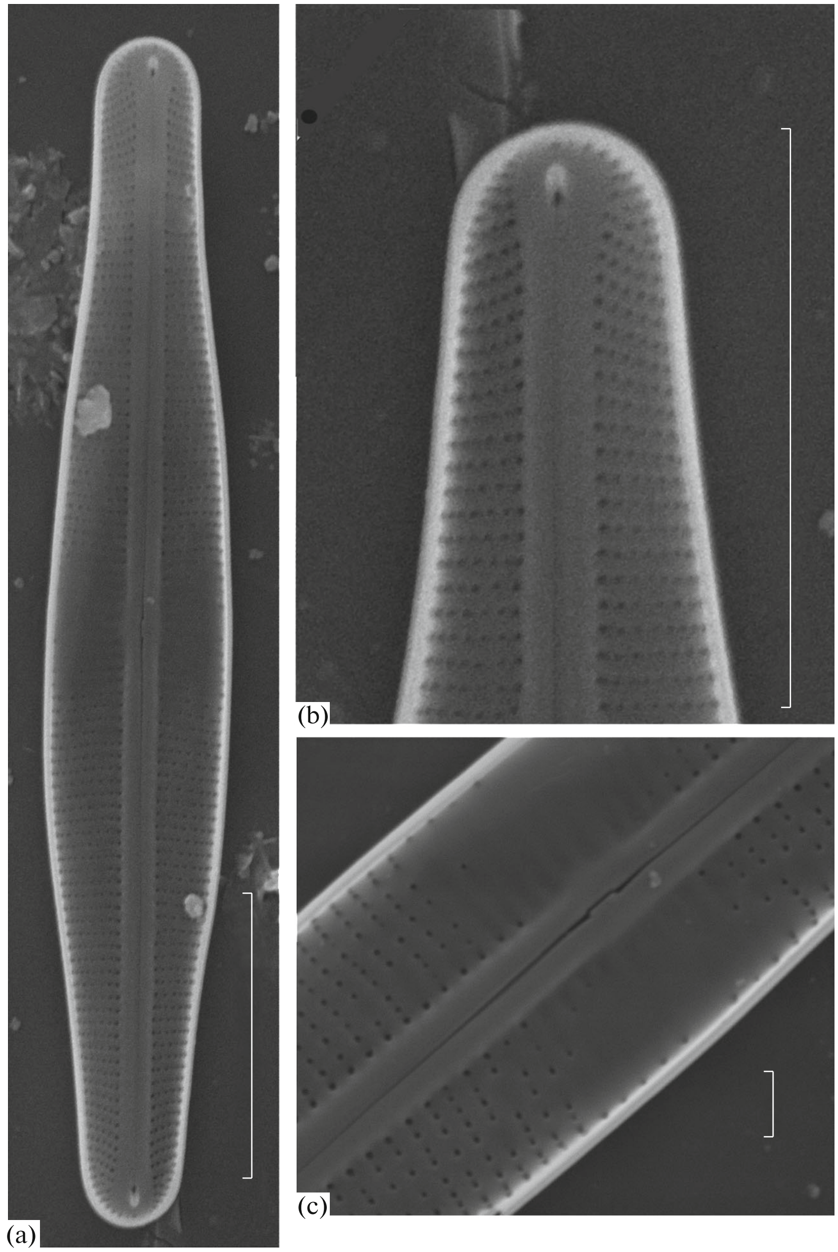

Fig. 2. SEM images of *Stenoneis obtuserostrata* (Hustedt) Poulin: a—whole valve; b—end of the valve; c—valve centre. Scale bar: a, b—10 μm, c—1 μm.

to existing data, total biomass of ice algae reaches its maximum in April. This means that our research, conducted in March, took place at the beginning of the time of active algal growth and biomass accumulation.

Taxonomic composition of diatoms. In total, 59 diatom taxa of different level were found in the ice of Velikaya Salma strait (Table 2). Part of the algae was determined to the genus level or higher. For such forms ecological preference is not determined. Out of those diatoms, that were determined to species level, 23 are typically ice species, or ice is one of their priority habitats. Planktonic diatoms (18 species) constituted a considerable proportion (38%) of all the diatoms, identified to species level.

These 59 diatom taxa comprise 61% of diatom taxa, recorded in the strait during the whole ice cover period (97 taxa, [11]) and 22% of all the ice diatom species of the White Sea (272 taxa, [5]).

Pennate species (Bacillariophyceae, 38 species) prevailed, which is a characteristic feature of ice algae communities of the Arctic seas [4].

Two species—*Stenoneis obtuserostrata* и *Gyrosigma concilians* (station 2) (Figs. 2 and 3)—were discovered in the White Sea ice for the first time. These species

Table 2. List of diatoms, recorded in the ice of Velikaya Salma strait of the White Sea at all stations, and their ecological preference (EP)

Species*	EP**	Stations				
		1	2	3	4	5
Coscinodiscophyceae						
Melosira arctica Dickie	I	+			+	+
Mediophyceae						
Attheya septentrionalis (Østrup) Crawford	P, I		+	+	+	+
Chaetoceros cf. *socialis* H.S. Lauder	P	+			+	+
Chaetoceros holsaticus F.Schütt	P				+	
Chaetoceros sp.	–		+		+	+
Skeletonema costatum (Greville) Cleve	P				+	
Skeletonema cf. *marinoi* Sarno & Zingone	P		+			
Thalassiosira hyalina (Grunow) Gran	P		+			
Thalassiosira nordenskioeldii Cleve	P				+	
Thalassiosira pacifica Gran & Angst	P		+			
Thalassiosira sp.	–		+	+	+	+
Bacillariophyceae						
Cocconeis sp.	–	+	+			+
Bacillariophyceae gen. sp.	–	+	+	+	+	+
Cylindrotheca closterium (Ehrenberg) Reimann & Lewin	P, I, B	+	+	+	+	+
Diploneis litoralis (Donkin) Cleve	B	+			+	+
Diploneis litoralis var. *clathrata* (Østrup) Cleve	B		+		+	
Entomoneis alata (Ehrenberg) Ehrenberg	I				+	+
Entomoneis kjellmanii (Cleve) Poulin & Cardinal	I				+	
Entomoneis paludosa (W. Smith) Poulin & Cardinal	I, B		+			+
Entomoneis paludosa var. *hyperborea* (Grunow) Poulin & Cardinal	I, B				+	+
Entomoneis sp.	–				+	+
Fallacia forcipata var. densestriata (A.W.F.Schmidt) Gogorev	I, P, B		+			
Fragilariopsis cylindrus (Grunow) Kriegera	P, I	+	+	+		
Fragilariopsis oceanica (Cleve) Haslea	P	+		+	+	
Fragilariopsis sp.	–	+		+		
Gomphonema exiguum var. *arctica* (Grunow) Cleve	B				+	
Gomphonema sp.	–				+	
Gyrosigma concilians (Cleve) Okolodkov	I		+			
Haslea sp.	–				+	
Licmophora sp.	–				+	
Lyrella sp.	–				+	
Martyana martyi (Héribaud-Joseph) Round	B		+			
Navicula algida Grunow	I					+
Navicula directa (W. Smith) Ralfs	I, P,B		+		+	+
Navicula granii (Jørgensen) Gran	P					+
Navicula cf. *kariana* var. *detersa* Grunow	P, I				+	+
Navicula pelagica Cleve	I, P	+	+	+	+	+
Navicula transitans Cleve	I		+		+	+
Navicula transitans var. *derasa* (Grunow) Cleve	I, B			+		

Table 2. (Contd.)

Species*	EP**	Stations				
		1	2	3	4	5
Coscinodiscophyceae						
Navicula cf. *valida* Cleve & Grunow	P		+		+	+
Navicula spp.	–	+	+	+	+	+
Nitzschia frigida Grunow	I	+	+	+	+	+
Nitzschia neofrigida Medlin	I, P	+			+	+
Nitzschia cf. *polaris* Grunow	P, I				+	
Nitzschia cf. *sinuata* (Thwaites) Grunow	P		+		+	+
Nitzschia cf. *subtilis* (Kützing) Grunow	F, P				+	
Nitzschia tryblionella Hantzsch	P					+
Nitzschia spp.	–	+	+	+	+	+
Pauliella taeniata (Grunow) Round & Basson	P, I	+	+			
Pinnularia quadratarea (Schmidt) Cleve	P, I	+			+	+
Pinnularia quadratarea var. *bicontracta* (Østrup) Heiden	P				+	
Pleurosigma angulatum (J.T.Quekett) W.Smith	P				+	
Pleurosigma elongatum W.Smith	P		+			
Pleurosigma cf. *normanii* Ralfs	P				+	
Pleurosigma stuxbergii Cleve & Grunow	I		+	+		
Pseudo-nitzschia cf. *seriata* (Cleve) H. Peragallo	P		+			
Stenoneis obtuserostrata (Hustedt) Poulin	I, P		+			
Tetracyclus cf. *lacustris* Ralfs	F, B		+			
Tryblionella cf. *littoralis* (Grunow) D.G.Mann	I	+				

Note: *—given according to the latest taxonomic revisions [24], **—given according to [25]. Key: B—benthic, F—freshwater, I—ice, P—plankton.

were previously detected in the ice of the Arctic shelf seas—Chukchi, East Siberian, Laptev [14]. *G. concilians* was also identified in the Barents sea ice [14].

Integral biomass of ice algae of the White sea varied between 2.5 and 38.4 mgC/m^2. Diatoms contributed 58–90%. Colony-forming pennate species such as *Nitzschia frigida*, *Navicula pelagica* and *Fragilariopsis cylindrus*, and also large cell species *Pleurosigma stuxbergii* dominated at different stations. High abundance of these species is typical for the Arctic ice [14]. However, high contribution to biomass at station 2 (2013) was made by *Thalassiosira* sp. Dominance of *Thalassiosira* species is unusual for ice communities, but has already been registered in landfast ice in Kandalaksha bay [11].

Table 3. Szymkiewicz-Simpson similarity coefficient for diatom species composition in the ice of Velikaya Salma strait

Stations	1	2	3	4
2	0.47**			
3	0.64^	0.73*		
4	0.60**	0.44**	0.64**	
5	0.67*	0.52*	0.73*	0.80^

Key: *—differences significant at $p = 0.05$; **—differences significant at $p = 0.01$; ^—differences insignificant.

Similarity of diatom taxonomic composition at different stations. The highest number of taxa was found at station 4 (38), the lowest—at station 3 (13).

Diatom species composition differed significantly between the stations, except pairs of stations 1 and 3, 4 and 5. Szymkiewicz-Simpson similarity coefficient for pairs of stations with significant difference was 0.44–0.80. Diatom community at station 2 was least similar to that at other stations, probably due to its position at the open part of the strait, where ice cover is most subject to deformation [11]. In general, pronounced spatial variability of composition and structure is typical for ice algae communities. Mesoscale (hundreds of metres to kilometres) variability is determined by combination of factors, the most important of which are: light conditions depending on ice and snow thickness [15–17], nutrient concentrations [15, 18], salinity and temperature [19], ice porosity and

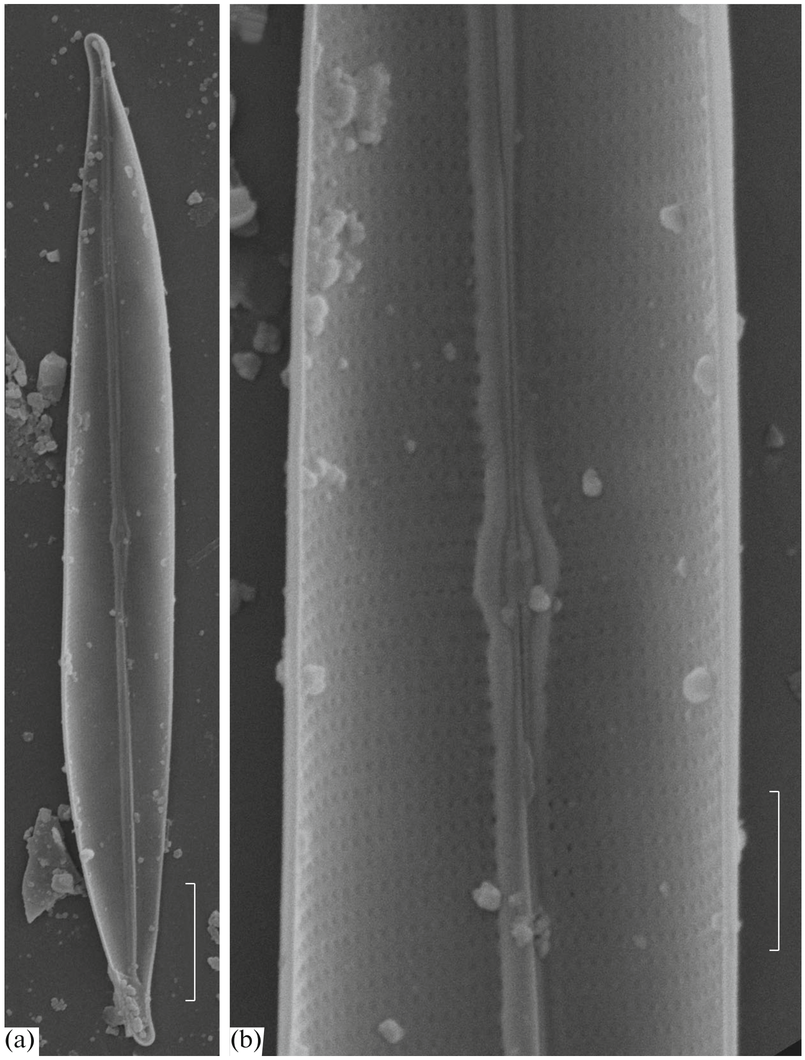

Fig. 3. SEM images of *Gyrosigma concilians* (Cleve) Okolodkov: a—whole valve, b—central part of the valve. Scale bar: a—10 μm, b—3 μm.

morphology of its bottom layer [20, 21], origin and physical deformation of the ice cover [16].

Variability of ice algae communities at the scale of thousands of kilometres may be illustrated by comparing ice diatom composition of Velikaya Salma strait of the Subarctic White Sea (present study) to that of land fast ice of the Arctic Beaufort sea at the winter to spring transition period [22]. Comparison showed significant difference between the two communities (p = 0.01), similarity coefficient being 0.45. Among diatoms that were common for both communities (21 taxa) prevailed those whose priority habitat was ice.

Similar analysis demonstrated even less similarity between ice diatoms of Velikaya Salma and of the vicinity of the North Pole in summer [23]. Similarity coefficient was 0.26. Species common for both regions were ice (*Nitzschia frigida*, *Nitzschia neofrigida*, *Melosira arctica*, *Fallacia forcipata* var. *densestriata*, *Fragilariopsis cylindrus*, *Navicula algida*, *Navicula directa*, *Cylindrotheca closterium*, *Navicula transitans*, *Navicula transitans* var. *derasa*, *Pinnularia quadratarea*), planktonic (*Thalassiosira nordenskioeldii*) and benthic (*Diploneis litoralis* var. *clathrata*) ones.

In summary, 47 species and 12 other higher taxa of diatoms were registered in the ice of Velikaya Salma straight of Kandalaksha Bay of the White Sea in the time before the spring bloom (March, 2013 and 2014). This number of diatom species constitutes 61% of those found in the ice of the strait during the whole ice period and 22% of all the diatom species recorded in the White Sea ice.

Stenoneis obtuserostrata and *Gyrosigma concilians* were identified in the White Sea ice for the first time; these species were previously recorded in the ice of the Arctic shelf seas.

Taxonomic composition of ice diatoms was characterised by pronounced mesoscale spatial patchiness. Similarity coefficient between pairs of stations with significantly different species composition was 0.44–0.80.

We are especially ebdebted to Elena D. Krasnova, Ph. D., Dmitry A. Voronov, Ph. D., and members of the WSBS for assistance in the field and laboratory.

The study was performed as a part of the government task of Lomonosov MSU, part 2 (topic AAAA-A16-116021660052-0) and with funding support of the Russian Science Foundation (project 14-50-00029).

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