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Current hydroecological situation of the Starooskolsko-Gubkinsky mining region on the example of the Oskolets River

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Abstract
The results of the hydroecological study of the small Oskolets river in the area of influence of mining enterprises are presented. It is shown that the residential industrial flow of Gubkin city has a leading influence on the hydrochemical situation. Discharges of drainage waters made by the Lebedinsky mining and processing plant have a definite impact on the hydro-ecological situation with respect to the content of fluorine and lead compounds, and occasionally with respect to nitrogen compounds. The dynamics of hydrochemical indicators makes it possible to note trends related both to the production activities of the mining complex and the development of agricultural and industrial-urban infrastructure. In particular, there is an increase in the contribution of nitrogen, nickel, and sulphate compounds from the industrial and urban sector of Gubkin city, a slight increase in the supply of copper from residential and agricultural areas with periodic peak values of copper concentrations from the urban sector.

Keywords: hydrochemical indicators, hydroecological situation, ecology of the mining region, water pollution indicators

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INTRODUCTION

Catchment basin of Oskolets river is located on the territory of the Starooskolsko-Gubkinsky mining region and, accordingly, is saturated with agricultural and industrial enterprises of various sectors of the economy. Almost the entire territory of this mountain-industrial region is characterized by varying degrees of environmental disturbance due to human activities (Kornilov et al. 2010, 2013, Petina et al. 2014). Here, the natural landscapes are greatly modified under the influence of buildings of Gubkin and Stary Oskol cities, as well as a whole complex of mining and other enterprises. In recent years, the architectural and industrial infrastructure of the district is actively developing, the mining and processing of iron ore, the volume of drainage water from the iron ore quarry to the Oskolets river has increased, the industrial infrastructure of other industrial enterprises in Gubkin and Stary Oskol cities has been modernized, and the elements of intensive agricultural production in suburban areas have been introduced. Changes in the production sector are obviously reflected in the dynamics of hydrochemical indicators, which are monitored according to Rosgidromet (Stock materials of the … n.d.).

MATERIALS AND METHODS

There are 3 sites for observation by Roshydromet on Oskolets river (**Fig. 4**): 1) it is located above Gubkin city, where the anthropogenic load on the catchment area is represented mainly by diffuse residential and agricultural flows; 2) it is below Gubkin city, here is the unorganized surface runoff of storm and melt water from urban areas and the discharge from urban sewage treatment plants, where the combined production and municipal wastewaters flow, have an additional effect on river water; 3) on the territory of Stary Oskol city, before Oskolets river falls into Oskol river, in the area between the second and third sections, drainage waters from the Lebedinsky mining and processing plant come in substantial volumes, the volumes of residential and agricultural diffuse flow, as well as unorganized diffuse flow of storm and melt waters of the territory of Stary Oskol city are supplemented.

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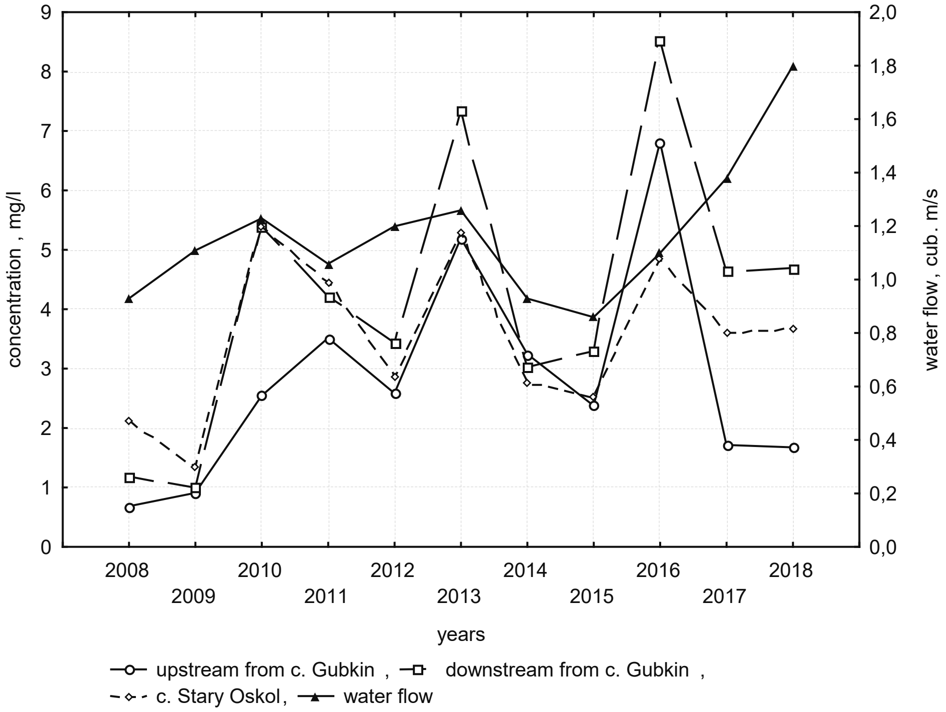

Fig. 1. Nitrate content in Oskolets river (Roshydromet) for 2008–2018

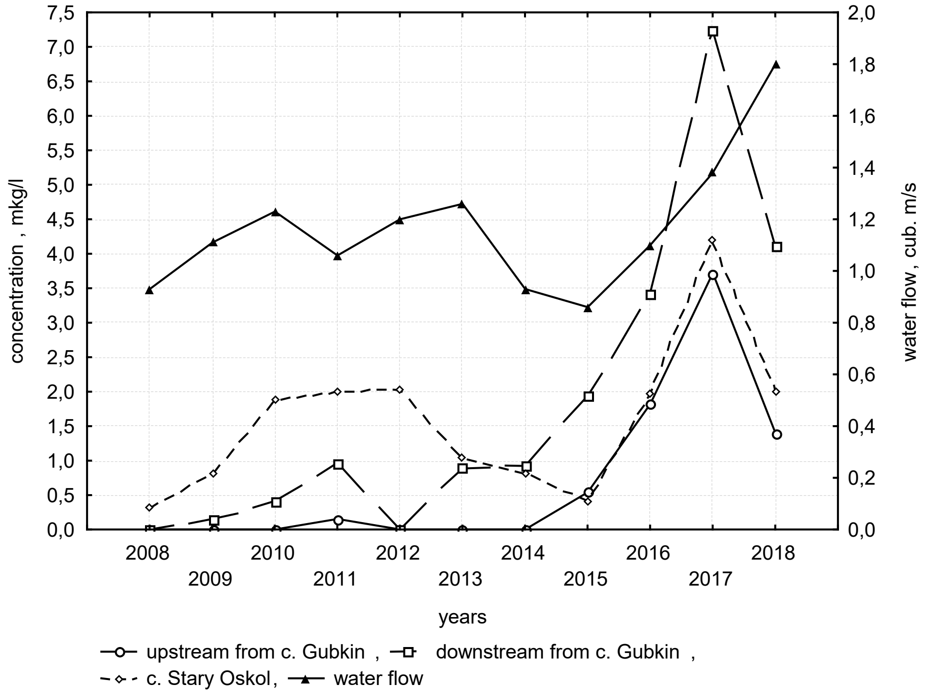

Fig. 2. Zinc content in Oskolets river (Roshydromet) for 2008–2018

RESULTS AND DISCUSSION

Significant changes in the time of hydrochemical state of Oskolets river are presented both in the corresponding graphs of changes in the concentrations of background and pollutanting means dissolved in river water (examples for nitrates and zinc are given in **Figs. 1** and **2**) and in the dendrogram of grouping of average annual hydroecological situations (**Fig. 3**). The inclusion of hydrometric data in the complex of indicators for cluster analysis (data on the annual water flow in Oskolets river) does not affect the nature of grouping of annual hydroecological situations, although the literature

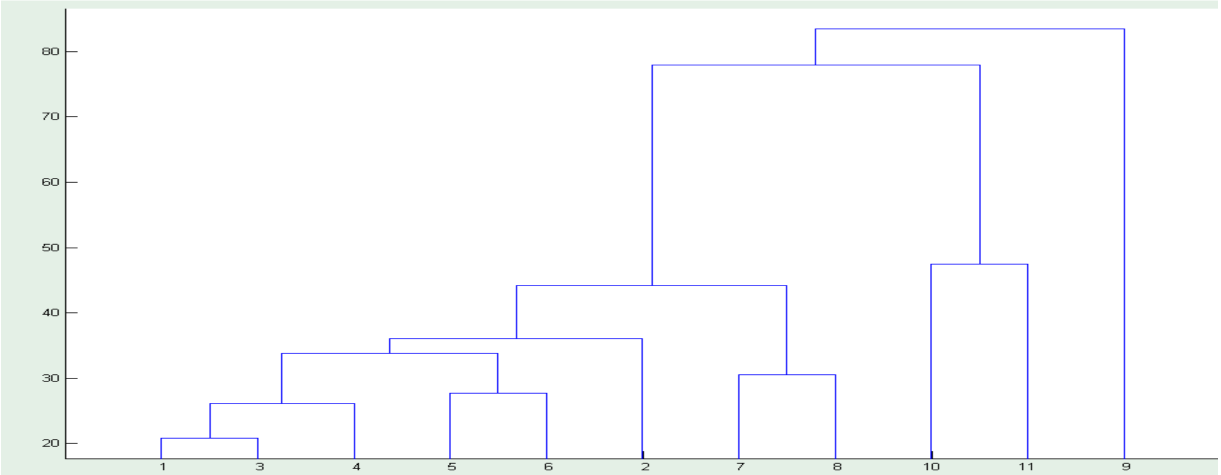

Fig. 3. Grouping of average annual hydroecological situations on Oskolets river of the Belgorod Region (from 1 to 11 years of observations for the corresponding period from 2008 to 2018)

Table 1. The correlation coefficients of the indicators of pollution content in relation to the indicators of content of the same substances in the previous sections

Sections No.	Mg	Cl	SO_4	BOD_5	NH_4	NO_2	NO_3	PO_4	Fe	Cu	Zn	Ni	Nft
2/1	0.56	**0.74**	**0.66**	**0.89**	0.54	0.47	**0.86**	**0.95**	**0.72**	**0.72**	**0.97**	**0.69**	0.53
3/1	0.13	0.44	0.49	**0.60**	**0.67**	0.11	**0.68**	**0.73**	0.34	0.17	**0.80**	0.23	0.40
3/2	0.50	**0.79**	**0.73**	0.57	0.08	0.22	**0.88**	**0.82**	0.20	0.13	**0.76**	**0.63**	0.01

Note: dependent and strongly dependent relationships are highlighted in bold

has adopted a statement about the determination of the relationship between the water regime and surface water pollution features (Barinova et al. 2006, Ter Braak and Verdonschot 1995).

The dendrogram shows that complex changes of state have been gradually increasing from 2014–2015 (clauses 7–8 in **Fig. 3**) and continue to increase in 2016–2018 (clauses 9–11 in **Fig. 3**).

The dynamics of hydrochemical indicators makes it possible to note trends related both to the production activities of the mining complex and to the development of agricultural (first section) and industrial-urban infrastructure (2 and 3 sections for Gubkin and Stary Oskol cities). In particular, this is an increase in the contribution of nitrogen, nickel, and sulphate compounds from Gubkin city, a certain increase in the supply of copper from residential and agricultural areas with periodic peak contributions to the copper content from the urban sector.

The analysis results of pairwise correlation of the content of chemical components in the waters of Oskolets river indicate a negative relationship between water consumption indicators in the river and indicators of substances that are indicators of fresh municipal pollution. In particular, r = - 0.75 for the ammonium ion in the first section, r = - 0.77 in the third section due to the dilution of the diffuse runoff of extensive residential areas not equipped with sewage systems. No connection was found between the indicators in the second section after the wastewater treatment plant of urban wastewaters. For cases of hydroecological situation with a large proportion of groundwater flow, there is a greater or lesser degree of relationship between water consumption and metal content: in the first section - Cu (r = 0.58), in the second section - Zn (r = 0.52), in the third section - Ni (r = 0.76) and Zn (r = 0.56). No relationship was found in relation to the water flow features for the rest of the ingredients.

The weak correlation between the indices of consumption and the content of metal ions indicates the complex origin of metal ions in river water, both due to diffuse and sewage runoff. Indicators of the content of petroleum products in the third section (indicator of surface runoff from urban areas) have a close negative relationship with such ion indicators as BOD, Cu, Zn, Niin the first and second alignments (r from - 0.65 to - 0.91).

Table 1 shows the correlation coefficients of the indicators of pollution content in relation to the indicators of content of the same substances in the previous sections. The values of r greater than 0.60 indicate a close relationship and can indicate both the role of contribution from the areas located above to the hydrochemical picture downstream and the similarity of the processes of forming the atmo-chemical flows in different parts of the river's catchment area. Low values of statistical relationships indicate the likelihood of intervention by off-site processes with respect to the respective components as the observation sites change. These can be additional large sources of supply (Mg, SO_4, Fe, etc.), changes in the conditions for self-purification of waterflow and chemical lability of chemical compounds (NO_2). In particular, this is inherent in iron,

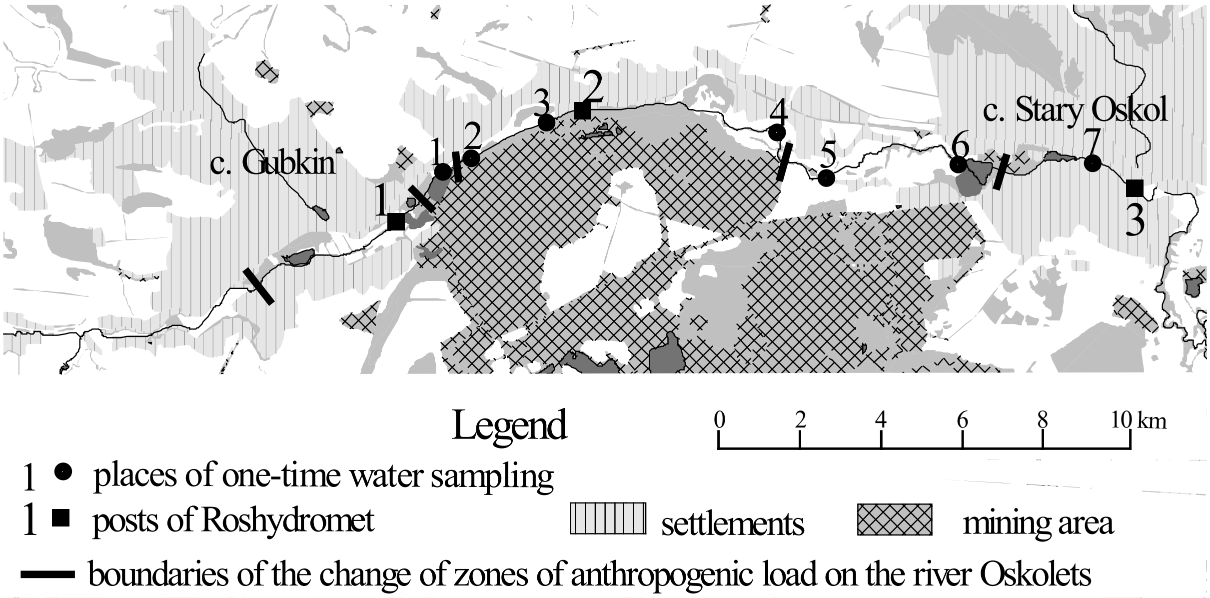

Fig. 4. Anthropofunctional zoning of catchment basin of Oskolets river (fragment)

which reflects the significant contribution of the Lebedinsky mining and processing plant, and for ammonium, copper and petroleum salts. This may be due to the contribution of the mining industry, as well as the contribution of surface runoff from Stary Oskol city.

For the observation site 1, such groups were identified with respect to interrelated indicators as “Zn - Cu - BOD”, r varies from 0.81 to 0.63 (priority of the surface washout contribution); “Cl - SO_4 - PO_4 - NO_2 - NH_4 - NO_3 - Fe”, r from 0.86 to 0.59 (priority of diffuse residential flow), although in pairs “NH_4 - NO_3” and “NO_3 - Fe” the relationship is absent (r = 0.42 and less); “Ni - Mg - NO_3”, r from 0.81 to 0.54 (possibly, it is runoff from farmland) and negative linkage group “SO_4 - Cu и Zn” r from – 0.66 to – 0.51 (increased runoff leads to dilution of the diffuse residential contribution).

With the occurrence of an organized discharge from the sewage treatment plant in Gubkin city, the groups are somewhat changed: “Ni - Mg - Zn - BOD - Cu - to a lesser extent Cl”, r from 0.96 to 0.60 (technospheric component), although copper in this group does not show the presence of a connection with BOD and chlorine; “NO_3 - Cl - to a lesser extent Mg and NO_2”, r from 0.82 to 0.52 (complex origin of nitrates and chlorine); “NH_4 - NO_2 - Fe - PO_4 - SO_4” r from 0.70 to 0.55 (priority of municipal waste).

For the third section in Stary Oskol city, with the addition of several heterogeneous sources of pollutants (drainage water of the Lebedinsky mining and processing plant, surface washout of Stary Oskol city), the grouping of interdependent components is changed again, the group size decreases: “Mg - Cl - BOD”, r from 0.77 to 0.62; “Fe - SO_4” r = 0.64 (supporting source - Lebedinsky mining and processing plant); “NH_4 - NO_2” r = 0.67; groups with negative link “NH_4 - Cl”, r = – 0.63 (an increase in chlorine content in surface runoff from urban areas); “NH_4 - Zn” and “NH_4 - Ni” r = – 0.73, as well as “Ni - PO_4” r = – 0.81 (urban surface runoff leads to the dilution of the diffuse residential contribution).

To differentiate the impact of the mining industry on the hydro-ecological situation of Oskolets river, taking into account our studies in 2007–2017 (Kornilov et al. 2013) and on the basis of modern materials of remote sensing, we created an updated map of anthropofunctional zoning of the catchment basin of Oskolets river (**Fig. 4**), on which 6 areas and observation stations are allocated.

The results of our own hydrochemical studies in the period of 2007–2012 (Kolmykov and Kornilov 2013) and 2016–2018 show (**Fig. 5**) that the content of such biogenic compounds as ammonium, nitrites, nitrates regularly decreases with distance from the discharge site of the Municipal Unitary Enterprise “Vodokanal” Gubkin. Although, depending on the technological and climatic situation, there are one-time cases of a moderate increase in the concentration of nitrates in the mining territory, nitrites in the area of influence of food industry enterprises.

With regard to the content of iron compounds, the pronounced influence of mining areas on Oskolets river have not been identified, although sometimes there is an increase in its concentration, and the salinity indicators are naturally higher at the section No. 3, although this increase is not significant. Concentrations of copper and zinc behave in different directions, but in general, graphs indicate a greater contribution of the residential area in the content of these elements. A weak but steady trend is observed in terms of an increase in the content of fluorine and lead compounds in mining areas.

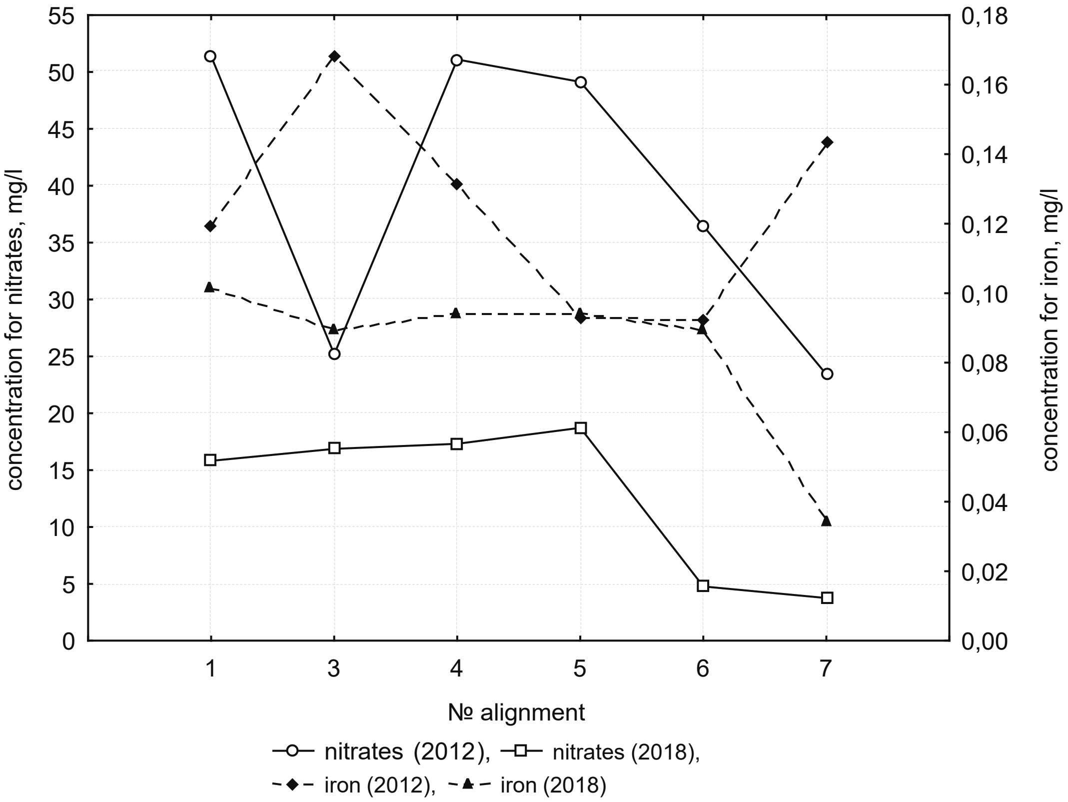

Fig. 5. The pollutants content per sections in Oskolets river for 2012–2018 (database fragment)

SUMMARY

Production control data show the multidirectional effects of drainage water of the Lebedinsky mining and processing plant on the hydrochemical situation in Oskolets river. For biogenic and/or background components for the Belgorod Region, such as ammonium salts, phosphates, fluorides, chlorides, and petroleum products, the hydrochemical situation due to dilution of river water with drainage water is somewhat improved or does not change. At the same time, drainage waters create an additional environmental burden in relation to the content indicators: iron (periodic increase by 20–60%), nitrates (periodic increase in concentrations by 15–25%); sulfates (a steady increase by 5-10%).

The analysis results of water in Oskolets river elected in Peschanka village (section No. 4 in **Fig. 4** - area of active influence of mining facilities) indicate episodic exceedances of the MPCr.x. on nitrites (1.4 MPC), sulfates (2.7 MPC), Ni (4.8 MPC), Cu (78 MPC), Zn (8.4 MPC), Fe (12.7 MPC). The values of ammonium, nitrates, fluorides, BOD, Cd, As, Pb do not exceed the MPC.

The composition and abundance of aquatic flora and fauna can serve as an indicator of the quality of water bodies (Barinova et al. 2006, Beninca et al. 2006, Hartel 2008, Ter Braak and Verdonschot 1995). The studies carried out according to the method (Schwoerbel 1970) showed that the increase in the saprobity index observed in 2012 and, as a consequence, the increase in the number of benthos and zooplankton organisms in areas 3–5 (see **Fig. 4**) can be associated with the commissioning of the second discharge of drainage waters of of the LGOK, which led to some changes in the hydrological features of the river (erosion of banks, redistribution of sediments, formation of backwaters). The decrease in the indicators noted by 2018 is associated with an increase in the volume of discharged drainage water (flushing of benthos and zooplankton and dilution of river water).

CONCLUSIONS

Long-term hydrochemical monitoring of Oskolets river shows a relatively prosperous environmental situation with regard to such controlled ingredients as ammonium, nitrates, fluorides, BOD, cadmium, arsenic, lead. For biogenic and/or background components for the Belgorod Region, such as ammonium salts, phosphates, fluorides, chlorides, and petroleum products, the hydrochemical situation due to dilution of river water with drainage water is somewhat improved or does not change.

For a number of components, the environmental situation cannot be considered satisfactory: iron (periodic increases in river water as compared with the background content before discharging mine water by

20–60%, in general, taking into account the background, up to 10–12 MPC), sulfates (increase by 5–20 10%, up to 2.7 MPC). There are periodic high concentrations of such pollutants that adversely affect the ichthyofauna (Cu, Zn), which are mainly of transit origin, including due to the wastewater above Gubkin city. At the same time, the content of copper and zinc requirements from the point of view of fisheries does not exceed the MPC of drinking water objects, household and recreational water use. Against the background of similar indicators for these ingredients for other rivers of the Black Soil Region, this effect can be considered moderate (Prozhorina et al. 2018, Kornilov et al. 2013).

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